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DEPARTMENT OF DEFENSE
JOINT SERVICE SPECIFICATION GUIDE

AIR VEHICLE SUBSYSTEMS

This specification guide is for guidance only.

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FOREWORD

JOINT SERVICE SPECIFICATION GUIDE (JSSG) RELEASE NOTE

This specification guide is predicated on a performance-based business environment approach to product development. It is intended to be used in the preparation of performance specifications. The JSSG Suite includes this document; JSSG-2000, Air System; JSSG-2001, Air Vehicle; JSSG-2005, Avionics; JSSG-2006, Structures; JSSG-2007, Engines; JSSG-2008, Vehicle Control and Management; JSSG-2010, Crew Systems; and JSSG-2011, Air Vehicle / Ship Integration. The JSSG Suite Compact Disc is available from AFLCMC/ENRS, BLDG 28 RM 118, 2145 MONAHAN WAY, WPAFB OH 45433-7017 USA; DSN 674-5476; COMMERCIAL (937) 904-5476; ENGINEERING.STANDARDS@US.AF.MIL.

The following direction and guidance is applicable to this document:

1. This specification guide, in conjunction with its companion JSSGs, is intended for use by Government and Industry program teams as guidance in developing program-unique specifications. This document may not be placed on contract.

2. The complete set of JSSGs establish a common framework to be used by Government-Industry Program Teams in the Aviation Sector to develop program-unique requirements documents for Air Systems, Air Vehicles, and major Subsystems. Each JSSG contains a compilation of candidate references; generically-stated requirements; verification criteria; and associated rationale, guidance, and lessons learned for the program teams' consideration. The JSSGs identify typical requirements for a variety of aviation roles and missions. By design, the JSSG sample language for "requirements" and "verification criteria" are written as generic templates, with blanks that need to be completed to make the requirements meaningful. Program teams need to review the JSSG rationale, guidance, and lessons learned to: (1) determine which requirements are relevant to their application; and (2) fill in the blanks with appropriate, program-specific requirements.

3. This document consists of two parts. Part 1 of this document is a template to develop the program-unique performance specification. As a generic document, it contains requirement statements for the full range of aviation sector applications. It must be tailored to delete non-applicable requirements to form the program-unique specification. In addition, where blanks exist, these blanks must be filled-in for the program-unique specification to form a complete and consistent set of requirements to meet program objectives. Part 2 of this document is a handbook which provides the rationale, guidance, and lessons learned relative to each statement in Part 1. The section 4 verification requirements must be tailored to reflect an understanding of: (1) the design solution, (2) the identified program milestones, (3) the associated level of maturity which is expected to be achieved at those milestones, and (4) the specific approach to be used in the design and verification of the required products and processes. It must be recognized that the rationale, guidance, and lessons learned are not only generic in nature but also document what has been successful in past programs and practices. This must not be interpreted to limit new practices, processes, methodologies, or tools.

PART 1 CONTENTS

JOINT SERVICE SPECIFICATION GUIDE

AIR VEHICLE SUBSYSTEMS

This specification guide is approved for use by all Departments and Agencies of the Department of Defense.

1. SCOPE

1.1 Scope.

This specification establishes the item definition, performance, operating characteristics, reliability, maintainability, physical characteristics, general design, installation, and interface requirements for Air Vehicle Subsystems. This specification also establishes the analysis, inspection, demonstrations, and test procedures required by the Using Service for satisfactory completion and acceptance of subsystem component qualifications at the SFR, PDR, CDR, FF, and SVR Milestones. This specification also establishes the content and format to be used by the Using Service or contractor for preparation of the acquisition or model specification.

The ___(TBS)____ Air Vehicle is composed of airframe, propulsion, avionics, crew station, flight controls, vehicle management system, and subsystems. This specification addresses only the subsystems. The purpose of __(TBS)__ air vehicle subsystems is to provide mechanization, hydraulic, electrical, auxiliary, and pneumatic power, landing provisions, electronics and airframe cooling, fuel, and fire protection.

1.2 Structure.

This specification complies with Guidance for Preparation and Use of Joint Services Guide Specifications, AEB 96-1.

1.3 Handbook.

This specification has an accompanying tailoring handbook to be used for contractual purposes in the development of air vehicle subsystems requirements.

1.4 Deviations.

Deviations from this specification which will result in improvement of the system performance, reduced life cycle cost, reduced developmental cost, or where the requirements of this specification result in compromise in operational capability, should be brought to the attention of the Using Service.

1.5 Environmental impact.

Air Vehicle Subsystems will be designed such that their operation, maintenance, and repair may be accomplished without violating the most stringent environmental regulations applicable to locations where subsystems are used or supported. Compliance with environmental regulations will not prevent subsystems from achieving and sustaining mission performance capability.

Materials, processes, and environmental control equipment necessary to meet these environmental requirements must currently be available in the Using Service's maintenance and supply system. The design will not use environmentally unsuitable materials such as ozone depleting fluorocarbons, chlorofluorocarbons, and halons, or highly volatile organic compounds in solvents and coatings during development, production, operation, maintenance, or repair. The Environmental Protection Agency maintains an online list of toxic chemicals and hazardous substances on its Ozone Layer Depletion Website at http://www.epa.gov/ozone/snap/ that should be consulted. The Significant New Alternatives Policy (SNAP) Program available thereon identifies substitutes for ozone depleting chemicals.

The contractor will conduct an environmental analysis of air vehicle subsystems.

1.6 Responsible engineering office.

The responsible engineering office (REO) for this specification is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL.

2. APPLICABLE DOCUMENTS

2.1 General.

The documents listed in this section are specified in sections 3 and 4 of this specification. This section does not include documents cited in other sections of this specification or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3 and 4 of this specification, whether or not they are listed.

2.2 Government documents

2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

DEPARTMENT OF DEFENSE SPECIFICATIONS

JSSG-2000	Air System Joint Service Specification Guide
JSSG-2001	Air Vehicle Joint Service Specification Guide

DEPARTMENT OF DEFENSE STANDARD

MIL-STD-130	Identification Marking of U.S. Military Property

(Copies of these documents are available online at http://quicksearch.dla.mil or from the Standardization Document Order Desk, 700 Robbins Avenue, Bldg 4D, Philadelphia PA 19111-5094.)

2.3 Order of precedence.

Unless otherwise noted herein or in the contract, in the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.4 Streamlining.

This specification has been streamlined. The documents listed herein which are required for acquisition have the same status as those referenced directly in section 2 (first tier). All other documents referenced through tiering may be used for guidance and information.

3. REQUIREMENTS

3.1 Definition.

The ___(TBS 1)___ air vehicle shall perform the identified table I functions and meet the requirements for safety, mission reliability, and vehicle growth as specified in __(TBS 2)__.

TABLE I. Subsystems functions.

__(TBS 3)__.

3.1.1 Functional diagram.

Functional diagrams for the __(TBS)__ shall be provided.

3.1.2 Interface drawing.

Interface drawings for the __(TBS)__ shall be provided.

3.2 Characteristics

3.2.1 Security.

Subsystem security shall be in accordance with __(TBS)__.

3.2.2 Computer resources.

The computer resources, hardware and software, dedicated to the control of air vehicle subsystems shall support allocated air vehicle subsystem functional requirements. Computer resources hardware defined as, electric/electronic sensor data collection devices (data input), electric and electronic effector devices (data output), analog, digital communication paths (serial and parallel data buses), data processing elements (general or specialized CPUs), and power supply characteristics shall be defined by computer resources. Computer resources software, defined as High Order Language (HOL), software development and testing tools (software environment), and software development processes shall be characterized by computer resources. Computer resources hardware and software shall be designed as an open architecture that is expandable, upgradable and compatible with other computer resources within the air vehicle to maintain security requirements.

The computer resources shall support the __(TBS)__ level maintenance concept.

A hardware and software obsolescence plan shall be implemented for computer resources to address maintenance of the air vehicle.

3.2.3 Observables.

Subsystem IR, acoustics, radar, and visual observable requirements shall be as follow: (TBS) .

3.2.3.1 Electromagnetic emissions.

Electromagnetic emissions shall be in accordance with (TBS) .

3.2.4 Survivability.

The air vehicle subsystems shall be designed and integrated into the air vehicle to meet the survivability requirements of the air vehicle as specified in (TBS 1) . Specific subsystem allocated and derived susceptibility and vulnerability requirements shall be as follow: (TBS 2) .

3.2.5 Reliability.

The air vehicle subsystem requirements shall be consistent with JSSG-2001 Air Vehicle "Reliability" requirements.

3.2.6 Maintainability.

The air vehicle subsystem maintainability requirements shall be in accordance with JSSG-2001.

3.2.7 Integrity and environment

3.2.7.1 Service life and usage

3.2.7.1.1 Design service life.

The subsystem design service life shall be in accordance with JSSG-2001 Air Vehicle "Design service life".

3.2.7.2 Environment.

Each subsystem shall meet the performance requirements of this specification before, during, and after exposure to any operational combination of the following natural and induced environments:

a. Natural environment: (TBS 1) .

b. Induced environment. The induced environments for the air vehicle subsystems shall be developed using the above natural environment and the environment imposed on the subsystems by the air vehicle design and its operating environment. Induced environments shall be established for all modes of operation or non-operation including normal operation, intermittent operation (transient operation), non-operation, storage and transport. These induced environments shall include (TBS 2) .

3.2.7.3 Crash worthiness.

Subsystems shall be in accordance with JSSG-2001, Air Vehicle "Crash worthiness".

3.2.7.4 Materials and processes.

The materials and processes shall ensure adequate strength, durability, and damage tolerance capabilities of components as required __(TBS)__. (See 6.3).

3.2.7.4.1 Coatings and finishes.

Surfaces shall be coated and finished in accordance with JSSG-2001, Air Vehicle Joint Service Specification Guide.

3.2.7.4.2 Prohibited materials and processes.

The following materials and processes shall be prohibited:

a. Chlorofluorocarbons (CFCs)

b. _(TBS)_.

3.2.7.4.3 Producibility.

The selected fabrication techniques, design parameters, and tolerances shall enable the product to be fabricated, assembled, inspected and tested with repeatable quality. A change in manufacturing process, vendor, vendor location shall be subject to a re-verification process.

3.2.7.4.4 Damage tolerance.

(See 6.3.)

3.2.7.4.4.1 Safety and mission critical functions.

User service specified subsystems and components that perform safety or mission critical functions shall be damage/fault tolerant. Damage/fault tolerance shall be achieved by _(TBS)_. (See 6.3.)

3.2.7.4.4.2 Damage tolerant - fail safe evident subsystems and components.

Damage tolerant - fail safe evident subsystems and components shall be specified.

3.2.7.4.4.3 Mechanical component damage tolerance.

Safety or mission critical components shall maintain adequate damage tolerance in the presence of the maximum undetected maintenance or manufacturing defect as __(TBS)__.

3.2.7.5 Strength.

Component strength shall be __(TBS)__.

3.2.7.6 Durability and economic life.

Subsystems shall be durable and economically maintainable throughout the service life. (See 6.3.)

3.2.7.6.1 Corrosion.

Corrosion shall not degrade the operational readiness or mission performance of the subsystem during the service life.

3.2.7.6.2 High cycle fatigue (HCF).

Subsystems shall not fail when subject to the combined steady state and vibratory induced stresses that occur anywhere within the operating envelope and during ground, flight, and logistics operations.

3.2.7.6.3 Low cycle fatigue (LCF).

Subsystems shall not fail when subject to the combined steady state and cyclic stresses due to repetitive cycles whether thermally induced, induced by mechanical start and stop cycles or both, or applied loads.

3.2.7.6.4 Dielectric materials.

Dielectric materials when exposed to maximum predicted voltage shall not fail.

3.2.7.6.5 Creep.

Subsystems shall not fail due to component creep. Part creep shall not interfere with disassembly, reassembly or function of the subsystem.

3.2.8 Transportability.

Transportability shall be in accordance with JSSG-2001, Air Vehicle “Transportability”.

3.2.9 Integrated diagnostics.

Hardware and software, when required by the Air Vehicle Subsystems Specification, shall be provided to monitor and record subsystem performance during flight and ground operation, and to provide data in an organized format for ground analytical condition checkout capability, component life tracking (if required), warranties, and scheduling maintenance actions. The malfunction of any diagnostic hardware or software shall not affect subsystem performance or operability. The diagnostic capability shall be compatible with the air vehicle maintenance system. The subsystem diagnostic system shall be completely functional after failure of any other subsystem or subsystem component.

3.2.9.1 Fault detection and isolation.

Diagnostics shall provide __(TBS)__ percent detection and isolation of all faults. The on-board subsystem diagnostics shall provide fault detection and isolation to the faulty LRU/WRA as required to meet the reliability and maintainability requirements of JSSG-2001. Subsystems shall be compatible with the mission critical functions of the on-board diagnostic system that monitors mission and safety critical parameters. The on-board subsystem diagnostics shall not cause failure of any other mission or safety critical system.

3.2.10 Nameplate and product marking.

Subsystems equipment, assemblies, modules, and parts shall be marked legibly with machine/man-readable markings per MIL-STD-130 and such that component removal is not necessary to read the data plate. The machine-readable markings are required for parts whose cost exceeds five thousand dollars, parts that are serially managed, or parts that are mission critical. These markings shall be as permanent as the normal life expectancy of the item and be able to withstand the environmental tests and cleaning procedures specified for the item to which they are affixed. The type and length of product identification characters on the data plate shall be compliant with MIL-STD-130 and applicable requirements documents referenced therein for format compatibility. The contractor shall upload the Item Unique Identification (IUID) assigned numbers and information into the Government UID (Unique Identification) database according to the Using Service's guidance and procedures.

3.3 Design and construction.

Design and construction shall be in accordance with JSSG-2001.

3.3.1 Interchangeability.

Subsystem equipment, which is to be interchangeable and the level of interchangeability shall be defined.

3.3.2 Non-interchangeability.

It shall not be possible to misconnect electrical or fluid inputs or outputs with like items from the same or other subsystem equipment.

3.3.3 Safety.

Subsystem safety features shall be provided to optimize the safety of the pilot, maintenance, and support personnel within the constraints of operational effectiveness, time, and cost.

3.3.3.1 Safety criteria.

Subsystem safety criteria shall be defined.

3.3.3.2 Foreign object damage (FOD).

Subsystem tolerance of foreign object damage shall be defined.

3.3.3.3 Software safety.

Air vehicle subsystem Software Safety Critical Items shall be identified and separated or partitioned from other less critical software.

3.3.3.4 Acoustic noise.

The contractor shall establish acoustic noise level limits for noise producing or noise transmitting air vehicle subsystems required to meet the acoustic noise level limits for air vehicle established in JSSG-2001.

3.3.4 Electromagnetic environmental effects (E^3).

Subsystem electromagnetic environmental effects shall be in accordance with JSSG-2001.

3.3.5 Standardization.

Standardization principles shall be used to the maximum extent possible without compromise in design, performance, operability, or economic life of the subsystem.

3.3.6 Environmental.

Environmental requirements for the Air Vehicle Subsystems shall be those specified in the Air System Joint Service Specification Guide, JSSG-2000, "Environmental," as applicable.

3.3.7 Health.

Health requirements for the Air Vehicle Subsystems shall be those specified in the Air System Joint Service Specification Guide, JSSG-2000, "Health," as applicable.

3.3.8 Installation hazards reduction.

The following designs shall be applied to subsystem installations:

a. Subsystem installation and associated equipment designs shall be such that normal operation of the subsystem will not contribute to or result in fire and explosion hazards.
b. Subsystem installations and associated equipment designs shall be such that fire and explosion hazards due to failure or accident are minimized.
c. Subsystem installation boundaries common to the air vehicle exterior shall be designed such that fire will not readily spread between subsystems due to the natural airflow over the air vehicle.

3.4 Subsystem characteristics

3.4.1 Landing subsystem.

Reference appendix A.

3.4.2 Hydraulic power subsystem.

Reference appendix B.

3.4.3 Auxiliary power subsystem.

Reference appendix C.

3.4.4 Environmental control subsystems.

Reference appendix D.

3.4.5 Fuel subsystem.

Reference appendix E.

3.4.6 Aerial refueling subsystem.

Reference appendix F.

3.4.7 Fire and explosion hazard protection subsystem.

Reference appendix G.

3.4.8 Electrical power subsystem.

Reference appendix H.

3.4.9 Mechanical subsystems.

Reference appendix I.

3.4.10 Cargo, aerial delivery, and special operations subsystem.

Reference appendix J.

3.4.11 Vertical takeoff and landing – short takeoff and landing power drive subsystems.

Reference appendix K.

3.4.12 Propeller subsystem.

Reference appendix L.

3.4.13 Pneumatic subsystem.

Reference appendix M.

3.4.14 Additional subsystems and functions.

Reference appendix *X*.

4. VERIFICATION

4.1 Definition.

The basic objective of verification requirements is to verify that the air vehicle subsystem performance and operability requirements specified in section 3 have been met. This section specifies the method(s) of verification for each section 3 subsystem requirement. Requirements shall be verified incrementally __(TBS)__.

4.1.1 Functional diagram.

Functional diagrams shall be verified.

4.1.2 Interface drawing.

Interface drawing shall be verified by __(TBS)__.

4.2 Characteristics

4.2.1 Security.

Subsystem security shall be verified by __(TBS)__.

4.2.2 Computer resources.

The functional requirements allocated to and implemented by computer resources shall be verified by __(TBS)__.

4.2.3 Observables.

Subsystem IR, acoustics, radar, and visual observable requirements shall be verified __(TBS)__.

4.2.3.1 Electromagnetic emissions.

The EME requirement shall be verified __(TBS)__.

4.2.4 Survivability.

The survivability requirements shall be verified as follows: __(TBS)__.

4.2.5 Reliability.

Reliability requirement shall be verified by __(TBS)__.

4.2.6 Maintainability.

The maintainability requirements shall be verified by __(TBS)__.

4.2.7 Integrity and environment

4.2.7.1 Service life and usage

4.2.7.1.1 Design service life.

Design service life shall be verified in accordance with JSSG-2001.

4.2.7.2 Environment.

The subsystems shall be capable of meeting the performance requirements of this specification before, during, and after exposure to the natural and induced environments as verified by analyses, tests, and demonstrations.

4.2.7.3 Crash worthiness.

Subsystem crash worthiness shall be verified through analysis and test.

4.2.7.4 Materials and processes.

Material and process requirements shall be verified __(TBS)__.

4.2.7.4.1 Coatings and finishes.

Surface coatings and finishes shall be verified to be in accordance with JSSG-2001.

4.2.7.4.2 Prohibited materials and processes.

It shall be verified by __(TBS)__ that prohibited materials and processes are not used.

4.2.7.4.3 Producibility.

The producibility shall be verified by __(TBS)__.

4.2.7.4.4 Damage tolerance

4.2.7.4.4.1 Safety and mission critical functions.

It shall be verified that all subsystems that perform safety or mission critical functions are damage and fault tolerant in the presence of material defects, manufacturing and processing defects, or maintenance/service induced damage. Damage and fault tolerance shall be verified by __(TBS)__.

4.2.7.4.4.2 Damage tolerant - fail safe evident subsystems and components.

Subsystem damage tolerance of fail safe-evident subsystems shall be verified by __(TBS)__.

4.2.7.4.4.3 Mechanical component damage tolerance.

The damage tolerance requirements shall be verified by analysis and test.

4.2.7.5 Strength.

Strength requirements shall be verified by __(TBS)__.

4.2.7.6 Durability and economic life.

The durability and economic life shall be verified by __(TBS)__.

4.2.7.6.1 Corrosion.

Corrosion protection and control measures shall be verified by __(TBS)__.

4.2.7.6.2 High cycle fatigue (HCF).

It shall be verified that subsystems subjected to the combined steady state and vibratory induced stresses that occur anywhere within the operating envelope and during ground, flight, and logistics operations do not fail.

4.2.7.6.3 Low cycle fatigue (LCF).

Low cycle fatigue shall be verified by __(TBS)__.

4.2.7.6.4 Dielectric materials.

Verification of specific dielectric materials when exposed to maximum predicted voltage shall be by __(TBS)__.

4.2.7.6.5 Creep.

Subsystems creep characteristics shall be verified by __(TBS)__.

4.2.8 Transportability.

Transportability requirements shall be verified by __(TBS)__.

4.2.9 Integrated diagnostics.

Integrated diagnostics requirements shall be verified by __(TBS)__.

4.2.9.1 Fault detection and isolation.

Fault detection and isolation shall be verified by __(TBS)__.

4.2.10 Nameplate and product marking.

The requirement of 3.2.10 shall be verified by inspection.

4.3 Design and construction.

Design and construction requirements shall be verified by __(TBS)__.

4.3.1 Interchangeability.

Interchangeability shall be verified by __(TBS)__.

4.3.2 Non-interchangeability.

Non-interchangeability shall be verified by __(TBS)__.

4.3.3 Safety.

Subsystems safety features to optimize the safety of pilot, maintenance, support personnel, and the air vehicle shall be verified by __(TBS)__.

4.3.3.1 Safety criteria.

The defined safety criteria shall be verified by __(TBS)__.

4.3.3.2 Foreign object damage (FOD).

Defined subsystem tolerance to FOD shall be verified by __(TBS)__.

4.3.3.3 Software safety.

It shall be verified that air vehicle subsystem Software Safety Critical Items are identified and separated or partitioned from other less critical software __(TBS)__.

4.3.3.4 Acoustic noise.

Acoustic noise levels shall be verified by __(TBS)__.

4.3.4 Electromagnetic environmental effects (E^3).

The E^3 performance of the subsystems shall be verified through a combination of inspection, analysis, and test.

4.3.5 Standardization.

The application of standardization principles shall be verified by inspection.

4.3.6 Environmental.

Environmental verification requirements for the Air Vehicle Subsystems shall be those specified in the Air System Joint Service Specification Guide, JSSG-2000, “Environmental Verification,” as applicable.

4.3.7 Health.

Health verification requirements for the Air Vehicle Subsystems shall be those specified in the Air System Joint Service Specification Guide, JSSG-2000, "Health verification," as applicable.

4.3.8 Installation hazards reduction.

By analysis and inspection it should be verified that installation hazards reduction designs have been used to the fullest extent practicable to prevent the occurrence of fire and explosion due to the uncontrolled presence of __(TBS 1)__. The adequacy of the provided design should be verified by __(TBS 2)__.

4.4 Subsystem characteristics

4.4.1 Landing subsystem.

Reference appendix A.

4.4.2 Hydraulic power subsystem.

Reference appendix B.

4.4.3 Auxiliary power subsystem.

Reference appendix C.

4.4.4 Environmental control subsystems.

Reference appendix D.

4.4.5 Fuel subsystem.

Reference appendix E.

4.4.6 Aerial refueling subsystem.

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4.4.7 Fire and explosion hazard protection subsystem.

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Reference appendix K.

4.4.12 Propeller subsystem.

Reference appendix L.

4.4.13 Pneumatic subsystem.

Reference appendix M.

4.4.14 Additional subsystems and functions.

Reference appendix *X* (to be included, as necessary).

5. PACKAGING

5.1 Packaging.

For acquisition purposes, the packaging requirements shall be as specified in the contract or order (see 6.2). When packaging of materiel is to be performed by DoD or in-house contractor personnel, these personnel need to contact the responsible packaging activity to ascertain packaging requirements. Packaging requirements are maintained by the Inventory Control Point's packaging activities within the Military Service or Defense Agency, or within the military service's system commands. Packaging data retrieval is available from the managing Military Department's or Defense Agency's automated packaging files, CD-ROM products, or by contacting the responsible packaging activity.

6. NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

6.1 Intended use.

The requirements in this specification are intended for the development of subsystems in air vehicles designed to perform combat and support missions in environments unique to military weapons systems.

6.2 Acquisition requirements.

Acquisition documents should specify the following:

a. Title, number, and date of this specification.

6.3 Definitions.

Methods of verification

Inspection: Inspection consists of visual examination, physical manipulation, weighing and measurement, as required to verify the hardware item conforms to the design requirements, and includes review of documentation that controls the configuration.

Analysis: Analysis is a technical evaluation of equations, graphs, data, etc. Verification by analyses should be used when it is not feasible to perform tests to obtain the required data. Analysis should also be used when testing is not warranted for verification of requirements, such as the capability of simple components to withstand accelerated loads.

Stress analysis: The air vehicle finite element model can be used as the basis for stress generated by airframe interactions (e.g., actuator hinge movements, leading edge flap side loads, etc.). Supplemental, vendor finite element models can be used as the basis for the stress analysis of individual components and design details, where needed. The stress analysis can also be used as a basis to determine the adequacy of structural changes throughout the life of the subsystem and to determine the adequacy of the subsystem structure for new loading conditions that result from increased weight or new mission requirements.

Durability analysis: Durability analyses address economic issues. Analysis should be performed to show individual subsystem components will perform for the required environments specified herein. These analyses could verify that the development of cracking, corrosion, wear, deterioration, etc., will not adversely affect subsystem performance within the required maintenance-free operational periods specified herein.

Damage tolerance: Damage tolerance analyses (see next definition) address safety issues. The approach to damage tolerance philosophy is based on the assumption that damage tolerance critical parts contain pre-existing material and/or manufacturing flaws or defects. These manufacturing flaws include any quality characteristics that contribute to a failure mode of the equipment. Therefore, it may be assumed that damage tolerance critical parts contain the maximum acceptable manufacturing defects, including initial cracks - size 0.05 in., excessive tube ovality - max ovality 5 percent (5%), solder slump/solder void of 25 percent (25%) or current board reworked 3 times. Note, this is a more general definition of damage tolerance than is usually associated with the discipline of fracture mechanics. These assumptions are then analyzed for the worst case to determine the part's damage tolerance.

The intent of Airplane Damage Tolerant Requirements is to ensure the maximum acceptable initial damage will not progress to a condition which would endanger flight safety during the service life of the air vehicle.

Similarly, the intent of the Integrity Program's Damage Tolerant Requirement is to ensure the maximum acceptable initial damage will not progress to a condition that compromises flight safety during the service life of the subsystem equipment. In addition, the Damage Tolerant Requirement applies to Mission Critical Equipment.

When applied, the Integrity Process will accomplish the Damage Tolerance intent through:

a. Proper material selection and control
b. Control of stress levels
c. Use of damage-resistant design concepts
d. Manufacturing process control
e. Use of qualified inspection procedures.

Tolerance analysis: The objective of tolerance analysis is to predict the effect on circuit performance of the tolerances inevitably associated with manufactured components.

Demonstration: Demonstration is a test where success is determined by a "GO" or "NO-GO" criteria.

Test: Test is the verification that a requirement is met by a thorough exercise of the subsystem or item. This includes actual measurement of unit performance with calculations/analysis as required and under controlled and recorded environment, as applicable.

Durability: Test articles must represent production configurations as closely as is necessary to ensure test validity. Durability testing may be combined with other functional tests.

Because most subsystems consist of many components, the verification of the durability and economic life must be accomplished by analysis and test of components and a further consideration of the system or subsystem as a whole.

Process control: This is an element of verification that provides objective evidence of controlled processes. Examples of evidence may be in the form of control charts derived from application of SPC, or data from automated inspection, non-destructive evaluation, data from machines operating under adaptive control, or periodic testing of production samples.

Mission critical item: The mission critical item is an item whose failure alone may generate a significant adverse impact to air vehicle survivability or result in less than acceptable handling qualities during air-to-air combat and weapon delivery launch flight phases as defined. The failure of an individual mission critical item would jeopardize the ability to disengage from a combat engagement successfully.

Mission essential item: This is an item whose fault-free operation is procedurally required from launch through recovery of a combat or training mission. All equipment contained in the Mission Essential Subsystems List (MESL) should be designated as mission essential items.

Safety critical: This is an aspect of the design engineering process that requires careful judgment and judicious evaluation because of the potential risk to safety. “Safety of Flight” and “Flight Critical” are terms equivalent to “Safety Critical.”

Safety critical function: This is a function that, if performed incorrectly or not performed, may result in death, loss of the air vehicle, severe injury, severe occupational illness, or major system damage.

Safety critical item: This is an item that contributes to a safety-critical function and whose failure alone may result in death or loss of the system (air vehicle).

Safety significant item. This is an item that contributes to a safety-critical function.

Economic life: The economic life of an asset is the time interval that minimizes the asset’s total equivalent annual costs. The economic life is also referred to as the “minimum-cost life” or the “optimum replacement interval.”

Materials and processes selection and characterization: The materials and processes specified for the subsystems should be selected for compatibility of design, manufacturing, and assembly while maintaining design integrity and reliability. Special attention should be paid to the use of materials which minimized materials problems encountered in the past with the other air vehicle subsystems. New and improved materials and processes which avoid stress corrosion and brittle fracture, coupled with a design philosophy which recognizes such problem areas, could result in increased durability.

Test requirements verification: This paragraph defines the various demonstrations, tests, and other methods of verification which should be utilized to verify quality conformance to section 3 requirements.

EMD test program: The EMD test program consists of laboratory, ground, and flight tests. The basic objective of the test program is to verify that the air vehicle subsystem design will satisfy the requirements of the air vehicle specification.

Subsystem verifications should be conducted at contractor-, vendor-, or government-furnished facilities. Subsystem verifications include:

a. inspections and analyses, performance demonstrations, pre-qualification (safety-of-flight), formal qualification tests, and pre-delivery tests conducted on the respective components or subsystems; and

b. subsystem compatibility, performance demonstrations, and system-level testing is to provide confidence that the functional and physical compatibility of the integrated subsystems has been achieved and supports system performance requirements.

Special tests:

Laboratory: Laboratory testing should be conducted on all Air Vehicle Subsystem Equipment. Major laboratory test articles include the following:

a. Integrated Vehicle Systems Simulator (Iron Bird)

b. Environmental Control System, Avionics and Cockpit Simulator

c. Electrical System Hot Mockup

d. Fuel System Simulator

e. Fire and Overheat System Simulator

f. Software Development Lab

g. Landing Gear Simulator

h. APS Test Stand

i. Hydraulic and pneumatic system simulator (Iron Bird)

j. Integrated diagnostic and controls simulator

k. Thermal Management System simulator.

Subsystem level: The air vehicle subsystem performance and operability verification should be conducted:

a. Subsystem performance verifications, using elements of the subsystem to verify that specified performance levels have been achieved.

b. Subsystem operability verifications, utilizing elements of the subsystem to demonstrate that the subsystem has achieved minimum specified levels of reliability, maintainability, safety, interface compatibility, and supportability with planned resources, training, and support equipment.

Methods of verification: **Methods of verification are inspection, analysis, demonstration, tests, or process control, or a combination thereof**.

Test article: Test articles represent production configurations as close as necessary to ensure test validity. Prior to subsequent testing, each test article should have successfully passed the applicable acceptance test.

In-process verification

Qualification: Qualification should be by the methods identified. Testing is generally classified as functional and environmental, but there are other tests classified by discrete disciplines; for example; reliability, maintainability, and safety.

Functional tests: The subsystems and components should be operated for a period of time sufficient to establish stability of performance. The performance and functional characteristics of the equipment should then be measured and data recorded.

Environmental tests: The subsystems and components should be subjected to specified natural and induced environments in specified combinations and cycles, with performance monitored.

Safety of flight: Certification of satisfactory completion of safety-of-flight testing should be submitted to the Customer prior to delivery of the first air vehicle.

Acceptance: Acceptance tests should be conducted. Acceptance tests should verify baseline functional characteristics.

TEMPEST: Refers to investigation, study, and control of compromising emanations from telecommunications and automated information systems equipment. Compromising emanations are unintentional signals that, if intercepted and analyzed, would disclose the information transmitted, received, handled, or otherwise processed by information-processing equipment.

Transmissions: Transmission systems includes all parts between the engine and the load absorbers. This includes gearboxes, shafting, universal joints, couplings, rotors, brake assemblies, clutches (overrunning, friction, and dog), supporting bearings for shafting and any attendant accessory pads or drives. Transmission oil cooling fan drives when driven by a component of the system are considered a part of the transmission system. The oil cooler is not considered part of the transmission, unless it is an integral part of a gearbox.

6.4 Acronyms.

The following list contains the acronyms/abbreviations contained within Parts 1 and 2 of this document.

AFGS	Air Force Guide Specification
AISI	American Iron and Steel Institute
APS	Auxiliary Power Subsystem
APU	Auxiliary Power Unit
BIT	Built-in Test
BTU	British Thermal Unit
CD-ROM	Compact Disk – Read Only Memory
CDR	Critical Design Review
CFC	Chlorofluorocarbons
CPU	Central Processing Unit
da/dn	Incremental crack growth per cycle
DoDISS	Department of Defense Index of Specifications and Standards
DSN	Defense System Network
E^3	Electromagnetic Environmental Effects
EMC	Electromagnetic Compatibility
EMD	Engineering Manufacturing Development
EME	Electromagnetic Effects
EMI	Electromagnetic Interference
FAA	Federal Aviation Administration
FF	First Flight
FMECA	Failure Modes and Effects Criticality Analysis
FOD	Foreign Object Damage
FRACAS	Failure Reporting and Corrective Action System
HCF	High Cycle Fatigue
HOL	High Order Language
IBIT	Initiated Built-in Test
IUID	Item Unique Identification
JSSG	Joint Service Specification Guide
LCC	Life Cycle Cost
LCF	Low Cycle Fatigue
LRU	Line Replaceable Unit

MAIT	Minimum Autogenous Ignition Temperature
MECSIP	Mechanical Equipment and Subsystems Integrity Program
MHGIT	Minimum Hot Gas Ignition Temperature
MTBF	Mean Time Between Failures
NALDA	Naval Aviation Logistic Data Analysis
NATO STANAG	North Atlantic Treaty Organization Standardization Agreement
NBC	Nuclear, Biological, Chemical
PBIT	Periodic Built-in Test
PDR	Preliminary Design Review
RCS	Radar Cross Section
R&D	Research and Development
REO	Responsible Engineering Office
SAE	Society of Automotive Engineers
SBIT	Start-up Built-in Test
SFR	System Functional Review
SPC	Statistical Process Control
SVR	System Verification Review
TBD	To Be Determined
TBS	To Be Supplied
TO	Technical Order
UID	Unique Identification
USA	United States Army
USAF	United States Air Force
USN	United States Navy
VTOL-STOL	Vertical Take-off and Landing – Short Take-off and Landing
WRA	War Reserve Assembly

6.5 Subject term (key word) listing.

Aerial refueling

Auxiliary power

Cargo

Corrosion

Crash worthiness

Creep

Electrical power subsystem

Environmental control

Explosion hazard

Fire

Fuel

Hydraulic

Integrity

Interchangeability

Landing gear

Maintainability

Mechanical subsystem

Observables

Pneumatic

Producibility

Propeller subsystem

Reliability

Strength

Transportability

VTOL-STOL

6.6 Amendment notations.

The margins of this specification are marked with vertical lines to indicate modifications generated by this amendment. This was done as a convenience only and the Government assumes no liability whatsoever for any inaccuracies in these notations. Bidders and contractors are cautioned to evaluate the requirements of this document based on the entire content irrespective of the marginal notations.

6.7 Responsible engineering office.

The office responsible for the development and technical maintenance of this specification is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL. Requests for additional information about this specification can be obtained from AFLCMC/ENRS, BLDG 28 RM 118, 2145 MONAHAN WAY, WPAFB OH 45433-7017 USA; DSN 674-5476; COMMERCIAL (937) 904-5476; ENGINEERING.STANDARDS@US.AF.MIL.

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HANDBOOK FOR AIR VEHICLE SUBSYSTEMS

JOINT SERVICES SPECIFICATION GUIDE

1. SCOPE

1.1 Scope.

This handbook provides tailoring guidance and background information for individual paragraphs of the Air Vehicle Subsystems Specification (AVSS). The handbook has been developed and coordinated by technical personnel from the Air Force, Navy, and Army and has been approved as an official guide for use by Government personnel for assistance in tailoring the AVSS for acquisition and model specifications. This handbook is a mandatory part of the specification guide. The information contained herein is intended for guidance only.

1.2 Structure.

The handbook structure replicates the structure of the Air Vehicle Subsystems Specification except it places each corresponding section 3 requirement and section 4 verification together.

1.3 Handbook.

This handbook provides tailoring guidance and background information for individual paragraphs of the Air Vehicle Subsystems Specification Guide. Guidance gives recommendations on how to tailor the specification paragraph. Where __(TBS)__ appears, the guidance paragraph provides recommended values or text that the Using Service may use to insert in the __(TBS)__. When contractors are expected to fill-in the __(TBS)__, the Guidance paragraph will so state. The Using Service makes the final decision on whom fills in the __(TBS) in the specification. Finally, Lessons Learned are provided to give insight to past events which could impact the tailoring of the specification.

1.4 Deviations.

Deviations from this specification which will result in improvement of the system performance, reduced life cycle cost, reduced developmental cost, or where requirements of the specification results in compromise in operational capability, should be brought to the attention of the Using Service.

1.5 Environmental impact.

Air Vehicle Subsystems will be designed such that their operation, maintenance, and repair may be accomplished without violating the most stringent environmental regulations applicable to locations where subsystems are used or supported. Compliance with environmental regulations will not prevent subsystems from achieving and sustaining mission performance capability. Materials, processes, and environmental control equipment necessary to meet these environmental requirements must currently be available in the Using Service's maintenance and supply system. The design will not use environmentally unsuitable materials such as ozone depleting fluorocarbons, chlorofluorocarbons, and halons, or highly volatile organic compounds in solvents and coatings during development, production, operation, maintenance, or repair. The Environmental Protection Agency maintains an online list of toxic chemicals and hazardous substances on its Ozone Layer Depletion Website at http://www.epa.gov/ozone/snap/ that should be consulted. The Significant New Alternatives Policy (SNAP) Program available thereon identifies substitutes for ozone depleting chemicals.

The contractor will conduct an environmental analysis of air vehicle subsystems.

1.6 Responsible engineering office.

The responsible engineering office (REO) for this Handbook is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL.

2. APPLICABLE DOCUMENTS

2.1 General.

The documents listed in this section are specified in sections 3 and 4 of this handbook. This section does not include documents cited in other sections of this guide specification or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3 and 4 of this handbook, whether or not they are listed.

2.2 Government documents

2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

DEPARTMENT OF DEFENSE SPECIFICATIONS

JSSG-2000	Air System Joint Services Specification Guide
JSSG-2001	Air Vehicle Joint Services Specification Guide

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-130	Identification Marking of U.S. Military Property
MIL-STD-882	System Safety Program Requirements

MIL-STD-1472	Human Engineering Design Criteria for Military Systems, Equipment & Facilities
MIL-STD-1798	Mechanical Equipment and Subsystems Integrity Program

DEPARTMENT OF DEFENSE HANDBOOKS

MIL-HDBK-189	Reliability Growth Management
MIL-HDBK-310	Global Climatic Data for Developing Military Products
MIL-HDBK-454	Electronic Equipment, General Guidelines for

(Copies of these documents are available online at http://quicksearch.dla.mil or from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia PA 19111-5094.)

2.2.2 Other Government documents, drawings, and publications.

The following other Government documents, drawings, and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

USAF TECHNICAL REPORT

AFCRL-TR-74-0603	World-Wide Extremes of Humidity with Temperatures between 85 and 120 Degrees F, Accession Number ADA007676

(Copies of this document are available from www.dtic.mil; the Defense Technical Information Center, 8725 John J. Kingman Road, Fort Belvoir VA 22060-6218; Phone: (703) 767-8274; DSN 427-8274.)

2.3 Non-Government publications.

The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

SAE INTERNATIONAL

SAE AIR 1826	Acoustical Consideration for Aircraft Environmental Control System Design
SAE AS 5202	Port or Fitting End, Internal Straight Thread

(Copies of these documents are available from www.sae.org; SAE International, 400 Commonwealth Drive, Warrendale PA 15096-0001 USA; and www.ihs.com to qualified users.)

2.4 Order of precedence.

Unless otherwise noted herein or in the contract, in the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.5 Streamlining.

The Air Vehicle Subsystems Specification has been streamlined. The documents listed in this handbook which are required for acquisition have the same status as those referenced directly in section 2 (first tier). All other documents referenced through tiering, may be used for guidance and information only.

3. REQUIREMENTS

4. VERIFICATIONS

3.1 Definition.

The ___(TBS 1)___ air vehicle shall perform the identified table I functions and meet the requirements for safety, mission reliability, and vehicle growth as specified in __(TBS 2)__.

TABLE I. Subsystems functions.

(TBS 3)

REQUIREMENT RATIONALE (3.1)

Defining the applicable subsystems with their required functions establishes the linkage and allocates key functional requirements of the air vehicle with that of the individual subsystems to be developed. This linkage will form the basis from which the lower-tier component specification requirements will be derived.

REQUIREMENT GUIDANCE (3.1)

TBS 1 should specify the air vehicle.

TBS 2 should reference the applicable air vehicle document that contains the overall requirements for safety, mission reliability, and vehicle growth.

TBS 3 is a table that identifies the individual subsystem functions that are to be provided for the air vehicle and assigns the key required air vehicle functions that are explicit in or derived from the air vehicle specifications. A partial example of conventional manned air vehicle subsystems is shown below:

SUBSYSTEM	FUNCTION
Auxiliary Power	- Auxiliary power generation for self-sufficient normal ground and maintenance operations - Main Engine Starting - Emergency Power Generation -Power Transmission (Engine shaft horsepower to airframe)

Fire Protection	Crew Safety - Air Vehicle Survivability - Fuel Tank Inerting -- Fire Prevention -- Fire Detection -- Fire Suppression -- Bleed Air Leak Detection
Environmental Control	- Pressurization - Air Conditioning & Control - Environmental Protection -- Fog & Frost Protection -- Rain Removal -- Ice Protection -Engine Bleed Air Distribution & Control
Fuel	- Fuel Storage - Fuel Management & Delivery - Aerial Refueling - Additional Functions as requirements dictate
Hydraulics	- Hydraulic Power Generation and Distribution for use in: -- Primary Flight Control actuation -- Utility subsystem actuation -- Additional Functions as requirements dictate

Landing Gear	- Air vehicle Ground Maneuvering & Recovery - Steering - Braking - Additional functions as requirements dictate
VTOL/STOL power drive	- Propellers - Additional functions as requirements dictate
Propellers	- Provide thrust (e.g., propellers, rotors, fans) - Additional functions as requirements dictate
Additional Subsystems as requirements dictate	

A more integrated solution, however, may allocate, assign, or group a different combination of functions such as in the following partial example:

SUBSYSTEM	FUNCTION
Thermal/Energy Management Module	- Auxiliary power generation for self-sufficient normal ground and maintenance operations - Main Engine Starting - Emergency Power Generation - Pressurization - Air Conditioning & Control - Environmental Protection -- Fog & Frost Protection -- Rain Removal -- Ice Protection - Thermal Management

Accessory Drive	- Power Transmission (Engine shaft horsepower to airframe)
Fuel	- Fuel Storage - Fuel Management & Delivery - Aerial Refueling - Additional Functions as requirements dictate
Hydraulics	- Hydraulic Power Generation and Distribution for use in: -- Primary Flight Control actuation -- Utility subsystem actuation -- Additional Functions as requirements dictate
Landing Gear	- Air Vehicle Ground Maneuvering & Recovery - Steering - Braking - Additional functions as requirements dictate
VTOL/STOL power drive	- Propellers - Additional functions as requirements dictate
Propellers	- Provide thrust (e.g., propellers, rotors, fans) - Additional functions as requirements dictate
Additional Subsystems as requirements dictate	

REQUIREMENT LESSONS LEARNED (3.1)

(TBD)

4.1 Definition.

The basic objective of verification requirements is to verify that the air vehicle subsystem performance and operability requirements specified in section 3 have been met. This section specifies the method(s) of verification for each section 3 subsystem requirement. Requirements shall be verified incrementally __(TBS)__.

VERIFICATION RATIONALE (4.1)

The purpose of incremental verification is to install design development discipline, provide engineering and program management with events and progress criteria for continually assessing the design effort toward achievement of contractual subsystem requirements, and to ensure key system engineering risk reduction activities are successfully accomplished prior to each demonstration milestone.

VERIFICATION GUIDANCE (4.1)

TBS should be filled in with verification cross-reference table. Table II is an example of a verification cross reference table, composed of five sections: Requirement Section, Requirement Reference, Requirement Criticality, Verification Section and Verification Method/Event. The requirement section should be a numerical listing of all section 3 requirements. The requirement reference should restate the respective requirement parameter from section 3. The requirement criticality should document whether the requirement, as designated by the User, is a critical system requirement. If the requirement is critical, then all the subordinate allocated requirements within and across the lower level specifications should carry the same rating. For critical subsystem requirements, the final incremental verification should culminate in a test. The verification section should be a numerical listing of all verifications for section 3 requirements. The verification method/event designate the method of verifying (I - inspection, A - analysis, D - demonstration, T- test, or P - process control) the requirement to show design maturity at designated events (SFR, PDR, CDR, FF, SVR and any other event necessary for the proper incremental verification of the subsystem and its components). The method of verification should be specified for each milestone event.

TABLE II. Incremental verification.

REQUIREMENT/VERIFICATION CROSS-REFERENCE MATRIX										
Section 3 Reqts.	**Requirement Reference**	**Requirement Criticality**	**Section 4 Verification**	**Verification Method/Event**						
				N/A	**SFR**	**PDR**	**CDR**	**FF**	**SVR**	**Other**
3.1	AVSS definition	C	4.1							
3.2	AVSS characteristics		4.2							
3.3	Design and construction		4.3							
3.4.1	Landing		4.4.1							
3.4.2	Hydraulic power		4.4.2							
3.4.3	Auxiliary power		4.4.3							
3.4.4	Environmental control		4.4.4							
3.4.5	Fuel		4.4.5							
3.4.6	Aerial refueling		4.4.6							
3.4.7	Fire and explosion hazard protection		4.4.7							
3.4.8	Electrical power		4.4.8							
3.4.9	Mechanical		4.4.9							
3.4.10	Cargo, aerial delivery, and special operations		4.4.10							
3.4.11	VTOL-STOL power drive		4.4.11							
3.4.12	Propellers		4.4.12							
3.4.13	Pneumatics		4.4.13							
3.4.14	Additional subsystems and functions		4.4.14							

Requirement Criticality: C – Critical, N – Non-Critical
Method of Verification: I – Inspection, A – Analysis, D – Demonstration, T – Test, P – Process Control
Events:
N/A – Not Applicable
SFR – System Functional Review
PDR – Preliminary Design Review
CDR – Critical Design Review
FF – First Flight
SVR – System Verification Review
Other – Include all events necessary for incremental verification of subsystems and components.

VERIFICATION LESSONS LEARNED (4.1)

(TBD)

3.1.1 Functional diagram.

Functional diagrams for the __(TBS)__ shall be provided.

REQUIREMENT RATIONALE (3.1.1)

Diagrams are needed to evaluate functional and physical characteristics.

REQUIREMENT GUIDANCE (3.1.1)

TBS should be filled with the subsystem for which procurement is being considered. Item diagrams for each subsystem should be included in the air vehicle specification.

REQUIREMENT LESSONS LEARNED (3.1.1)

Diagrams are useful design tools.

4.1.1 Functional diagram.

Functional diagrams shall be verified.

VERIFICATION RATIONALE (4.1.1)

Diagrams are needed for verification to assure subsystem functional and physical correctness.

VERIFICATION GUIDANCE (4.1.1)

Functional diagrams should be verified by inspection.

VERIFICATION LESSONS LEARNED (4.1.1)

(TBD)

3.1.2 Interface drawing.

Interface drawings for the __(TBS)__ shall be provided.

REQUIREMENT RATIONALE (3.1.2)

Interface between airframe and subsystem/component(s) must be established and controlled to ensure compatibility. Interface drawings are required to ensure physical compatibility between subsystems, components and airframe.

REQUIREMENT GUIDANCE (3.1.2)

TBS should be filled with interface drawings for each subsystem.

REQUIREMENT LESSONS LEARNED (3.1.2)

Past air vehicle procurements have benefited from the inclusion of interface drawings.

Fluid drains, drain characteristics, and collection requirements have been included on interface drawings. Component clearances have also been included.

4.1.2 Interface drawing.

Interface drawing shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.1.2)

Drawings are needed for verification to assure physical compatibility between subsystems/ components and airframe.

VERIFICATION GUIDANCE (4.1.2)

TBS should be accomplished by inspection.

VERIFICATION LESSONS LEARNED (4.1.2)

(TBD)

3.2 Characteristics

4.2 Characteristics

3.2.1 Security.

Subsystem security shall be in accordance with __(TBS)__.

REQUIREMENT RATIONALE (3.2.1)

This is a flowdown requirement from JSSG-2001, Air Vehicle Joint Services Specification Guide.

REQUIREMENT GUIDANCE (3.2.1)

TBS should be in accordance with the JSSG-2001 requirement.

REQUIREMENT LESSON LEARNED (3.2.1)

(TBD)

4.2.1 Security.

Subsystem security shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.2.1)

(TBD)

VERIFICATION GUIDANCE (4.2.1)

(TBD)

VERIFICATION LESSONS LEARNED (4.2.1)

(TBD)

3.2.2 Computer resources.

The computer resources, hardware and software, dedicated to the control of air vehicle subsystems shall support allocated air vehicle subsystem functional requirements. Computer resources hardware defined as, electric/electronic sensor data collection devices (data input), electric and electronic effector devices (data output), analog, digital communication paths (serial and parallel data buses), data processing elements (general or specialized CPUs), and power supply characteristics shall be defined by computer resources. Computer resources software defined as, High Order Language (HOL), software development and testing tools (software environment), and software development processes shall be characterized by computer resources. Computer resources hardware and software shall be designed as an open architecture that is expandable, upgradable and compatible with other computer resources within the air vehicle to maintain security requirements.

The computer resources shall support the __(TBS)__ level maintenance concept.

A hardware and software obsolescence plan shall be implemented for computer resources to address maintenance of the air vehicle.

REQUIREMENT RATIONALE (3.2.2)

Hardware characteristics such as bus bandwidth, bus type, input device impedance/voltage range, output device impedance/voltage range, and CPU type must be “owned” by one design group. This stops proliferation of hardware and forces commonality.

REQUIREMENT GUIDANCE (3.2.2)

Hardware and software processing resources should be an open, expandable architecture using a minimum number of module types.

TBS: Computer resources should support the air vehicle subsystem diagnostics, fault detection, fault isolation, fault reconfiguration, and life management requirements.

See JSSG-2001, Air Vehicle Computer Systems, for additional guidance.

REQUIREMENT LESSONS LEARNED (3.2.2)

(TBD)

4.2.2 Computer resources.

The functional requirements allocated to and implemented by computer resources shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.2.2)

(TBD)

VERIFICATION GUIDANCE (4.2.2)

TBS: The functional requirements implemented into computer resources should be verified by stand-alone computer resource testing air vehicle. Additional functional verification should be accomplished during system-level tests described in each subsystem.

Architectural requirements and the expansion capability should be verified by analysis. An analysis of the module types should verify that the minimum number of modules is used consistent with the need to partition functions and to minimize overall hardware complexity.

A testability analysis should verify that the air vehicle subsystem computer resources support the fault detection, fault isolation, and reconfiguration requirements. Specific functional requirements should be verified as called out in the specified requirement section.

The support-level maintenance should be verified by testability analysis and demonstration on the VSS. The electrical design should be analyzed to verify that electrical failures can be detected and isolated to the quantitative level required to support air vehicle requirements.

VERIFICATION LESSONS LEARNED (4.2.2)

(TBD)

3.2.3 Observables.

Subsystem IR, acoustics, radar, and visual observable requirements shall be as follow: (TBS).

REQUIREMENT RATIONALE (3.2.3)

This is a flowdown requirement from JSSG-2001.

REQUIREMENT GUIDANCE (3.2.3)

TBS should be in accordance with JSSG-2001, “Susceptibility“.

REQUIREMENT LESSONS LEARNED (3.2.3)

In the past, the dynamic RCS signature of the rotating blades on propellers have been a significant design observable consideration.

4.2.3 Observables.

Subsystem IR, acoustics, radar, and visual observable requirements shall be verified (TBS) .

VERIFICATION RATIONALE (4.2.3)

This verification is to ensure survivability.

VERIFICATION GUIDANCE (4.2.3)

TBS should be filled in with analysis of model measured data, analysis of EMC radiated emissions data, and data collected during ground and flight tests.

VERIFICATION LESSONS LEARNED (4.2.3)

(TBD)

3.2.3.1 Electromagnetic emissions.

Electromagnetic emissions shall be in accordance with (TBS) .

REQUIREMENT RATIONALE (3.2.3.1)

This is a flowdown requirement from JSSG-2001.

REQUIREMENT GUIDANCE (3.2.3.1)

TBS should be in accordance with the JSSG-2001 requirement.

REQUIREMENT LESSONS LEARNED (3.2.3.1)

(TBD)

4.2.3.1 Electromagnetic emissions.

The EME requirement shall be verified (TBS).

VERIFICATION RATIONALE (4.2.3.1)

(TBD)

VERIFICATION GUIDANCE (4.2.3.1)

TBS: The EME requirement should be verified by analysis of EMC radiated emissions test.

VERIFICATION LESSONS LEARNED (4.2.3.1)

(TBD)

3.2.4 Survivability.

The air vehicle subsystems shall be designed and integrated into the air vehicle to meet the survivability requirements of the air vehicle as specified in (TBS 1) . Specific subsystem allocated and derived susceptibility and vulnerability requirements shall be as follow: (TBS 2) .

REQUIREMENT RATIONALE (3.2.4)

The air vehicle subsystems must be able to withstand and perform in the intended environment in order for the air vehicle to be effective.

REQUIREMENT GUIDANCE (3.2.4)

TBS 1: JSSG-2001, along with the applicable paragraphs and any associated supplemental program specific documents identifying vulnerability/survivability requirements, should be referenced.

TBS 2: The following hazards and vulnerability areas should be considered as to how the subsystems would contribute to the total air vehicle performance:

- Ballistic impact from conventional munitions and missile fragmentation
- Chemical and Biological agents to include decontamination agents
- Lasers and other directed energy weapons such as high power microwave
- Nuclear
- Birds
- Observables
    - IR, UV, and EM radiation
    - Radar Cross Section (RCS)
    - Visible, such as smoke and vapor trails.

Survivability is divided into two areas: vulnerability (provisioning so that once hit, damage is minimized) and susceptibility (provisioning such that you do not get hit).

VULNERABILITY AREAS	SUSCEPTIBILITY AREAS
- Ballistic impact ...	- Observables ...
- Chemical and Biological	- Stealth
- Lasers	- Countermeasures
- Nuclear	- Chaff
- Birds	

REQUIREMENT LESSONS LEARNED (3.2.4)

(TBS)

4.2.4 Survivability.

The survivability requirements shall be verified as follows: __(TBS)__.

VERIFICATION RATIONALE (4.2.4)

Verification that the subsystems can meet their allocated requirements is necessary for air vehicle verification.

VERIFICATION GUIDANCE (4.2.4)

TBS: Vulnerability techniques should be verified by inspection of design drawings and tests. The specific vulnerability reduction techniques used to enhance the survivability of the subsystem should be verified in accordance with tailored verification methods which are specific for the threat environments. The susceptibility reduction techniques should be verified as specified in JSSG-2001.

VERIFICATION LESSONS LEARNED (4.2.4)

(TBD)

3.2.5 Reliability.

The air vehicle subsystem requirements shall be consistent with JSSG-2001 Air Vehicle “Reliability” requirements.

REQUIREMENT RATIONALE (3.2.5)

This is a flowdown requirement from JSSG-2001.

REQUIREMENT GUIDANCE (3.2.5)

The primary reliability requirement is the mission reliability requirement. It is derived, by allocation, from the mission reliability statement in the operational requirements. It cannot be measured satisfactorily in the R&D environment. It assumes mature equipment under field operating conditions and would require the completion of many missions to obtain a high confidence measurement. It is for this reason that Mean Time Between Failure (MTBF) measurements are used. The MTBF requirement is related to the mission success requirement through the reliability equation. The MTBF required to meet the mission success requirement is increased 15 to 20 percent (15-20%) to allow for failures induced by operational and maintenance problems handling damage, etc.

The required reliability is not generally achieved in development: when achieved it is generally well into production after all correctable problems have been resolved and necessary improvements have been retrofitted into delivered equipment. Reliability is a growth process. It starts at a low level and grows as failures and problems are observed and corrected. Reliability is a growth process and is discussed in MIL-HDBK-189, Reliability Growth Management. Recognizing the growth process, two sets of reliability are generally used; the first represents the operational requirement while the second applies strictly to the development phase of the program.

Reliability does not just occur; it must be planned for. Reliability activities that must be planned and performed might include:

Subcontractor and Supplier Control

Failure Reporting and Corrective Action System (FRACAS)

Reliability Analysis and Prediction

Failure Modes, effects, and Criticality Analysis

Identification and Control of Critical Items

Development, Qualification, and Production Tests.

A more complete list of reliability activities and instructions on their implementation are found in MIL-STD-785B, Reliability Program for Systems and Equipment, Development and Production. The selection of reliability activities will be determined by the reliability requirements, program requirements and/or constraints, and past experience.

The key to achieving the required degree of reliability growth is to accelerate the occurrence and correction of correctable failures in the system. In some cases a system is dedicated to performing reliability development tests at simulated operational environments. These tests are run in parallel with other development tests. All failures are processed through the FRACAS, corrective action is defined and installed in the test hardware to provide verification. Otherwise, data from all tests, laboratory and flight, must be processed through FRACAS to determine the required corrective actions. After development and into production, the process continues using data from factory, flight, and operational tests.

REQUIREMENT LESSONS LEARNED (3.2.5)

(TBD)

4.2.5 Reliability.

Reliability requirement shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.2.5)

Verification is an element of the Reliability Program for air vehicle subsystems and provides information and data for the verification process. Reliability is a design attribute and is achieved principally by applying appropriate controls to every step of the design process, and by applying appropriate quality controls to the manufacture of the item so that the inherent reliability of the design will not be degraded. A good prediction will indicate the feasibility of meeting the reliability requirements. The prediction process should be thoroughly understood so that the prediction can be analyzed to identify problems that should be corrected before the design is mechanized.

VERIFICATION GUIDANCE (4.2.5)

TBS should be filled in according to JSSG-2001.

The FMECA should be used to identify the critical failure modes that require correction. The FRACAS should be used in all development testing to analyze all failures and identify those needing correction. Special laboratory reliability tests might be required for some critical component items to assure that their performance is compatible with the subsystem reliability and life requirements. No special reliability test is recommended for the subsystems, but data for all tests at the subsystem and higher levels should be utilized to enlarge the reliability data base and provide a continuing measurement of reliability.

One factor that should not be overlooked is experience; the extent to which the reliability history of previous subsystem designs might apply to this design. A "new" subsystem design might be merely a physical rearrangement of the components in a previous design. This factor should be carefully studied to make effective use of prior experience.

Test methods of the past have not yielded high confidence measurements of subsystem reliability. The verification methods discussed herein do not represent a break with the past so that the confidence level of the reliability measurements will continue to be low. The procedures discussed and recommended here emphasize the early identification and correction of problems that might seriously impact the field reliability of the subsystem.

VERIFICATION LESSONS LEARNED (4.2.5)

General practice has been to subject the subassemblies and components to extensive qualification testing then perform functional verifications, including, reliability in flight test as part of the air vehicle contractors development test program. This might be called hybrid testing since it is performed in many steps throughout the development process. Tests and analyses are selected and structured so as to optimize the test time required and be beneficial to costs.

3.2.6 Maintainability.

The air vehicle subsystem maintainability requirements shall be in accordance with JSSG-2001.

REQUIREMENT RATIONALE (3.2.6)

This is a flowdown requirement from JSSG-2000, Air System Joint Services Specification Guide.

REQUIREMENT GUIDANCE (3.2.6)

The subsystem design maintainability should be capable of meeting subsystem or air vehicle availability goals for the mission and mission mix profile. Maintainability Qualitative and Quantitative requirements should be specified.

The diagnostic capabilities necessary to meet subsystem maintainability requirements should be specified.

All excluded maintenance and repair functions should be listed.

Subsystem design should permit maximum use of non-destructive inspection techniques and multi-purpose test and inspection equipment. Inspection provisions, including access envelopes, should be shown on the subsystem item diagrams.

Required tooling should be held to a minimum. Ideally, the subsystem should be capable of being maintained with a set of standard hand tools to the maximum extent possible. Where provisions for standard hand tools are not feasible, the design should provide, wherever possible and cost effective, for special tools and test equipment that are available and in use on other in-service subsystems of the same type.

Subsystems should be designed to be maintained by at least the central ninety percent (90%) of the maintainer population (5th percentile female stature through 95th percentile male stature) wearing a full complement of personal protective equipment, under all defined environmental conditions (including day/night), and all defined operational scenarios at operating bases and deployed locations.

The capability for battle damage repair should be considered. Combat damage repair design techniques should utilize tools and materials found at organizational and intermediate levels if practical.

All subsystem components should be permanently marked to indicate all instrumentation and oil connections. Components and items of the subsystems requiring routine servicing or adjustment should be made readily accessible without removal of other parts. Each line replaceable unit (LRU) should be removable from the system without removal of other LRU's.

Parts subject to wear and which require replacement prior to expected life achievement of the system component, should be individually replaceable.

Subsystem components should be accessible for inspection, cleaning, adjustment, or replacement, with tools normally found in a mechanic's toolbox, while installed and without removal of other components or structures. Exceptions should be identified.

Safety wire and cotter keys should not be used at an organizational level.

REQUIREMENT LESSONS LEARNED (3.2.6)

Clearance provisions for installing hose nipples or flared tube fittings have been a problem in the past.

In the past, safety wire and cotter keys have punctured and torn NBC protective gear exposing personnel to possible contamination.

4.2.6 Maintainability.

The maintainability requirements shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.2.6)

The maintainability requirement is a flowdown from JSSG-2001.

VERIFICATION GUIDANCE (4.2.6)

TBS should be filled in with Verification Requirements of JSSG-2001.

VERIFICATION LESSONS LEARNED (4.2.6)

(TBD)

3.2.7 Integrity and environment

4.2.7 Integrity and environment

3.2.7.1 Service life and usage

4.2.7.1 Service life and usage

3.2.7.1.1 Design service life.

The subsystem design service life shall be in accordance with the JSSG-2001, "Design service life".

REQUIREMENT RATIONALE (3.2.7.1.1)

This is a flowdown requirement from JSSG-2001.

REQUIREMENT GUIDANCE (3.2.7.1.1)

The subsystems should be designed to satisfy the performance requirements of this specification for the design service life of the air vehicle.

Operational service life data should be used for developing subsystems and components design, analysis, and test criteria. Validity of information should be verified.

Reliability, durability and service life of subsystems are all dependent on Service usage. The design usage will be supplied by the using service as part of the request for proposal. The contractors should identify any recommended changes based on their experience to the using service for consideration. It is recommended that the contractors conduct trade studies to establish cost (Life Cycle Cost - LCC, Weight, Performance) as a function of structural life (inspection intervals, economic life). The results of these trade studies should be presented to the using service for consideration to establish a preferred design service life.

If specific design usage requirements are not specified by the using service, the contractor should convert the airframe mission profile information supplied by the using service to Subsystem usage profiles as required (e.g., to convert airplane thrust requirements for profile segments into engine power settings). The design usage should be included as part of the contract specifications.

The design usage should include:

a. Missions and Mission Mix (both training and operational)
b. Usage parameters
c. Externally applied forces
d. Ambient temperature extremes and ambient temperature distribution for principal sited bases

e. Mix of ship and shore based operations

f. Storage and shipment.

REQUIREMENT LESSONS LEARNED (3.2.7.1.1)

(TBD)

4.2.7.1.1 Design service life.

Design service life shall be verified in accordance with JSSG-2001.

VERIFICATION RATIONALE (4.2.7.1.1)

(TBD)

VERIFICATION GUIDANCE (4.2.7.1.1)

Operational service life should be verified by analysis and test.

VERIFICATION LESSONS LEARNED (4.2.7.1.1)

(TBD)

3.2.7.2 Environment.

Each subsystem shall meet the performance requirements of this specification before, during, and after exposure to any operational combination of the following natural and induced environments:

a. Natural environment: __(TBS 1)__.

b. Induced environment. The induced environments for the air vehicle subsystems shall be developed using the above natural environment and the environment imposed on the subsystems by the air vehicle design and its operating environment. Induced environments shall be established for all modes of operation or non-operation including normal operation, intermittent operation (transient operation), non-operation, storage, and transport. These induced environments shall include: __(TBS 2)__.

REQUIREMENT RATIONALE (3.2.7.2)

This is a flowdown requirement from the JSSG-2001. The intent is to provide a definition of the natural and induced environments under which the air vehicle is expected to operate. The air vehicle designer must add induced effects to determine overall subsystem exposure.

REQUIREMENT GUIDANCE (3.2.7.2)

TBS 1 should be filled in with the following guidance, except for air vehicle operating in limited geographical areas:

Air vehicle subsystems should be designed to meet the entire specified requirement while operating under the worst expected natural extremes. These design conditions are usually based upon MIL-HDBK-310, formerly MIL-STD-210, which established extreme climatic design criteria for military equipment intended for worldwide usage.

The difficulty in applying MIL-HDBK-310 is in selecting the severity of the extreme to be used. Systems being designed for specialized applications or limited usage may be designed to more lenient requirements as determined by the program office. Listed below are the natural environments, which must be considered during the analysis, design, and test of air vehicle subsystems. Generally, many of these environmental conditions are specified in the air vehicle specification based upon the operational requirements. The project engineer must review these requirements to determine if all the appropriate environmental conditions have been specified, and if not, address them in this paragraph. The engineer must be sure the requirements specified are consistent with those established by the program office; i.e., if the program office selects the MIL-HDBK-310 10-percent (10%) extreme flight operation high temperature, the 1-percent (1%) extreme flight operation humidity would probably not be appropriate. MIL-HDBK-310 defines the 1-percent (1%) extreme, 10-percent (10%) extreme, etc., and how the design criteria were established. The handbook should be consulted when this requirement is being prepared. The engineer must make it clear that these values represent the extremes and that the equipment is expected to meet specification at all conditions less than (or greater than) the extremes.

Listed below are the environmental conditions that typically should be given for air vehicle subsystems. When values are not provided in the air vehicle specification, the following values are recommended for unlimited, worldwide usage:

Note: Since MIL-HDBK-310 is a handbook, it is not contractually binding. If any of the values below are to be contractually binding, including the tables, they must be directly inserted into the specification as requirements.

a. Ground operation high temperature. 120°F (MIL-HDBK-310, Worldwide Surface Environment 1-percent (1%) extreme)

b. Ground operation low temperature. -60°F (MIL-HDBK-310, Worldwide Surface Environment 20-percent (20%) extreme)

c. Flight operation high temperature. (MIL-HDBK-310, 5.3.1.1.2, Worldwide Air 1-percent (1%) extreme)

d. Flight operation low temperature. (MIL-HDBK-310, 5.3.1.2.2, Worldwide Air 1-percent (1%) extreme)

e. Ground operation of high absolute humidity with high temperature. The "GROUND" curve on figure 1 should be used. This curve represents data from MIL-HDBK-310, Worldwide Surface Environment 1-percent (1%) extreme, and is based on the curves developed in Air Force Cambridge Research Laboratories Report AFCRL-TR-74-0603, dated 5 December 1974.

f. Ground operation high relative humidity. (MIL-HDBK-310, Worldwide Surface Environment 1-percent (1%) extreme [table VI])

g. Flight operation high humidity. (MIL-HDBK-310, 5.3.1.2.2, Worldwide Air 1-percent (1%) extreme)

h. In-flight operation of high absolute humidity with high temperature. The "IN-FLIGHT" curve on figure 1, herein, should be used. This curve represents the 1-percent (1%) extreme of figure 14 from the Air Force Cambridge Research Laboratories Report AFCRL-TR-74-0603, dated 5 December 1974. The curve is for sea level conditions. Extrapolating the curve to altitude conditions should be considered. The report also provides other frequencies of occurrences.

i. Low humidity for all ground and flight conditions: zero percent (0%).

j. Ground operation rainfall rate. (MIL-HDBK-310, 5.1.11.2, Worldwide Surface Environment 0.5-percent (0.5%) extreme.) In addition, externally mounted equipment should be operable without significant degradation in performance and should sustain no physical damage, during periods of extreme rainfall with a rate of 1.8 mm/min and with intermittent wind.

k. Flight operation rainfall rate. (MIL-HDBK-310, 5.3.2.5.2, Worldwide Air 0.5-percent (0.5%) extreme)

l. Solar radiation intensity. As defined on figure 2, herein. This data was extracted from figure 10 of WADC Technical Report 55-254. The upper limit is consistent with the ASHRAE Handbook – Fundamentals Volume (1989 edition, page 27.2), which gives the solar intensity at the outer edge of the atmosphere as between 449.6 BTU/hr-ft^2 (1418.2 W/m^2) in mid-winter and 419.9 BTU/hr-ft^2 (1324.5 W/m^2) in mid-summer. The lower limit has been adjusted to reflect the MIL-HDBK-310 (table II) value of 355 BTU/hr-ft^2 (119.8 W/m^2).

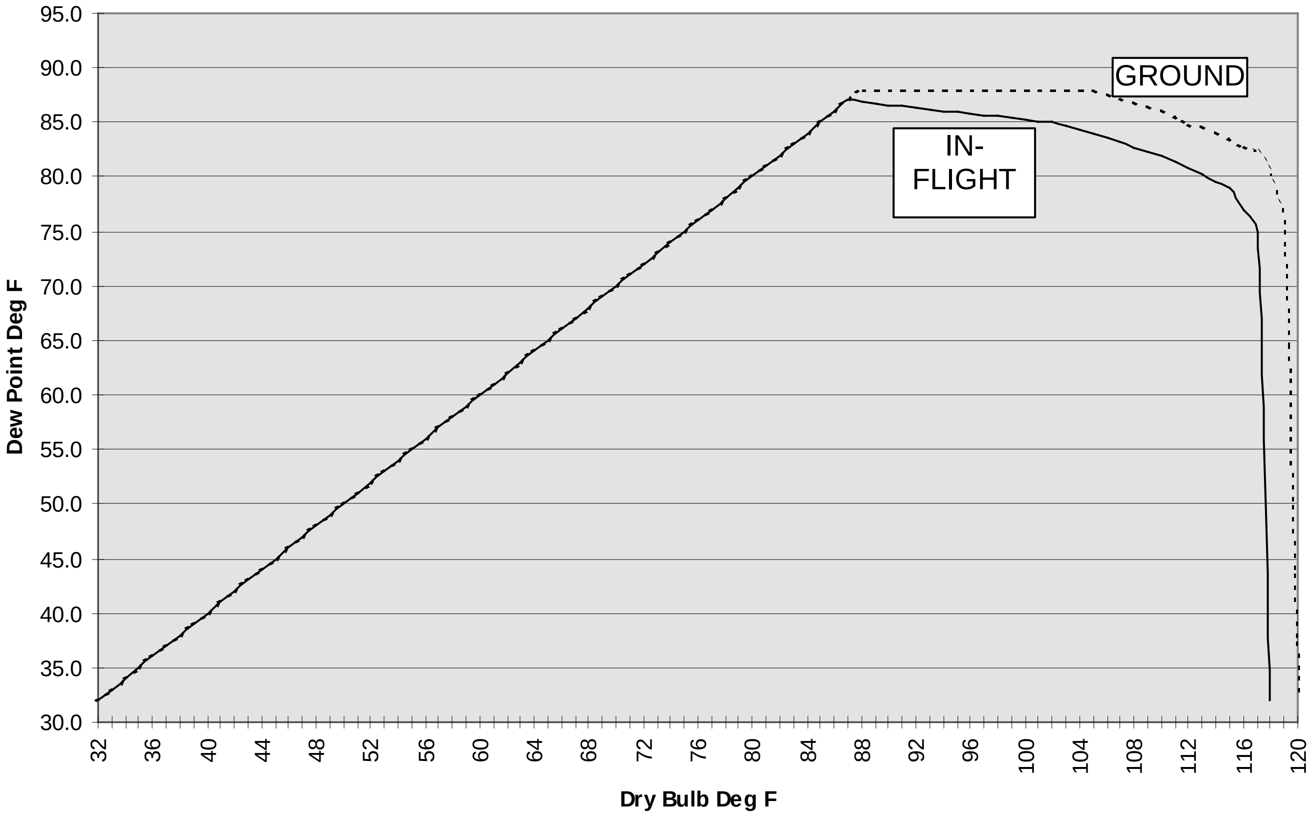

FIGURE 1. Joint values of high temperature with high humidity.

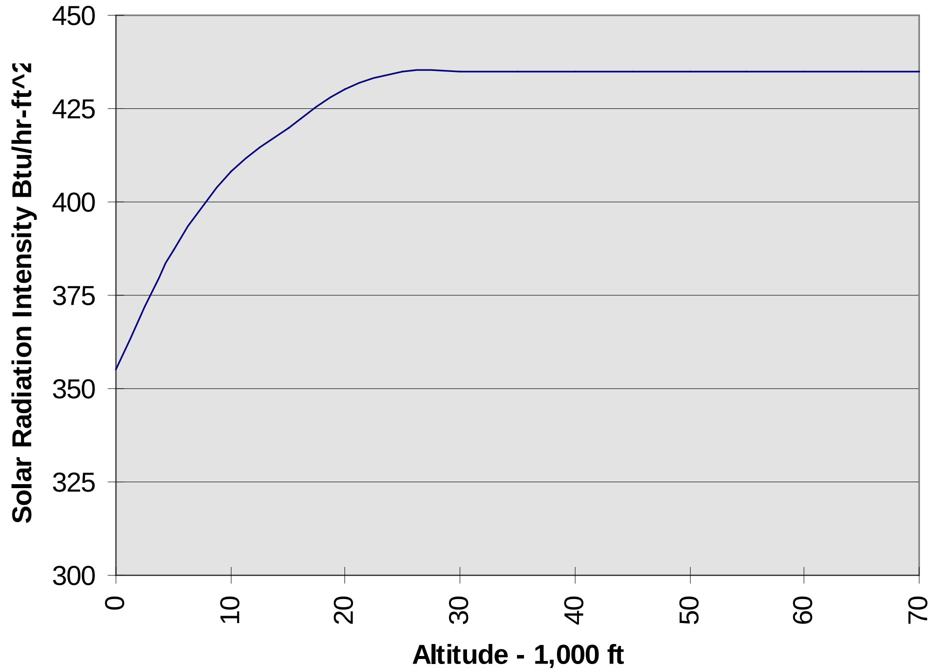

FIGURE 2. Solar radiation intensity.

m. Ground hot soak conditions. MIL-HDBK-310, Worldwide Surface Environment Daily Cycle of Temperature and Other Elements, 1 percent (1%) extreme (MIL-HDBK-310, table I). This should be used for requirements where longer-term duration is an issue such as storage and start-up from hot soaked condition. Worldwide Surface Environment Daily Cycle of Temperature and Other Elements, 1 percent (1%) extreme (MIL-HDBK-310, table IV) should also be used where humidity may be a factor.

n. Atmospheric pressure. Pressure altitudes from 1,300 ft (396 m) below sea level to the operational ceiling of the vehicle. Use of 1,300 ft (396 m) below sea level allows for both normal atmospheric pressure changes and those geographic areas with below sea-level elevations.

o. Salt spray. A sea salt fallout of at least 27 kg/ha/yr should be used.

p. Icing conditions:

1. In-flight. The icing environments should be those represented on figure 3, herein, for in-flight icing from supercooled droplets. The particle droplet distribution must be considered and can be approximated by the "Langmuir B" distribution modified for cloud type, maritime, and orographic effects. The duration of exposure should not be less than 45 minute with 90 minutes a worst-case desired exposure capability. The guidance information given in "Air vehicle Icing Handbook" DOT/FAA/CT-88/8-1 is the most up-to-date central source of icing design data to date (beyond ADS-4), is

updated on a regular basis by the FAA and the SAE AC-9C Icing Subcommittee, and should be used for air vehicle design. The specification should include in-cloud and precipitating hydrometeors such as supercooled liquid droplets, basic ice crystals, crystal aggregations, freezing rain, sleet, graupel, hail, and snow. Airframe configurational phenomena such as condensation icing and vortex icing should be addressed.

2. Ground. The icing environments should be those represented in the Ground Environment of MIL-HDBK-310. The subsystem specification should consider effects during/after exposure due to (layer and accretion of precipitating, blowing and recirculating snow; sleet; hail; graupel; freezing rain; slush; and de-icing/anti-icing fluid residual using the references cited above.

3. Ship. The icing environments should be those represented in the Naval Surface and Air Environment of MIL-HDBK-310. Use the references cited above to develop the subsystem specification with consideration to effects during/after exposure due to accretion of precipitating, blowing, and recirculating snow; sleet; hail; graupel; freezing rain; slush; and de-icing/anti-icing fluid residual.

   (a.) Salt spray. Protection against sea salt fallout of at least 27 kg/ha/yr should be provided.

   (b.) Fungus. Fungus types for operation and stowage should be defined using MIL-STD-810 as a guide.

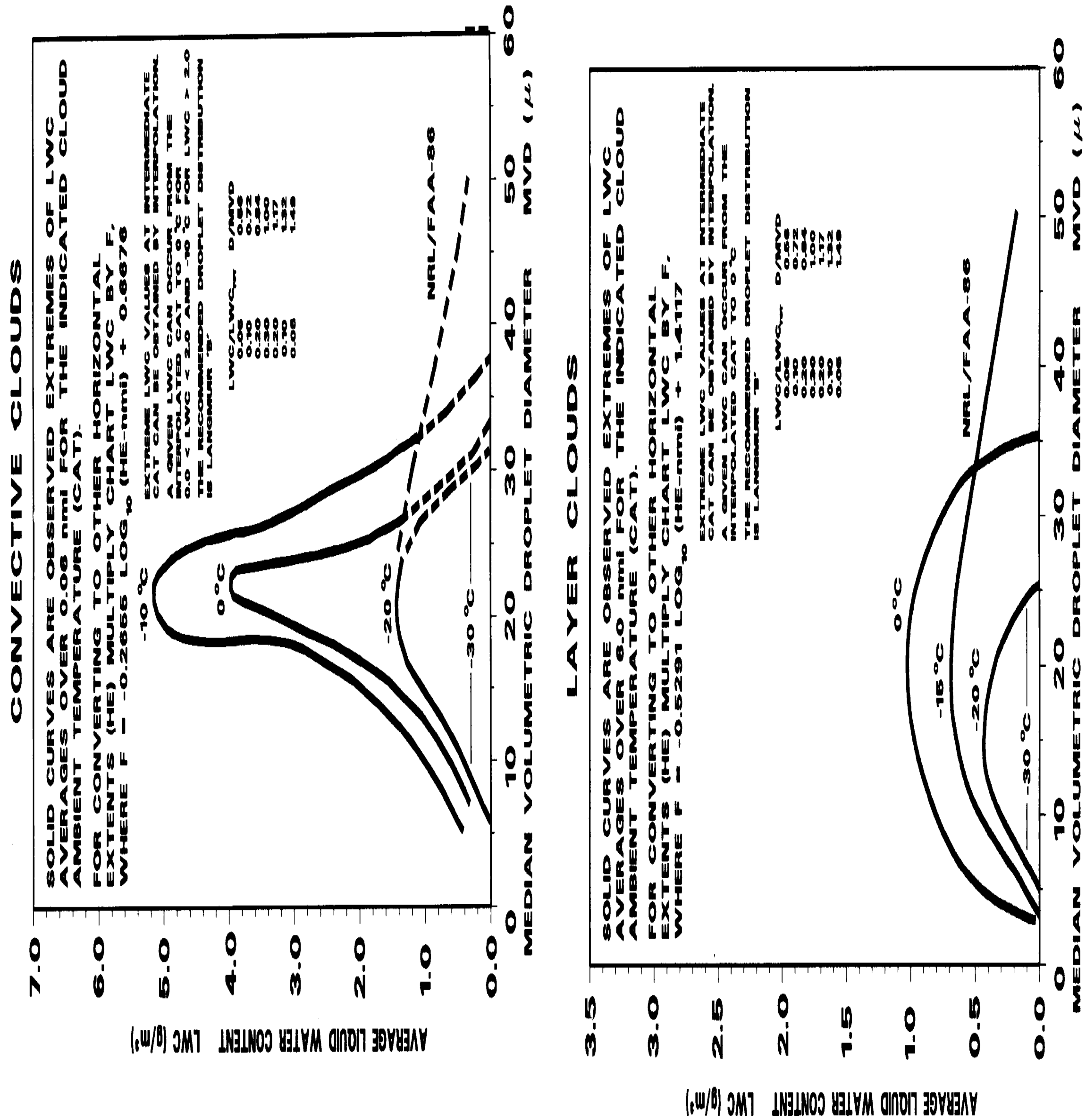

FIGURE 3. In-flight supercooled cloud icing environment (layer and convection).

TBS 2 should be filled in with the following guidance on induced environments: MIL-STD-810, although a test specification, is helpful in establishing many of the requirements.

a. External Ground Temperature. Using the ground ambient temperatures established above the contractor should be required to develop the induced environment accounting for such effects as radiative and convective heating off of tarmacs and air vehicle exhaust that may be recirculated back to the air vehicle. Where air vehicle operate from different types of environments such as air vehicle carriers, a separate requirement for the individual environments should be considered.

b. External Skin and Ram Temperature. Using the in-flight ambient temperatures established above the contractor should be required to develop the induced environment accounting for aerodynamic heating of the skin and boundary layer air.

c. Operating Temperature

d. High Temperature (internal)

e. Low Temperature (internal)

f. Temperature Shock

g. Vibration (including gunfire where applicable)

h. Acceleration

i. Shock

j. Acoustic Noise

k. Humidity

l. Low Pressure (altitude)

m. Fungus

n. Sand and Dust

o. Explosive Atmosphere

p. Leakage (immersion)

q. Attitude

r. Pitching, Rolling, Yawing Angular Velocities and Accelerations and Load Factors (up, down, aft, forward, and side)

s. Electromagnetic

t. Typically, the contractor is required to develop this data for regions and compartments in the air vehicle using MIL-STD-810 as a guide and to submit it for government approval. When levying this requirement, a contract data item should be prepared to require the data to be delivered and approved. Electromagnetic environment is not covered in MIL-STD-810.

REQUIREMENT LESSONS LEARNED (3.2.7.2)

On the V-22 FSD air vehicle, the induced environment resulting from hot exhaust from the engines being deflected into the air vehicle on the ground resulted in the air temperatures at inlets being much higher than predicted, resulting in failure to meet cabin, cockpit and avionics specified temperatures.

C-130H air vehicles stationed at Dyess AFB TX experienced extreme clogging of heat exchangers on the ram airside with sand and dust. This clogging was found to be due to the high fin density and location of the ram air inlet in the plane of rotation of the propellers and near the ground.

4.2.7.2 Environment.

The subsystems shall be capable of meeting the performance requirements of this specification before, during, and after exposure to the natural and induced environments as verified by analyses, tests, and demonstrations.

VERIFICATION RATIONALE (4.2.7.2)

The intent of this requirement is to verify the capability of the subsystem to withstand and operate in the natural and induced environments to which it will be subjected.

VERIFICATION GUIDANCE (4.2.7.2)

All individual components and/or subsystems of the air vehicle should be analyzed and/or tested to verify compatibility with the natural and induced environments. The following will not apply to all subsystems or part of subsystems. Such factors as whether they are internal or external or have electronic equipment or not should be considered. The potential effect of the environmental factor on the subsystem will also vary from subsystem to subsystem and component to component. This can only be determined during the design process. The contractor should be required to submit a data item to specify which environmental tests will be run on which subsystems and their components. Combining environments in tests should be considered where the interaction of factors may be critical. It may be considered for cost effectiveness where verification is not compromised. MIL-STD-810 should be used as a guide to develop verification requirements.

a. Ground operation high temperature
b. Ground operation low temperature
c. Flight operation high temperature
d. Flight operation low temperature
e. Ground operation high absolute humidity with high temperature
f. Ground operation high relative humidity
g. Flight operation high humidity
h. Low humidity
i. Ground operation rainfall rate
j. Flight operation rainfall rate
k. Solar radiation intensity
l. Ground hot soak conditions
m. High temperature (internal)
n. Low temperature (internal)
o. Temperature Shock
p. Vibration (including gunfire where applicable)
q. Acceleration

r. Shock

s. Acoustic Noise

t. Low Pressure (altitude)

u. Fungus

v. Salt Fog (carrier based air vehicle should add sulfur to this)

w. Sand and Dust

x. Explosive Atmosphere

y. Leakage (immersion)

z. Solar Radiation

aa. Icing/Freezing Rain

bb. Electromagnetic - Should be in accordance with JSSG-2001.

VERIFICATION LESSONS LEARNED (4.2.7.2)

The experience of one-type fighter in recovery from spins, hard landings, and arrested landings shows the acceleration and shock limits (MIL-STD-810) to which the air vehicle was tested were exceeded. After one incident, a method of post-flight inspection had to be instituted to ensure there was no damage to the mechanical equipment (rotating, valves).

3.2.7.3 Crash worthiness.

Subsystems shall be in accordance with JSSG-2001, “Crash worthiness”.

REQUIREMENT RATIONALE (3.2.7.3)

This is a flowdown requirement from the JSSG-2001, “Crash worthiness”.

REQUIREMENT GUIDANCE (3.2.7.3)

Crash worthiness should be considered during the initial design phase by selecting the most effective mix of crash resistance factors including the following:

a. retention of high mass components, equipment, and cargo;

b. occupant environment hazards; and

c. post crash hazards.

Specific subsystems contributing to crash protection include crash resistant fuel systems, energy absorbing landing gear, crash resistant cargo restraint systems, and air vehicle flotation systems. Relative to rotary wing air vehicle, all gearbox support structures should prevent the gearbox from being displaced into occupied space at crash load factors equal to or less than those specified for a survivable air vehicle crash.

REQUIREMENT LESSONS LEARNED (3.2.7.3)

(TBD)

4.2.7.3 Crash worthiness.

Subsystem crash worthiness shall be verified through analysis and test.

VERIFICATION RATIONALE (4.2.7.3)

This is a flowdown requirement from JSSG-2001.

VERIFICATION GUIDANCE (4.2.7.3)

Verification should be in accordance with JSSG-2001, “Safety verification.”

VERIFICATION LESSONS LEARNED (4.2.7.3)

(TBD)

3.2.7.4 Materials and processes.

The materials and processes shall ensure adequate strength, durability, and damage tolerance capabilities of components as required __(TBS)__.

REQUIREMENT RATIONALE (3.2.7.4)

Some materials do not ensure adequate strength, durability, and damage tolerance capabilities due to corrosion, degradation, toxic vapors, out gassing, nutrients for fungi.

REQUIREMENT GUIDANCE (3.2.7.4)

TBS: Durability considerations should include low cycle fatigue, high cycle fatigue, current-carrying capacity, dielectric materials margins, and corrosion resistance.

Damage tolerance considerations should include fracture toughness, crack growth rate, stress corrosion cracking, and corrosion resistance.

Elastomers and other materials exposed to lubricants, fluids and chemical agents used to operate and maintain the subsystem should be compatible with such fluids throughout the entire system temperature range without experiencing detrimental swelling, shrinkage, hardening or other forms of material deterioration.

REQUIREMENT LESSONS LEARNED (3.2.7.4)

(TBD)

4.2.7.4 Materials and processes.

Material and process requirements shall be verified __(TBS)__.

VERIFICATION RATIONALE (4.2.7.4)

(TBD)

VERIFICATION GUIDANCE (4.2.7.4)

TBS: Verification of the materials and processes requirements could be by material data analysis and characterization testing. Material characterization testing may include yield strength, ultimate strength, S/N data, da/dn testing, etc., for various materials and processing variables as required by strength, durability, damage tolerance, and other analysis methods. Historical data may be used in lieu of material characterization testing if available.

VERIFICATION LESSONS LEARNED (4.2.74)

(TBD)

3.2.7.4.1 Coatings and finishes.

Surfaces shall be coated and finished in accordance with the air vehicle specification.

REQUIREMENT RATIONALE (3.2.7.4.1)

This is a flowdown requirement from JSSG-2001, "Exterior color".

REQUIREMENT GUIDANCE (3.2.7.4.1)

Coatings and finishes should be in accordance with JSSG-2001, "Exterior color".

REQUIREMENT LESSONS LEARNED (3.2.7.4.1)

(TBD)

4.2.7.4.1 Coatings and finishes.

Surface coatings and finishes shall be verified to be in accordance with JSSG-2001.

VERIFICATION RATIONALE (4.2.7.4.1)

This is a flowdown requirement from JSSG-2001.

VERIFICATION GUIDANCE (4.2.7.4.1)

Verification should be by inspection.

VERIFICATION LESSONS LEARNED (4.2.7.4.1)

(TBD)

3.2.7.4.2 Prohibited materials and processes.

The following materials and processes shall be prohibited:

a. Chlorofluorocarbons (CFCs)

b. (TBS).

REQUIREMENT RATIONALE (3.2.7.4.2)

The prohibition of certain materials is intended to assure that materials and processes that could cause system degradation or hazards to personnel are eliminated.

REQUIREMENT GUIDANCE (3.2.7.4.2)

TBS: The following materials and processes should be considered:

a. magnesium;

b. silicon rubber;

c. room temperature vulcanizing rubber which comes in contact with lubricants, and

d. ge-sensitive elastomers;

e. unstabilized, austenitic steels above 700°F;

f. cold-rolled stainless steel at a temperature of more than 50° below the recovery temperature;

g. precipitation hardenable stainless steels above 750°F;

h. nickel on heat exchangers where a sulfur environment will be encountered such as on air vehicle carriers and where the temperature will exceed 600°F.

REQUIREMENT LESSONS LEARNED (3.2.7.4.2)

Castings. Castings should be clean, sound, and free from blow holes—excess porosity, cracks, and other defects that may reduce the physical properties below design requirements.

Magnesium and magnesium alloys. Marine atmospheric exposure and most acids and salts attack magnesium alloys rapidly. They are also highly susceptible to galvanic corrosion when in contact with most other metals. Corrosion problems of this nature were experienced on pneumatic controls and other components of the F-104 air vehicle. The corrosion caused plugging or orifices and resulted in having to change components to eliminate the magnesium. Therefore, magnesium and its alloys should be avoided. When it must be used, the contractor must take the necessary precautions to prevent corrosion problems.

Corrosion-resistant steel. Prolonged exposure to high temperatures can result in the sensitization and intergranular corrosion of certain stainless steels. A good example is 19-9DL stainless steel, which the USAF has had to replace in the bleed air systems of the F-4 and F-111 air vehicles and the Navy in F-4 and F-14 air vehicles.

Cadmium-plated material. The USAF experienced failures of cadmium-plated bolts on the B-52 bleed air system. High heat-treated cadmium-plated bolts, when installed in a high-stress, high-temperature environment for an extended period, are subject to diffusion of the cadmium into the base metal, resulting in cadmium embrittlement. Bolts in which cadmium embrittlement has occurred will fail at a much lower load than their allowable strength. By limiting cadmium-plated material application to temperatures less than 450°F, cadmium embrittlement failures can be avoided.

Cadmium vapors and dust are highly toxic and should not be used in applications where the cadmium vapors or dust could be delivered to the occupied compartments during normal conditions or following component failure. A near-accident on the C-130 was attributed to cadmium poisoning of the crew following failure of a cooling turbine with a cadmium-plated turbine nozzle. The crew became nauseous and the pilot lost consciousness and was hospitalized for 2 years. The same toxic conditions exist for beryllium.

Neoprene. Another experience on the B-52 was the use of neoprene-covered insulation on low-temperature ducts. Corrosion of the duct surfaces occurred, caused by hydrochloric acid that results from the combination of condensate and chloride ions emitted from the neoprene at elevated temperatures. Neoprene can be used satisfactorily at temperatures up to 250°F. It should not, however, be used at temperature above the boiling point of water when in contact with or in close proximity to any material that is sensitive to chlorides, such as stainless steel.

Organic materials. Materials that are nutrients for fungi should be avoided because of the problems of preventing the growth of fungus and the resulting decomposition of the material. Typical problems caused by fungi are:

a. Micro-organisms digest organic materials as a normal metabolic process, thus degrading the substrate, reducing the surface tension, and increasing moisture penetration.

b. Enzymes and organic acids produced during metabolism diffuse out of the cells and onto the materials and cause metal corrosion, glass etching, hardening of grease, and other physical and chemical changes to the materials.

c. The physical presence of microorganisms produces living bridges across components, which may result in electrical failures.

Adhesives, tapes and sealants should not decompose, break down, degrade, or outgas to combine with moisture to form corrosive compounds. The USAF has had numerous instances where adhesives, tapes have been used on systems and have ultimately decomposed and combined with moisture to form corrosive compounds. It is extremely important that all materials used be carefully selected and fully investigated for each application. The following examples serve to emphasize this requirement:

An adhesive was used as an assembly aid to install insulation on ducting for the F-111 air vehicle. This adhesive broke down when heated and in the presence of moisture formed an acid that corroded the ducting.

The ends of ducts on the F-101 were wrapped with a pressure-sensitive tape before they were covered with insulation. When heated, the chloride in the tape formed hydrochloric acid and corroded the duct.

4.2.7.4.2 Prohibited materials and processes.

It shall be verified by __(TBS)__ that prohibited materials and processes are not used.

VERIFICATION RATIONALE (4.2.7.4.2)

(TBD)

VERIFICATION GUIDANCE (4.2.7.4.2)

(TBD)

VERIFICATION LESSONS LEARNED (4.2.7.4.2)

(TBD)

3.2.7.4.3 Producibility.

The selected fabrication techniques, design parameters, and tolerances shall enable the product to be fabricated, assembled, inspected and tested with repeatable quality. A change in manufacturing process, vendor, vendor location shall be subject to a re-verification process.

REQUIREMENT RATIONALE (3.2.7.4.3)

This requirement is directed toward achieving a design that is compatible with the realities of the manufacturing capability of the defense industrial base. Producibility is a coordinated effort by design engineering and manufacturing engineering to create a functional design that can be easily and economically manufactured. The requirement documents establish what the system must accomplish. These statements are the performance objectives for the system. Subsequent statements in the requirement documents describe the physical, functional, and support framework for the system. These statements operate as constraints on the design. The relationship between the performance objectives and the constraints establish the potential standards of producibility for the design.

The issue of design producibility and capabilities of the production system should be specifically considered when tailoring the system specification and other contractual requirements for the development contract.

REQUIREMENT GUIDANCE (3.2.7.4.3)

Certain design practices can make a substantial contribution to attaining a high level of producibility in the system. Among these are:

a. Simplicity of design – eliminate components of an assembly by building their function into other components or into integral components through application of unique manufacturing processes.

b. Standardization of materials and components – a wide variety of off-the-shelf materials and components are available which, when incorporated in the design, reduce cost and increase availability.

c. Manufacturing process capability analysis – determine the available manufacturing capacity, and its capability to produce the desired end item without special controls. This includes an analysis of process variability.

d. Design flexibility – offer a number of alternative materials and manufacturing processes to produce an acceptable system.

REQUIREMENT LESSONS LEARNED (3.2.7.4.3)

If the beneficial effects on the design process, unit production cost and system producibility are to be realized, the procuring activity will need to emphasize producibility activity and be willing to allow time and funds for the accomplishment of design trade studies which are the foundation of the producibility effort.

4.2.7.4.3 Producibility.

The producibility shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.2.7.4.3)

Verification is employed to mitigate the risk associated with production, to ensure the ability to maintain design tolerances during the manufacturing process, and to confirm that the contractor has a process to control quality in production.

VERIFICATION GUIDANCE (4.2.7.4.3)

TBS: Verification of producibility should be based on inspections, demonstrations, analyses and tests. The level of inspection, demonstration, analysis and test should be dependent on the criticality of the system or component.

VERIFICATION LESSONS LEARNED (4.2.7.4.3)

(TBD)

3.2.7.4.4 Damage tolerance

4.2.7.4.4 Damage tolerance

3.2.7.4.4.1 Safety and mission critical functions.

User service specified subsystems and components that perform safety or mission critical functions shall be damage/fault tolerant. Damage/fault tolerance shall be achieved by __(TBS)__.

REQUIREMENT RATIONALE (3.2.7.4.4.1)

Since damage tolerance is the ability of a system, subsystem or component to resist failure due to the presence of flaws, cracks, or other damage for a specified period of operation, this requirement protects safety and mission critical subsystems and components from potentially degrading effects of handling damage and material, manufacturing and processing anomalies which could result in premature failures and loss of air vehicle.

REQUIREMENT GUIDANCE (3.2.7.4.4.1)

Damage tolerance requirements should be applied to subsystems that perform safety or mission critical functions and to individual safety or mission critical components.

TBS: Looking at the wide variety of air vehicle systems, subsystems, and individual safety and mission critical components, damage and fault tolerance requirements should be met by the following approaches:

a. Redundant or fail-safe-evident design
b. Damage tolerance design approaches in which the subsystem continues to function in the presence of material defects, manufacturing and processing defects or maintenance/service induced damage.

REQUIREMENT LESSONS LEARNED (3.2.7.4.4.1)

In the past, damage tolerance requirements have supplemented LCF requirements during design and development. Significant damage tolerance, to the level required by the specification, was then designed into the subsystem or critical components. Damage tolerance requirements were stated in terms of hours or cycles after the specified damage has been incurred. These parts have then been referred to as “damage tolerant designed.”

Damage tolerant design does not imply or require scheduled in-service inspections. However, some subsystems may be designed for damage tolerance under structural integrity programs such as MECSIP (Mechanical Equipment and Subsystems Integrity Program) which may employ scheduled in-service inspections.

4.2.7.4.4.1 Safety and mission critical functions.

It shall be verified that all subsystems that perform safety or mission critical functions are damage and fault tolerant in the presence of material defects, manufacturing and processing defects, or maintenance/service induced damage. Damage and fault tolerance shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.2.7.4.4.1)

Safety and mission critical functions must be verified to assure that the required functions are actually met.

VERIFICATION GUIDANCE (4.2.7.4.4.1)

TBS: Safety and mission critical requirements should be verified by tests which will assure continuation of the functions with the specified damage for the specified duration.

VERIFICATION LESSONS LEARNED (4.2.7.4.4.1)

(TBD)

3.2.7.4.4.2 Damage tolerant - fail safe evident subsystems and components.

Damage tolerant - fail safe evident subsystems and components shall be specified.

REQUIREMENT RATIONALE (3.2.7.4.4.2)

Fail safe evident refers to situations where on some subsystems or components, damage tolerance may be more appropriately achieved by assuring that the failure is detectable and a redundant system provides for mission completion and “get home” capability.

REQUIREMENT GUIDANCE (3.2.7.4.4.2)

Those subsystems and components that are damage tolerant -fail safe - evident should be identified. Fail-safe evident subsystem design may be achieved by redundancy which assures that failure within a subsystem does not result in loss of the air vehicle or mission capability, both of which should be maintained by a backup or secondary subsystem. The loss of redundancy should be evident in flight and on the ground to personnel conducting routine maintenance.

REQUIREMENT LESSONS LEARNED (3.2.7.4.4.2)

(TBD)

4.2.7.4.4.2 Damage tolerant - fail safe evident subsystems and components.

Subsystem damage tolerance of fail safe-evident subsystems shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.2.7.4.4.2)

Damage tolerant-fail safe evident designs must be verified to assure that the failure is evident and that safety or mission critical functions will actually be met by the backup or secondary system.

VERIFICATION GUIDANCE (4.2.7.4.4.2)

TBS: Subsystem damage tolerance should be verified by analysis to verify redundancy of the fail-safe system design. Verification that failure will be evident in flight should be achieved by a Failure Modes, Effects and Criticality Analysis (FMECA) of the subsystem. Verification that failure will be evident to personnel conducting routine maintenance should be by demonstration.

VERIFICATION LESSONS LEARNED (4.2.7.4.4.2)

(TBD)

3.2.7.4.4.3 Mechanical component damage tolerance.

Safety or mission critical components shall maintain adequate damage tolerance in the presence of the maximum undetected maintenance or manufacturing defect as __(TBS)__.

REQUIREMENT RATIONALE (3.2.7.4.4.3)

Damage tolerance is the ability of a component to resist failure due to the presence of flaws, cracks, or other damage for a specified period of operation. The damage tolerance requirement protects safety and mission critical subsystems and components from potentially degrading effects of handling damage and material, manufacturing, and processing anomalies that could result in premature failures.

REQUIREMENT GUIDANCE (3.2.7.4.4.3)

TBS: Damage tolerant design should be achieved by design to a maximum anticipated undetected maintenance or manufacturing induced defect and a functional capability for specified duration. Both the assumed defect size and the operational duration should be specified by the procuring agency. The size of the defects typically dictated by the minimum defect size detectable by production or in-service inspection methods. The period of damage tolerance is often stated in terms of scheduled in-service inspection. It may be desirable to no scheduled inspections during the design life. Since damage tolerance is conventionally stated as an average capability, the magnitude of which is twice the minimum capability for forged parts, the required period of damage tolerance operation is often stated as two design service lives. This would insure a damage tolerant operation with minimum capability for one design service life. The weight penalty that may be incurred to achieve this may not be feasible. Therefore the period of average damage tolerant operation may be specified as equal to the design service life with a minimum damage tolerant capability equal to one-half ($^1/_2$) the design service life. Scheduled inspections at one-half ($^1/_2$) the design service life could then be conducted at the discretion of the user to ensure damage tolerant operation for the entire service life.

REQUIREMENT LESSONS LEARNED (3.2.7.4.4.3)

In the past, damage tolerance of safety and mission critical components has been achieved by damage tolerant design methods such as slow crack growth, leak before burst or composite impact design. Slow crack growth can be assured by control of stress levels, choice of damage tolerant materials, use of fracture mechanics methods, and manufacturing and process controls. The key design assumption is that a low cycle fatigue crack is present at any or all surface or subsurface locations in the most unfavorable location and orientation.

The MIL-STD-1798 for Mechanical Equipment and Subsystems Integrity Program can be used for reference on relevant damage tolerance requirements for air vehicle subsystems. This document was created to address damage tolerance and structural integrity concerns regarding mechanical equipment and subsystems.

4.2.7.4.4.3 Mechanical component damage tolerance.

The damage tolerance requirements shall be verified by analysis and test.

VERIFICATION RATIONALE (4.2.7.4.4.3)

Damage tolerant designs must be verified to ensure safety- and mission-critical functions will actually be met.

VERIFICATION GUIDANCE (4.2.7.4.4.3)

Safety- and mission-critical requirements should be verified by analysis and tests that will ensure continuation of the functions with the specified defects for the specified duration. Early analysis and test will enable identification of and focus on structurally sensitive areas and will minimize occurrences of deficiencies later in development. Final verification may be by component or subsystem test.

VERIFICATION LESSONS LEARNED (4.2.7.4.4.3)

(TBD)

3.2.7.5 Strength.

Component strength shall be __(TBS)__.

REQUIREMENT RATIONALE (3.2.7.5)

(TBD)

REQUIREMENT GUIDANCE (3.2.7.5)

TBS: The components within each subsystem should not exhibit permanent set due to flight, ground, and limit load conditions.

In addition, the component structure should not temporarily deform to the extent that functional performance is significantly degraded within the flight and ground operating envelope conditions.

The components should not experience catastrophic failure when subjected to ultimate loads or combinations of ultimate loading.

REQUIREMENT LESSONS LEARNED (3.2.7.5)

(TBD)

4.2.7.5 Strength.

Strength requirements shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.2.7.5)

(TBD)

VERIFICATION GUIDANCE (4.2.7.5)

TBS: Verification of the strength requirements should be by analysis or test, or both.

a. Stress analysis. Stress analysis will determine the stresses, deformation, and margins of safety resulting from the loads (including over speed, over pressure, burst pressure, vibration, etc.) and environments imposed on both the electronic and mechanical components of the subsystem.

   The ability of the subsystem component to support the critical loads and to meet the specified strength requirements and performance requirements will be established by analysis. In addition, the stress analysis will be used as a basis for durability and damage tolerance analyses, selection of critical component parts for design development tests, material review actions, and selection of loading conditions to be used in the subsystem structural test program.

b. Stress testing (mechanical components only). Static load tests of components and associated parts should verify that the static strength requirements are met. The applied test loads, including ultimate loads should reflect those loads resulting from operational and maintenance loading conditions.

VERIFICATION LESSONS LEARNED (4.2.7.5)

(TBD)

3.2.7.6 Durability and economic life.

Subsystems shall be durable and economically maintainable throughout the service life.

REQUIREMENT RATIONALE (3.2.7.6)

(TBD)

REQUIREMENT GUIDANCE (3.2.7.6)

Limited life criteria should be established based on the optimization of durability life analysis (which determines the repair and replacement interval from a structural fatigue or wear standpoint), durability testing, an economic life analysis (which determines the optimum repair and replace interval from a cost standpoint), or a weight impact analysis.

The provisions could allow for durability and economic life less than the design service life, but must be incorporated into the subsystem unique integrity requirements.

Durability analysis should demonstrate adequate durability margins for safety critical, mission critical, and durability critical subsystems to ensure that no structural failure will occur in one lifetime; therefore, analysis should predict that no structural failures will occur for at least two design service lifetimes.

Durability for mechanical components should be adequate to resist fatigue damage (cracking and delamination), wear and deterioration, thermal degradation, and corrosion during operational and maintenance use such that the operational and maintenance capability of the subsystems is not degraded to functional impairment for the durability, and economic life.

Durability for electrical components should be adequate to resist vibration fatigue, thermal fatigue, electrical derating, dielectric material failure, and corrosion during operational use such that the operational and maintenance capability of the subsystems is not degraded to functional impairment for the durability and economic life.

Subsystem durability and economic life should not be degraded by wear or deterioration of components, elements, seals, and major bearing surfaces.

REQUIREMENT LESSONS LEARNED (3.2.7.6)

The policy for propulsion system components has always been to base all material properties on minimum material capability.

In the past, rolling element bearings in magnesium, aluminum, or composite housings have been required to be installed in liners which are retained or locked by a positive method to prevent rotational and axial motion.

4.2.7.6 Durability and economic life.

The durability and economic life shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.2.7.6)

(TBD)

VERIFICATION GUIDANCE (4.2.7.6)

TBS: The durability and economic life of subsystems should be verified by analysis and test.

a. Economic analysis. A life cycle analysis should be performed on components to determine the optimum economic life from a cost standpoint. The result of this analysis, which includes maintenance, spare part procurement, down time should define the economic life of the subsystem.

b. Durability analysis. Analysis should be conducted to show that the durability life of the subsystem is at least equal to the economic life. These analyses should verify that the development of cracking, corrosion, wear, deterioration would not adversely affect subsystem performance within the economic life of the subsystem. Durability analysis should include the assumption of the average manufacturing defects for typical manufacturing quality. Analysis should also be performed on the electronic assemblies assuming the maximum undetectable manufacturing process defects for use in sensitivity analysis and variability reduction.

c. Durability tests. Durability testing should be conducted to verify that the specific durability requirements are met. The loading must simulate the major environmental and operational spectrum, which influence failure. Any critical areas, not previously identified by analyses or development tests, should be identified. Any special inspection and identification requirements necessary to achieve the durability life could be derived from this test.

   Accelerated testing may be performed, if it is shown by analysis, test, or historical data that the usage-environment-imposed produced damage levels equivalent to the damage level produced by the usage environment as specified.

   In all cases, installation details should be included. Test loads and environments should represent the equivalent usage specified herein in representative sequence of application, to simulate service. Test duration should demonstrate confidence in achieving durability and therefore should not be less than the equivalent of one times the durability and economic life for electronic equipment, and two times the durability and economic life for mechanical equipment. In no case should the test time be less than one equivalent lifetime. The success criteria for durability testing are the completion of one durability and economic life, as well as, meeting the operational periods without maintenance associated with that life.

Failures caused by operator error, test equipment malfunction, or unrealistic test loads should not be counted as a durability test failure. All failures should be analyzed and appropriate corrective action taken.

Development testing should verify the durability life. The development tests should be performed on selected sample configurations (production representative) and should consist of production representative mounting designs and manufacturing processes.

Off-the-shelf hardware whose previous durability test levels have been analyzed as meeting or exceeding the equipment’s environments and usage requirements may be used without additional durability testing.

VERIFICATION LESSONS LEARNED (4.2.7.6)

(TBD)

3.2.7.6.1 Corrosion.

Corrosion shall not degrade the operational readiness or mission performance of the subsystem during the service life.

REQUIREMENT RATIONALE (3.2.7.6.1)

This is a flowdown requirement from the JSSG-2001, “Environmental resistance”.

REQUIREMENT GUIDANCE (3.2.7.6.1)

Subsystems should operate in the corrosion producing usage and environments as specified.

Corrosion that affects the operational readiness of the subsystems should not occur during the service life for the usage and environment specified.

Corrosion prevention, including finishes, and coatings, should be resistant to surface damage and should remain effective during the service life for the usage and environment specified.

The use of dissimilar metals in contact with each other should be suitably protected against galvanic corrosion. Dissimilar metals are defined in MIL-STD-889.

REQUIREMENT LESSONS LEARNED (3.2.7.6.1)

(TBD)

4.2.7.6.1 Corrosion.

Corrosion protection and control measures shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.2.7.6.1)

This is a flowdown requirement from JSSG-2001.

VERIFICATION GUIDANCE (4.2.7.6.1)

TBS: Corrosion prevention and control measures should be established and implemented in accordance with the air vehicle corrosion control program; the criteria for the selection of corrosion resistant materials, coatings, and finishes should be defined. Implementation of the corrosion control program and analysis and testing necessary to meet specific requirements within the program should verify that the corrosion control system provides resistance to the environments specified.

VERIFICATION LESSONS LEARNED (4.2.7.6.1)

(TBD)

3.2.7.6.2 High cycle fatigue (HCF).

Subsystems shall not fail when subject to the combined steady state and vibratory induced stresses that occur anywhere within the operating envelope and during ground, flight, and logistics operations.

REQUIREMENT RATIONALE (3.2.7.6.2)

(TBD)

REQUIREMENT GUIDANCE (3.2.7.6.2)

The equipment should withstand vibration-induced stresses that occur throughout the air vehicle-operating envelope and during ground, flight, and logistics operations for the equipment's durability and economic life for the usage and design environments at installed location.

Potential flow resonances due to forced air or liquid cooling, and vibration coupled from the structure into lower level assemblies should be considered.

For purposes of infinite life, table III represents standard design practice for HCF.

TABLE III. High cycle fatigue.

MATERIAL	LIFE (cycles)
Ferrous, Nickel-Base Superalloys	10^7 cycles
Titanium	10^9 cycles
Other Materials	3×10^7 cycles

REQUIREMENT LESSONS LEARNED (3.2.7.6.2)

(TBD)

4.2.7.6.2 High cycle fatigue (HCF).

It shall be verified that subsystems subjected to the combined steady state and vibratory induced stresses that occur anywhere within the operating envelope and during ground, flight, and logistics operations do not fail.

VERIFICATION RATIONALE (4.2.7.6.2)

(TBD)

VERIFICATION GUIDANCE (4.2.7.6.2)

The durability and economic life analysis and tests should verify adequate life for the vibration-induced fatigue life requirements.

VERIFICATION LESSONS LEARNED (4.2.7.6.2)

(TBD)

3.2.7.6.3 Low cycle fatigue (LCF).

Subsystems shall not fail when subject to the combined steady state and cyclic stresses due to repetitive cycles whether thermally induced, induced by mechanical start and stop cycles or both, or applied loads.

REQUIREMENT RATIONALE (3.2.7.6.3)

Low Cycle Fatigue is one of the most severe and costly problems encountered in service. The intent of the requirement is to insure that the specified design considerations are applied to LCF.

REQUIREMENT GUIDANCE (3.2.7.6.3)

Common design practice is to design to at least two times the design service life. Components should withstand low cycle fatigue throughout the operating envelope of the vehicle and during ground, flight, and logistics operations for the durability and economic life for the specified service usage and environment. Components must also withstand mechanical start and stop or ground-air-ground (GAG) loading cycles.

REQUIREMENT LESSONS LEARNED (3.2.7.6.3)

(TBD)

4.2.7.6.3 Low cycle fatigue (LCF).

Low cycle fatigue shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.2.7.6.3)

The LCF lives must be verified to preclude the occurrence of part failures.

VERIFICATION GUIDANCE (4.2.7.6.3)

TBS: Verification should be by analysis and testing.

VERIFICATION LESSONS LEARNED (4.2.7.6.3)

(TBD)

3.2.7.6.4 Dielectric materials.

Dielectric materials when exposed to maximum predicted voltage shall not fail.

REQUIREMENT RATIONALE (3.2.7.6.4)

(TBD)

REQUIREMENT GUIDANCE (3.2.7.6.4)

Dielectric materials used in the electronic equipment should be able to withstand the maximum predicted voltage without failure when subjected to the electrical power spectra and environment specified.

REQUIREMENT LESSONS LEARNED (3.2.7.6.4)

(TBD)

4.2.7.6.4 Dielectric materials.

Verification of specific dielectric materials when exposed to maximum predicted voltage shall be by __(TBS)__.

VERIFICATION RATIONALE (4.2.7.6.4)

(TBD)

VERIFICATION GUIDANCE (4.2.7.6.4)

TBS should be filled in with test and circuit tolerance analysis. Historical data may be used in lieu of test.

VERIFICATION LESSONS LEARNED (4.2.7.6.4)

(TBD)

3.2.7.6.5 Creep.

Subsystems shall not fail due to component creep. Part creep shall not interfere with disassembly, reassembly or function of the subsystem.

REQUIREMENT RATIONALE (3.2.7.6.5)

Creep during service life must be accounted for to ensure that acceptable operation and maintenance is not impaired.

REQUIREMENT GUIDANCE (3.2.7.6.5)

One approach to accounting for creep is to specify a maximum allowable value. Common design practice is to allow a value of 0.1 percent to 0.2 percent (0.1%-0.2%) elongation.

REQUIREMENT LESSONS LEARNED (3.2.7.6.5)

(TBD)

4.2.7.6.5 Creep.

Subsystems creep characteristics shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.2.7.6.5)

Creep verification is required to ensure the subsystem can operate satisfactorily for the service life.

VERIFICATION GUIDANCE (4.2.7.6.5)

TBS: Design documentation inspection, analysis, or tests should verify compliance with the creep requirement.

VERIFICATION LESSONS LEARNED (4.2.7.6.5)

(TBD)

3.2.8 Transportability.

Transportability shall be in accordance with JSSG-2001, "Transportability".

REQUIREMENT RATIONALE (3.2.8)

This is a flowdown requirement from the JSSG-2001, "Transportability".

REQUIREMENT GUIDANCE (3.2.8)

The transportability of the subsystems should be in accordance with JSSG-2001. Subsystems should be suitable for installation and transportation on appropriate static and mobile ground equipment.

REQUIREMENT LESSONS LEARNED (3.2.8)

In order to prevent contamination and hazards to personnel and equipment, cover plates have been furnished for covering all drive openings when driven components were not to be mounted for shipment. Suitable provisions for covering or plugging all other connection openings were required to be made.

4.2.8 Transportability.

Transportability requirements shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.2.8)

This is a flowdown requirement from the JSSG-2001, "Transportability".

VERIFICATION GUIDANCE (4.2.8)

TBS: Verification should be by analyses or test or both.

VERIFICATION LESSONS LEARNED (4.2.8)

(TBD)

3.2.9 Integrated diagnostics.

Hardware and software, when required by the AVSS, shall be provided to monitor and record subsystem performance during flight and ground operation, and to provide data in an organized format for ground analytical condition checkout capability, component life tracking (if required), warranties, and scheduling maintenance actions. The malfunction of any diagnostic hardware or software shall not affect subsystem performance or operability. The diagnostic capability shall be compatible with the air vehicle maintenance system. The subsystem diagnostic system shall be completely functional after failure of any other subsystem or subsystem component.

REQUIREMENT RATIONALE (3.2.9)

This is a flowdown requirement from the JSSG-2001, "Integrated diagnostics". Diagnostic capability monitors and records subsystem status.

REQUIREMENT GUIDANCE (3.2.9)

The diagnostic system should be compatible with organizational, intermediate, or depot maintenance, depending on the level of maintenance that will retrieve and use the data. It may be completed by the using service to drive the design if a firm maintenance concept has been established, or the contractor may complete it to allow greater flexibility in optimizing the design.

Diagnostics should be an integral part of the subsystem maintenance system and should be compatible with both the air vehicle data collection and ground support systems. Diagnostic data may or may not be retrieved through the air vehicle system, and the description should state whether or not the air vehicle system is used. All air vehicle subsystem interfaces should be described in the interface section of this specification. The contractor should describe the components included as part of the subsystem diagnostic system (such as subsystem data collection box and sensors, and if applicable, the air vehicle data collection system and ground support, data transfer system). A detailed description of the diagnostic system is not necessary, but a sufficient system level description is needed so that the using service and contractor understand the system's capability.

The subsystem diagnostic system should include installed airborne equipment, ground equipment, flight line support equipment, intermediate level support equipment, depot support equipment, technical publications, manual inspections and personnel required to accomplish the complete task. However, collecting data is only a small part of the system approach required to develop an effective diagnostic system. Some details to be considered in the design are the sensors, signal conditioners, data processor, data storage, crash survivability, data exchange rate(s), air vehicle mounting, ground based processing station, and programming language.

There has been considerable proliferation of diagnostic ground support equipment. It is generally recognized that the airborne diagnostic equipment will be somewhat application unique, but the ground equipment required to extract, transmit, process, and distribute the data can be adaptable to the application.

Diagnostic system software algorithms and instrument range, system accuracy, time response, sample rate, and electrical characteristics for each parameter should be provided to the using service.

REQUIREMENT LESSONS LEARNED (3.2.9)

The USAF has had numerous experiences with engine monitoring systems that did nothing more than collect data. The data that were collected could not be reduced into useful information, and some of the more important parameters were not collected.

4.2.9 Integrated diagnostics.

Integrated diagnostics requirements shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.2.9)

This is a flowdown requirement from the JSSG-2001, "Integrated diagnostics". Verification is required to assure user needs are satisfied.

VERIFICATION GUIDANCE (4.2.9)

TBS: Integrated diagnostics requirements should be verified through a combination of analyses, inspections and demonstrations.

An analysis should be performed to show that faults can be detected and isolated using a combination of Startup BIT (SBIT), Periodic BIT (PBIT), Initiated BIT (IBIT), ancillary tools and test equipment, or computer assisted manual procedures.

It is important that the diagnostic system tested on the subsystem ensures that the system works properly. An important function of the test should be to establish thresholds for determining out of range faults, verifying when false faults occur, determining if signal noise is present, and revealing other problems that may occur. Flight-testing is needed since that is when the true diagnostic environment and usage will concur.

The contractor should select and demonstrate a number of these fault detection and isolation procedures.

VERIFICATION LESSONS LEARNED (4.2.9)

(TBD)

3.2.9.1 Fault detection and isolation.

Diagnostics shall provide __(TBS)__ percent detection and isolation of all faults. The on-board subsystem diagnostics shall provide fault detection and isolation to the faulty LRU/WRA as required to meet the reliability and maintainability requirements of JSSG-2001. Subsystems shall be compatible with the mission critical functions of the on-board diagnostic system that monitors mission and safety critical parameters. The on-board subsystem diagnostics shall not cause failure of any other mission or safety critical system.

REQUIREMENT RATIONALE (3.2.9.1)

Subsystem diagnostic fault detection and isolation capabilities and equipment and maintenance effects necessary to accomplish these functions need to be specified.

REQUIREMENT GUIDANCE (3.2.9.1)

TBS: Fault detection and isolation rate should be between 90-100 percent (90-100%), depending on the system. However, for ground based fault detection systems, the fault detection rate should be between 95 and 100 percent (95-100%).

The list of functions may include; the on-board subsystem diagnostics, inspections, results from processed diagnostic data, and troubleshooting (automated, computer assisted, or manual).

The goal is to have the on-board system identify any faulty LRU/WRA and have maintenance personnel only conduct minor troubleshooting tasks on the ground. A higher percentage of the fault detection and isolation should be accomplished through automated processes to save maintenance work hours. Evaluating the problem in the field through diagnostics can also save depot rework hours and other supply costs by reducing the number of “cannot duplicate” occurrences. Diagnostics should be compatible with existing subsystem maintenance systems, Core Automated Maintenance System (CAMS), Naval Aviation Logistic Data Analysis (NALDA), and Aviation Maintenance - Materials - Management System.

REQUIREMENT LESSONS LEARNED (3.2.9.1)

(TBD)

4.2.9.1 Fault detection and isolation.

Fault detection and isolation shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.2.9.1)

Verification is required to assure diagnostic usefulness as a maintenance, performance trending, and warranty tool.

VERIFICATION GUIDANCE (4.2.9.1)

TBS: Fault detection and isolation requirements should be verified through a combination of analyses, inspections, tests and demonstrations.

Testing should be performed throughout the development cycle and should include qualification testing, test cell testing, and flight-testing. The flight-testing should evaluate the effectiveness of the entire system including airborne equipment, ground equipment, and data output product usage. Flexibility of diagnostics during flight-testing should be maintained so that changes can be made to the system to ensure it is a useful maintenance tool.

VERIFICATION LESSONS LEARNED (4.2.9.1)

Many diagnostic systems have been tested from a functional standpoint and adequate hardware testing has also been performed. However, the software area has been neglected, resulting in problems after fielding. These problems were due to "bugs" that were not discovered during functional testing, but surfaced when the system became operational. Thorough testing of the software is necessary to prevent this from happening.

3.2.10 Nameplate and product marking.

Subsystems equipment, assemblies, modules, and parts shall be marked legibly with machine/man-readable markings per MIL-STD-130 and such that component removal is not necessary to read the data plate. The machine-readable markings are required for parts whose cost exceeds five thousand dollars, parts that are serially managed, or parts that are mission critical. These markings shall be as permanent as the normal life expectancy of the item and be able to withstand the environmental tests and cleaning procedures specified for the item to which they are affixed. The type and length of product identification characters on the data plate shall be compliant with MIL-STD-130 and applicable requirements documents referenced therein for format compatibility. The contractor shall upload the Item Unique Identification (IUID) assigned numbers and information into the Government UID (Unique Identification) database according to the Using Service's guidance and procedures.

REQUIREMENT RATIONALE (3.2.10)

All subsystem components require marking or identification. The maximum number of digits or characters must be limited due to computer limitations used for inventory and logistical control.

REQUIREMENT GUIDANCE (3.2.10)

ASME Y14.24, ASME Y14.34, ASME Y14.35M, ASME Y14.100, and the most current version of MIL-STD-130 should be used for guidance. Night vision goggles preclude the need for red lighting. Whenever possible, the markings should be visible through normal access openings on the subsystem and aircraft. Modern subsystem programs are moving towards the use of 2-dimensional (2D) markings. ATA Spec 2000, DoD IUID, or other ISO specifications marking capability can be used for reference.

REQUIREMENT LESSONS LEARNED (3.2.10)

Components have had to be removed to examine nameplates and markings during inspection and maintenance due to the poor placement of those markings. The limitation on number of characters in the part number was identified as impacting select DoD Weapon System programs.

4.2.10 Nameplate and product marking.

The requirement of 3.2.10 shall be verified by inspection.

VERIFICATION RATIONALE (4.2.10)

Verification of man-readable property marking or identification can be accomplished only by inspection.

VERIFICATION GUIDANCE (4.2.10)

Verify completeness, accuracy, and visibility of the information supplied. Verify machine-readable information was obtained with properly-calibrated barcode verification equipment. Machine-readable information must be verified by the supplier through use of a verification process that ensures conformance to the grading requirements of MIL-STD-130.

VERIFICATION LESSONS LEARNED (4.2.10)

(TBD)

3.3 Design and construction.

Design and construction shall be in accordance with JSSG-2001.

REQUIREMENT RATIONALE (3.3)

This is a flowdown requirement from JSSG-2001.

REQUIREMENT GUIDANCE (3.3)

Materials, processes, and part integrity, electromagnetic environmental effects, including electromagnetic compatibility, lightning (for example direct and indirect, grounding and bonding, electrostatic discharge, hazards of electromagnetic radiation, TEMPEST, high power microwave, precipitation static) should be considered and specified accordingly.

REQUIREMENT LESSONS LEARNED (3.3)

(TBD)

4.3 Design and construction.

Design and construction requirements shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.3)

This is a flowdown requirement from JSSG-2001.

VERIFICATION GUIDANCE (4.3)

TBS: Design and construction should be verified by test, demonstrations, inspection, and analysis.

VERIFICATION LESSONS LEARNED (4.3)

(TBD)

3.3.1 Interchangeability.

Subsystem equipment, which is to be interchangeable and the level of interchangeability shall be defined.

REQUIREMENT RATIONALE (3.3.1)

It is desirable that all equipment having the same part number be interchangeable to reduce logistic support requirements, minimize maintenance and repair problems, and assure that subsystem performance and operability are not compromised.

REQUIREMENT GUIDANCE (3.3.1)

Subsystem equipment, which has been identified as being interchangeable, having the same manufacturer's part number should be functionally and physically interchangeable and should meet all applicable subsystem performance, operability, and durability. Matched or selective fits may be permitted where necessary to meet design requirements. The use of matched and selective fits should be held to a minimum. A list of non-interchangeable, matched, and selective fit equipment should be identified and submitted to the using service during the subsystem development program to focus attention on these exceptions and force early, improved design changes.

REQUIREMENT LESSONS LEARNED (3.3.1)

(TBD)

4.3.1 Interchangeability.

Interchangeability shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.3.1)

Testing and demonstrations are required to evaluate the functional and physical interchangeably of subsystem equipment.

VERIFICATION GUIDANCE (4.3.1)

TBS: Interchangeability requirement should be verified by testing and demonstrations.

Interchangeability of subsystem equipment may be evaluated during the course of routine assembly, maintenance, and testing. Documentation of this evaluation is recommended to insure complete coverage of all equipment.

VERIFICATION LESSONS LEARNED (4.3.1)

(TBD)

3.3.2 Non-interchangeability.

It shall not be possible to misconnect electrical or fluid inputs or outputs with like items from the same or other subsystem equipment.

REQUIREMENT RATIONALE (3.3.2)

(TBD)

REQUIREMENT GUIDANCE (3.3.2)

(TBD)

REQUIREMENT LESSONS LEARNED (3.3.2)

(TBD)

4.3.2 Non-interchangeability.

Non-interchangeability shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.3.2)

(TBD)

VERIFICATION GUIDANCE (4.3.2)

(TBD)

VERIFICATION LESSONS LEARNED (4.3.2)

(TBD)

3.3.3 Safety.

Subsystem safety features shall be provided to optimize the safety of the pilot, maintenance, and support personnel within the constraints of operational effectiveness, time, and cost.

REQUIREMENT RATIONALE (3.3.3)

This is a flowdown requirement from JSSG-2001.

REQUIREMENT GUIDANCE (3.3.3)

Subsystems should incorporate features to eliminate or control all identified hazards to acceptable levels of risk and prevent mishaps. Hazard risk acceptability criteria should be defined. Features should be provided to minimize the number of occurrences of logistics and operations related mishaps.

Pilot and maintenance personnel should be protected from all identified hazards (for example toxic and corrosive substances, electrical and mechanical hazards, extremes in temperature, and hazardous radiation and acoustical hazards). Subsystems should provide personnel protection in accordance with MIL-HDBK-454, Requirement 1. The MIL-STD-1472 paragraph on “Hazards and Safety” (5.13) should be used as a guide.

Subsystem hazards should be eliminated or controlled to acceptable levels of risk in accordance with the requirements of paragraph on “Risk assessment,” “Hazard severity,” and “Hazard probability” (4.5 through 4.5.2) of MIL-STD-882. The hazard risk assessment matrix contained in the air vehicle System Safety Program Plan should be used to determine risk acceptability.

REQUIREMENT LESSONS LEARNED (3.3.3)

(TBD)

4.3.3 Safety.

Subsystems safety features to optimize the safety of pilot, maintenance, support personnel, and the air vehicle shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.3.3)

This is a flowdown requirement from JSSG-2001.

VERIFICATION GUIDANCE (4.3.3)

TBS: Subsystem safety features to optimize the safety of pilot, maintenance support personnel and the air vehicle should be verified by analyses, inspection and test, as applicable. Engineering drawings, diagrams, specifications, and safety hazard analyses should be inspected to assure that functional safety relationships have been identified, that all identified hazards have been eliminated or controlled to an acceptable level, and that safety design features have been incorporated including features to minimize operations- and logistics-related mishaps. Preliminary Technical Orders (T.O.s) should be analyzed during validation to assure, prior to use, that appropriate cautions, warnings, notes, inspection provisions, and special emergency procedures have been incorporated and are consistent with those developed by the system safety analyses. Test data should be inspected to determine the existence of previously unidentified hazards and to evaluate the sufficiency of established safety provisions.

Protection of pilot and maintenance personnel from all identified hazards (for example, toxic and corrosive substances, electrical and mechanical hazards, extremes in temperature, radiation and acoustical hazards) should be verified by safety hazards analysis, inspection and test, as applicable.

VERIFICATION LESSONS LEARNED (4.3.3)

(TBD)

3.3.3.1 Safety criteria.

Subsystem safety criteria shall be defined.

REQUIREMENT RATIONALE (3.3.3.1)

(TBD)

REQUIREMENT GUIDANCE (3.3.3.1)

The appropriate level of redundancy for subsystem operation should be determined. The system should provide the specified level of redundant operation. For example, the subsystem could either fail-safe or fail to operate.

REQUIREMENT LESSONS LEARNED (3.3.3.1)

(TBD)

4.3.3.1 Safety criteria.

The defined safety criteria shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.3.3.1)

(TBD)

VERIFICATION GUIDANCE (4.3.3.1)

(TBD)

VERIFICATION LESSONS LEARNED (4.3.3.1)

(TBD)

3.3.3.2 Foreign object damage (FOD).

Subsystem tolerance of foreign object damage shall be defined.

REQUIREMENT RATIONALE (3.3.3.2)

(TBD)

REQUIREMENT GUIDANCE (3.3.3.2)

Subsystem design should treat tolerance of FOD as a prime concern, to the greatest extent practical, consistent with other requirements such as cost, weight and space.

REQUIREMENT LESSONS LEARNED (3.3.3.2)

(TBD)

4.3.3.2 Foreign object damage (FOD).

Defined subsystem tolerance to FOD shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.3.3.2)

(TBD)

VERIFICATION GUIDANCE (4.3.3.2)

(TBD)

VERIFICATION LESSONS LEARNED (4.3.3.2)

(TBD)

3.3.3.3 Software safety.

Air vehicle subsystem Software Safety Critical Items shall be identified and separated or partitioned from other less critical software.

REQUIREMENT RATIONALE (3.3.3.3)

(TBD)

REQUIREMENT GUIDANCE (3.3.3.3)

(TBD)

REQUIREMENT LESSONS LEARNED (3.3.3.3)

(TBD)

4.3.3.3 Software safety.

It shall be verified that air vehicle subsystem Software Safety Critical Items are identified and separated or partitioned from other less critical software __(TBS)__.

VERIFICATION RATIONALE (4.3.3.3)

(TBD)

VERIFICATION GUIDANCE (4.3.3.3)

(TBD)

VERIFICATION LESSONS LEARNED (4.3.3.3)

(TBD)

3.3.3.4 Acoustic noise.

The contractor shall establish acoustic noise level limits for noise producing or noise transmitting air vehicle subsystems required to meet the acoustic noise level limits for air vehicle established in JSSG-2001.

REQUIREMENT RATIONALE (3.3.3.4)

This is a flowdown requirement from JSSG-2001. Many aircraft subsystems produced significant noise. It is important to establish noise levels consistent with air vehicle requirements in order that the requirements be considered during the design phase of the subsystems. Correcting noise problems after the air vehicle and its subsystems are already designed can be costly and have impact on volume and weight constraints.

REQUIREMENT GUIDANCE (3.3.3.4)

Noise transmitting portions of subsystems, such as ECS ducts that supply the occupied compartments, must be considered.

REQUIREMENT LESSONS LEARNED (3.3.3.4)

SAE AIR 1826 provides excellent guidelines for acoustical considerations in the design of ECS. Much of it is applicable to other subsystems as well.

4.3.3.4 Acoustic noise.

Acoustic noise levels shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.3.3.4)

(TBD)

VERIFICATION GUIDANCE (4.3.3.4)

(TBD)

VERIFICATION LESSONS LEARNED (4.3.3.4)

(TBD)

3.3.4 Electromagnetic environmental effects (E^3).

Subsystem electromagnetic environmental effects shall be in accordance with the JSSG-2001.

REQUIREMENT RATIONALE (3.3.4)

This is a flowdown requirement from JSSG-2001.

REQUIREMENT GUIDANCE (3.3.4)

The Defense Standard MIL-STD-464 requirements should be applied directly to the subsystems. The architecture of the air vehicle plays an important role in determining the electromagnetic interaction between onboard items and translation of external environment stresses (including lightning, external RF fields, and electromagnetic pulse (if required)) to internal stresses at the electrical interfaces of onboard equipment. This flowdown is generally based on transfer functions of the external stress outside the air vehicle to internal stresses expressed as electrical cable currents or field quantities, which are included as part of the electromagnetic interference (EMI) JSSG-2001 requirements. The Defense Standard MIL-STD-464 contains detailed rationale, guidance, and lessons learned information for the requirement areas addressed in subsequent subparagraphs.

REQUIREMENT LESSONS LEARNED (3.3.4)

Emphasis on systems engineering aspects of E^3 is important. In the past, the E^3 area was often viewed as a test and fix effort with little influence on the actual design at the air vehicle level. With the proper performance of electronics playing a more important role for safety and mission completion and the extensive use of composite materials in air vehicle structure, it is essential that the response of the air vehicle to external electromagnetic stresses be analyzed, understood, and translated into EMI requirements for the subsystems.

The types of requirements, placement of limits, and applicable frequency ranges in MIL-STD-461D are based on lessons learned on past programs. MIL-STD-461D includes an appendix to explain the rationale for the requirements and to provide guidance in tailoring the requirements. There had been a great deal of misunderstanding and confusion in the past regarding MIL-STD-461D requirements.

Electrical bonding is often one of the first areas reviewed for adequacy when a electromagnetic compatibility problem develops at the air vehicle-level. Some problems have been fixed simply by improving the bonding. The actual need for a certain level of bonding is dependent on a number of issues including shielding topology, type of circuit interfaces, and ground referencing of circuits to the electronics enclosures. The increasing use of differential circuit interfaces make bonding somewhat less critical because of the better rejection of common mode signals.

Problems have been found on air vehicle from ground loop currents in the electrical power system coupling into low frequency circuits. Modification of the current return path normally fixes the problem.

Lightning protection of air vehicle in the past was mostly concerned with direct effect issues to fuel systems, control surfaces, antennas and radomes. With the increased importance of electrical and electronic systems onboard air vehicle due to the dependence on these items to keep the air vehicle flying and to complete missions, indirect effect protection has been receiving much more emphasis. Also, the use of composite materials in airframe results in much larger electrical stresses appearing on electrical interfaces internal to the air vehicle during a lightning event.

The electrical circuit internal to an electrically initiated device is usually a small resistive element termed a bridgewire. The general concern with electroexplosive circuits is heating of the bridgewires from induced currents caused by electromagnetic fields potentially resulting in inadvertent initiation. Some of the factors involved in potential initiation are transmitter power output, modulation characteristics, operating frequency, antenna characteristics, electroexplosive wiring configuration (shielding, length, and orientation) and the thermal time constants of the bridgewire.

4.3.4 Electromagnetic environmental effects (E^3).

The E^3 performance of the subsystems shall be verified through a combination of inspection, analysis and test.

VERIFICATION RATIONALE (4.3.4)

This is a flowdown requirement from JSSG-2001.

VERIFICATION GUIDANCE (4.3.4)

Electromagnetic environmental effects requirements should be verified through an incremental verification process. "Incremental" implies that verification that E^3 requirements are met in a continuing process of building an argument (audit trail) throughout development that the design satisfies the imposed performance requirements. Initial engineering design must be based on analysis and models. As hardware becomes available, testing of components of the subsystem can be used to validate and supplement the analysis and models. The design evolves as better information is generated. When the subsystem hardware is available, inspection, final testing and follow-on analyses complete the incremental verification process.

It is important to note that testing is often necessary to obtain information that may not be amenable to determination by analysis. However, testing also is often used to determine a few data points with respect to a particular performance requirements with analysis (and associated simulations) filling in the total picture.

VERIFICATION LESSONS LEARNED (4.3.4)

A tri-service and industry-working group issued the ”D” revision of MIL-STD-462 in January 1993. This group considered many of the lessons learned from past problems with electromagnetic interference testing and incorporated required changes into the document. One important area is that the testing is generally better related to measurable and predictable physical parameters at the air vehicle-level, such as bulk cable currents induced from electromagnetic fields outside the air vehicle and electrical power quality. MIL-STD-462 contains an appendix which provides guidance on electromagnetic interference testing.

Powerline filtering arrangements in equipment can result in hazardous voltages on the enclosure if the safety ground is disconnected. Typically, filters will be present on both the high and return sides that will have capacitance to chassis. If the chassis is floating with respect to earth ground, the capacitors act as a voltage divider for AC waveforms with half the AC voltage present on the case with respect to earth. The value of the capacitors determines the amount of current that may flow.

A concern with safety ground wire routing inside electronic enclosures is the possibility of creating a coupling mechanism for conducting interference emissions out of the enclosures with subsequent re-radiation or conducting induced levels from electromagnetic fields into the enclosure. To ease this concern, safety ground wires should be grounded inside the box in as short a distance as possible and should be kept away from other wiring.

Flight testing of an air vehicle often begins prior to verification of immunity of the vehicle to lightning. Under this circumstance, the flight test program must include restrictions to prohibit flight within a specified distance from thunderstorms, usually 25 miles. Lightning flashes sometimes occur large distances form the thunderstorm clouds.

Instrumentation used to monitor induced levels and demonstrate safety margins during electroexplosive subsystem testing needs to effectively simulate the response of the actual electroexplosive devices. Important parameters are maintaining the electrical impedance of electroexplosive devices, including their thermal time constants (heating characteristics of the bridgewires) in assessing responses, and considering the response times of the instrumentation.

3.3.5 Standardization.

Standardization principles shall be used to the maximum extent possible without compromise in design, performance, operability, or economic life of the subsystem.

REQUIREMENT RATIONALE (3.3.5)

This is a flowdown requirement from the JSSG-2001.

REQUIREMENT GUIDANCE (3.3.5)

Government or industry standard parts should be used whenever possible and identified by their standard part numbers. Items already in the Government inventory should be used to the maximum extent possible where suitable for the intended purpose. Variation in similar components or parts should be held to the absolute minimum. Proprietary designs should be kept to a minimum. Where general-purpose standards are used in critical or high strength applications, parts should be identified by the manufacturer's part number. Parts derived from general purpose standards or Government standards solely on an inspection or selection basis should be identified by contractor part numbers and all previous identification marks should be removed.

Government and industry standards and parts developed specifically for a particular type of subsystem should be used unless they are unsuitable for the intended purpose.

Standard screw thread forms should be used whenever possible. Taper threaded plugs should not be used in castings and nonferrous parts. Tapered pipe threads may be used only for permanent plugging of drilled passages or openings in steel.

REQUIREMENT LESSONS LEARNED (3.3.5)

(TBD)

4.3.5 Standardization.

The application of standardization principles shall be verified by inspection.

VERIFICATION RATIONALE (4.3.5)

This is a flowdown requirement from JSSG-2001.

VERIFICATION GUIDANCE (4.3.5)

Design documentation should be inspected for compliance with the standardization requirement.

VERIFICATION LESSONS LEARNED (4.3.5)

(TBD)

3.3.6 Environmental.

Environmental requirements for the Air Vehicle Subsystems shall be those specified in the Air System Joint Service Specification Guide, JSSG-2000, “Environmental,” as applicable.

REQUIREMENT RATIONALE (3.3.6)

Rationale for the need for environmental requirements is explained in the Air System JSSG Handbook, JSSG-2000.

REQUIREMENT GUIDANCE (3.3.6)

Guidance for implementation of environmental requirements is included in the Air System JSSG Handbook, JSSG-2000.

REQUIREMENT LESSONS LEARNED (3.3.6)

Lessons learned to justify the need for environmental requirements can be found in the Air System JSSG Handbook, JSSG-2000.

4.3.6 Environmental.

Environmental verification requirements for the Air Vehicle Subsystems shall be those specified in the Air System Joint Service Specification Guide, JSSG-2000 “Environmental Verification,” as applicable.

VERIFICATION RATIONALE (4.3.6)

Rationale for the need for verification of environmental requirements is explained in the Air System JSSG Handbook, JSSG-2000.

VERIFICATION GUIDANCE (4.3.6)

Guidance for implementation of verification of environmental requirements is included in the Air System JSSG Handbook, JSSG-2000.

VERIFICATION LESSONS LEARNED (4.3.6)

Lessons learned to justify the need for verification of environmental requirements can be found in the Air System JSSG Handbook, JSSG-2000.

3.3.7 Health.

Health requirements for the Air Vehicle Subsystems shall be those specified in the Air System Joint Service Specification Guide, JSSG-2000, "Health," as applicable.

REQUIREMENT RATIONALE (3.3.7)

Rationale for the need for health requirements is explained in the Air System JSSG Handbook, JSSG-2000.

REQUIREMENT GUIDANCE (3.3.7)

Guidance for implementation of health requirements is included in the Air System JSSG Handbook, JSSG-2000.

REQUIREMENT LESSONS LEARNED (3.3.7)

Lessons learned to justify the need for health requirements can be found in the Air System JSSG Handbook, JSSG-2000.

4.3.7 Health.

Health verification requirements for the Air Vehicle Subsystems shall be those specified in the Air System Joint Service Specification Guide, JSSG-2000, "Health verification," as applicable.

VERIFICATION RATIONALE (4.3.7)

Rationale for the need for verification of health requirements is explained in the Air System JSSG Handbook, JSSG-2000.

VERIFICATION GUIDANCE (4.3.7)

Guidance for implementation of verification of health requirements is included in the Air System JSSG Handbook, JSSG-2000.

VERIFICATION LESSONS LEARNED (4.3.7)

Lessons learned to justify the need for verification of health requirements can be found in the Air System JSSG Handbook, JSSG-2000.

3.3.8 Installation hazards reduction.

The following designs shall be applied to subsystem installations:

a. Subsystem installation and associated equipment designs shall be such that normal operation of the subsystem will not contribute to or result in fire and explosion hazards.

b. Subsystem installations and associated equipment designs shall be such that fire and explosion hazards due to failure or accident are minimized.

c. Subsystem installation boundaries common to the air vehicle exterior shall be designed such that fire will not readily spread between subsystems due to the natural airflow over the air vehicle.

REQUIREMENT RATIONALE (3.3.8)

Good subsystem installation design includes the consideration of fire and explosion.

REQUIREMENT GUIDANCE (3.3.8)

Dump provisions. Fuel system dump provisions should be designed to direct the dumped fuel away from the air vehicle. Also, should be designed so that dumped fuel will not impinge on any part of the air vehicle so that fire and explosion hazards will not result, and that dumped fuel will not re-enter the air vehicle, during any known mission attitude. Location and design of the dump provisions (mast, chute) should be based on sound aerodynamic considerations. This guidance also applies to other flammable fluid dump systems.

Protrusions. Powerplant installations should consider the possibility of protrusions into the airstream acting as flame holders. Under high airflow conditions, protrusions into the airstream can cause air pockets. In the event of fire, these protrusions may hold isolated flames which may persist and cause reignition after the extinguishing agent is used. This problem is associated with both main engines and ancillary units and may be alleviated by the use of smooth aerodynamic design on the interior and exterior of nacelle installations and the interior of compartment installations.

Subsystem installation and associated equipment designs should include provisions that will protect system components, fluid carrying lines and electrical wiring from interference with each other or the air vehicle structure, or bulkheads, and prevent damage to them. Chafing of lines and wiring against each other, or the structure can lead to fire and explosion hazards through leaks in combustible fluid and vent lines and the destruction of the insulation on electrical lines. Lines and wiring should be properly spaced to prevent interference that will cause the noted damage. Secure mounting provisions should be used. Resilient material has been used to protect lines and wiring where they pass through bulkheads. A careful analysis of potential interference and chafing areas is important to the provision of a safe installation.

System lines and wiring should be routed as directly as practicable to minimize the occurrence of fire or explosion hazards. This design is applicable to both fluid carrying lines and electrical wiring. Where practicable, routing flammable fluid system lines through tanks and routing flammable fluid lines and electrical wiring internal to components will reduce the potential hazards that may result from fitting failure or line or wiring damage. The intent is to minimize the length of system and equipment lines and wiring that may be subject to damage or that may fail from normal or accidental means and present fire and explosion hazards through the uncontrolled presence of flammable fluids, ignition sources, or oxidizers or reducing agents.

Sharp bends and restrictions in fluid lines should be avoided. Tubing should not be installed in a stressed condition. Tubing installations should be configured so that vibration or deflection of the tubing attaching structure should not result in tubing damage. Flexible fluid line connections should be used between the structure and engines and on similar type installations.

The doors for wheel wells and other similar openings should be designed to seal tightly upon closure to prevent rearward streaming fire from entering and igniting combustible materials within these compartments.

REQUIREMENT LESSONS LEARNED (3.3.8)

Oil, hydraulic, and water-alcohol tanks have been designed to withstand a 2000 Deg. F fire for 10 minutes without leakage. Oil, hydraulic, and water-alcohol tanks in compressor sections of engines have been kept, as far as practicable, toward the front of the compressor and were located as low as practicable. These have not been located adjacent to burner, turbine, and tailpipe areas. Oil tanks for auxiliary power plants have been designed to withstand a 2000 Deg. F fire for 10 minutes without leakage.

Magnesium has not been used (see Design and Construction of Aircraft Weapon Systems, SD-24, Vol. I and Vol. II).

Aluminum alloy has not been used within or close to a potential fire zone for structure or equipment, the breakdown of which will endanger the integrity of the air vehicle structure or controls necessary for flight, jeopardize the controllability of the air vehicle, or cause hazardous spread of fire.

Insulation has been nonabsorbent as a material, or as a material configuration, and designed and installed so that fluids were not retained on or under it.

Nonmetallic material which is combustible has been used only when use of more fire-resistant material is impractical. Nonmetallic material should not ignite spontaneously under all environmental temperatures of installation, and it should be self-extinguishing after removal of a flame. When used in potential fire zones with fire extinguishing capabilities, it should not afterglow.

Metallic shock-absorbing elements has been used in potential fire zones, whenever practical, instead of elements made of elastomeric material. When metallic shock-absorbing elements could not be used, the elements were designed so that the supported components remained adequately supported and continued to function effectively, in spite of failure of the nonmetallic material in the mounting system due to fire.

All nuts, bolts, and fasteners in burner, turbine, and exhaust sections which can cause leakage of flammable fluid, when loose, have been safety-wired or otherwise mechanically locked.

Flammable Fluid Subsystems

Location of fuel tanks above engine compartments has been avoided. If fuel tanks were located above engine compartments for justifiable reasons, provisions were made to prevent leakage of fuel into engine compartments or onto exhaust systems. A ventilated and drained space has been provided between fire wall and tank to afford safe disposal of any fuel leakage from the tank. Insulation was also provided, if necessary, to prevent ignition within the tank, or in the shrouded air space, in case of a power plant fire.

Flammable fluid lines in potential fire zones has been reduced to a minimum total length and a minimum number of connectors. They were arranged as low as practical in the compartment and away from potential fire sources.

Flammable fluid accessories have been located in potential fire zones only when justifiable reasons for such locations existed. Flammable fluid accessories which were located in potential fire zones were designed so that not more than 0.5 gallons of flammable fluid were likely to be released into an existing fire, as a consequence of an existing fire, within the first five minutes of a fire. If necessary to accomplish this, flammable fluid accessories have been able to withstand a flame of 2000°F (1093°C) for five minutes, or flow restrictions were provided, where feasible. Simultaneous leakage from multiple accessories or tanks is not likely to be released into an existing fire if accessories or tanks are located remote from each other and so that spread of fire to both accessories and tanks is unlikely.

Fuel tanks have been located laterally as far from the plane of the propulsion engine turbine as possible. If fuel tanks were located in the plane of the turbine for justifiable reasons, the turbine was tested for blade containment up to a speed which produces kinetic energy of the maximum allowable overspeed of the engine, or strategic armoring around the turbine was provided.

Fuel tank location has been avoided in an area within plus or minus 5 degrees of propeller planes.

Fuel tanks with walls adjoining the free atmosphere has been avoided in protrusions and extremities of the aircraft, and in areas less than 12 inches from leading edges and trailing edges for reasons of lightning protection. Fuel tanks located in these areas for justifiable reasons, were protected against lightning. Fuel has not been stored in fore or aft extremities, such as in the nose of the fuselage, or in the nose or aft cone of a wing tip tank.

Fittings have been located above the fuel level, preferably on top of the tank whenever practicable. Fuel tank shutoff valves have been located as near to the fuel tank outlets as possible. This location provided the greatest protection against battle damage and fuel line leakage. If practicable, filler caps, vents, gage units, outlets, etc., were incorporated in one inspection plate at the top of the tank. Fuel tank fittings in or close to the bottom of the aircraft were avoided, or provisions were made to minimize the hazards of tank rupture in a crash landing or due to gunfire.

Fuel lines were routed through fuel tanks and close to heavy structure, wherever possible, to provide the greatest possible protection against combat damage, and fire hazard resulting from line leakage. Metallic tubing has not been in contact with the walls of self-sealing tanks, and fuel tank fittings were located that they are as well protected against battle damage as practicable. Fuel tank fittings have been located as high as practicable in the tank so that battle damage to a fitting causes a minimum of fuel loss. Fuel tanks have not been located immediately adjacent to gun compartments; they were separated from such compartments by at least one liquid and vapor-tight bulkhead in addition to the tank boundary structure. Fuel tank shutoff valves have been integral with or as close as possible to the tanks. The fuel sequencing from multiple fuel tanks has been arranged to result in lowest vulnerability to battle damage.

Self-locking units utilizing nonmetallic locking devices have not been used in oil tanks because of loss of locking characteristics through oil and heat. Nonmetallic have not been used on tanks containing flammable fluids where frequent threading of the nuts is required.

Bladder cells have been supported by the tank cavity so the bladder is not required to withstand fluid loads. Negative loads on bladder cells has been avoided by proper vent size and design. Interior surfaces of bladder cell cavities should be smooth and free of projections which could cause wear of the bladder, unless provisions are made for protection of the bladder at such points of unless the construction of the bladder itself provides such protection. Tank fittings and accessories should have been mounted so that their loading is transmitted to the structural cavity. The bladder has been sized to fit the cavity without clearance. The tank cavity has been liquid and vapor-tight, and drained.

Metal structural members such as stiffeners, hat sections, etc., have been kept to a minimum in cavities for rigid nonmetallic self-sealing tanks. The minimum clearance between metal structure and the tank has been one inch. However, it may be necessary to use the tops of stringers for tank support to maintain tank shape. The above requirements with regard to surrounding structure do not apply to the top surface of the tank. The tank cavity has been liquid and vapor-tight, drained and ventilated.

All surface of the tank cavity of flexible self-sealing tanks, other than the top surface, have been lined with plastic panels conforming to MIL-P-8045. The tank cavity has been liquid and vapor-tight, and should be drained. The cavity structure and the plastic panels have withstood the forces produced by the passage of projectiles, specified in MIL-T-5576, 4.6.12, through the confined liquid to such a degree that no additional hazards evolve.

Unsupported sections of lines carrying flammable fluids whose natural frequency would be such that dangerous amplitudes of vibration might occur in operation have been avoided. Rubber lined clamps, such as MS21919, have been used to support metal tubing and hoses. Chafing of lines has been prevented by clamping, or in bulkheads or other structure by grommets. Grommets, however, have not been used for support of rigid lines. Grommets in firewalls have withstood a flame of 2000ºF for 15 minutes without flame penetration in installed condition. Lines have not been supported from each other.

Cut hose and clamps have not been used in any part of a flammable fluid system. Hose assemblies have been protected by shielding or other means against temperatures in excess of the maximum specified allowable temperature for the particular hose.

Tubes, carrying flammable fluid, with below standard radii have not been used. Tubes have been provided with bends or other expansion means to avoid rupture during normal services, or during a fire if located in or close to a fire zone.

Lines have had as few joints as possible, consistent with economical installation requirements. Fittings for hoses and tubes $^3/_8$-inch I.D. and smaller have been made of steel.

Flammable fluid lines in wheel wells have been installed to have the maximum protection against rocks, frozen mud or exploding tires.

Excessive internal pressure in components carrying flammable fluids, during normal service, or during exposure to a fire, if located in a potential fire zone, have been prevented by positive means.

All filler units for tanks containing flammable fluids, both gravity and pressure fueling type, which are recessed behind access doors, have incorporated positive provisions whereby the access doors physically were not secured unless the filler cap or safety cap was properly installed. Unless specifically authorized, all filler units were sealed to the exterior of the aircraft against the entrance of flammable fluids or vapors to the interior of the aircraft. If necessary, filler basins (scuppers) were provided with drains of at least $^3/_8$-inch I.D. The scupper was adequately sealed to the surrounding structure to prevent spilled fluid from entering the fuselage, engine compartment, or wing. The cap incorporated provisions for positive locking. Filler caps were designed so that visual inspection of the installed cap from a distance of at least 10 feet in daylight gave positive indication that the cap was properly and positively locked in the closed position. An electric ground receptacle for grounding pressure and gravity fueling nozzles, conforming to MS 33645, was installed, with the exception that the receptacle was located: (a) not more than 20 inches or less than 5 inches from the adapter, and (b) not near fuel vents or openings.

If dipsticks were used in fuel tanks which have provisions for pressure fueling, they were either made of material which is electrically nonconductive and does not retain an electrostatic surface charge, or they were contained in an electrically conductive sheath, made of metal screen or perforated tube, or any other suitable design, which was electrically bonded to the metal filler adapter and carries away static charges rapidly from the fuel surface in the vicinity of the dipstick.

All vent and drain exits which carry flammable fluids and vapors overboard were arranged such that there is no impingement on the aircraft under any normal condition or aircraft operation. Vent discharge, drain discharge, fueling and defueling nozzles were not located in close proximity to fittings for air crew oxygen replenishment, engine start and electric power cable connections. Where the prevention of impingement was impractical, there was no re-entry of the flammable fluid or vapor into aircraft spaces where a possible source of ignition existed, considering seams which might “open” during normal operation of the aircraft, throughout the service life of the aircraft. Further, fuel tank vents were installed so that fluids discharged will not contact ground equipment normally parked about the aircraft, when servicing the aircraft. Fuel tank vent exit configurations should such that they do not protrude from the surface of the aircraft whenever there is a possibility of a lightning clinging on to the exit and causing a flame propagation to the tank, or adequate protection against lightning should be provided. Vent and drain exits permitted free drainage of fluid from the lines without wetting the skin when the aircraft is standing on the ground. The line exits were sealed at the aircraft around the periphery of the line to prevent entrance of fluid or vapor into the aircraft. Vent and drain discharge were away from engine and rocket exhaust, to the extent necessary to prevent flame propagation into drained and vented compartments. Fuel tank vent exits were located so that fuel vapors are not likely to enter areas in the fuselage, wing and power plant during fueling. Vent line exits for fuel tanks which have provisions for pressure fueling were designed so that inadvertent blocking of the vent exit by masking tape or by stoppers used for system leakage checks, was eliminated to the greatest practical extent.

The support structure of tanks containing flammable fluids was designed such that the stresses in the tank are low. Support in padded cradles is recommended, whenever practicable. Material for padding was nonabsorbent, and fuel and oil resistant. Supports of tanks containing flammable fluids, which are located in engine compartments were designed to withstand a 2000ºF fire for 10 minutes without failure. The tank support pads have been able to withstand a 2000ºF fire for five minutes without losing the ability to retain the tank in position under normal flight loads.

Airscoops into potential fire zones were located and constructed so that flammable fluids and vapors, or flames, cannot enter a potential fire zone under any reasonable flight attitude.

Electrical Subsystems

Electric equipment was located in potential fire zones only when justifiable reasons for such location exist.

All electric equipment, and all metal lines within a fuel tank connected to electric equipment, regardless of size, have been grounded. All electric wires and equipment in fuel tanks has been designed with the highest degree of protection against sparking, arcing, or overheat under normal operating and emergency conditions, and during maintenance. Arc-over from electric equipment or wiring being removed from or installed into fuel tanks has been prevented by positive means, if such arcs are a potential ignition source. In addition, metal wire conduit wall thickness, joints, and attachments have carried maximum fault current without dangerous external heating or conduit burn through under conditions of an internal power fault to the wall of the conduit or between adjacent wires.

Conduits which are open to the exterior of the tank for breathing purposes, or for easy removal of the wires have discharged safely any leakage of fuel into the conduit.

All electric equipment in fuel tanks should be explosion-proof.

Electric equipment which can be an ignition source in a normal operating or failed condition has not been located in compartments containing flammable fluid components, or in compartments adjacent to fuel tanks, or in compartments into which leakage of flammable vapor from other compartments was likely due to lack of adequate sealing. Such lack of adequate sealing is normal in many cases after extended maintenance and service.

Leakage of flammable vapors into electrical compartments was avoided, when practicable, by providing a positive pressure head in the electrical compartment relative to any adjacent compartment containing flammable fluid components.

All accessory unit such as filters, valves, etc., the weight of operation of which impose adverse stresses or vibration on tubing carrying flammable fluid, were supported by means other than the tubing. If rigid connections are used between accessories, then all accessories so connected should be rigidly mounted on the same base.

Electric motor driven pumps for flammable fluids have used shaft seals and suitable drain chambers and overboard drains to allow any fluids which leak past the main seal to drain to the outside before entering the motor. The drain were terminated on the outside of the pump in a boss in accordance with SAE AS 5202. The only possibility of seal leakage was between the rubbing members of the seal. In the event that an electric motor is utilized, wherein its rotating element operates immersed in the fluid, this requirement does not apply. On electric motor driven pumps, unless the motor operates immersed in fluid, the motor was vented overboard. The vent line was integral with the pump without connectors. Motor cases of electric motor driven pumps with immersed motor had a vent hole to the tank cavity, which incorporates a proven flame arrestor. The electric motors were explosion-proof.

Electric motor driven pumps which, in case of a failure, can reach case temperature higher than the autogenous ignition temperature of the fluid have incorporated thermal protection. The thermal protection has cut off the current to the motor so that no point of the motor case exceeds at any time a temperature which is 50ºF below the autogenous temperature of the fluid. The thermal protection was not be resettable in flight.

Electric motor driven pumps were such that current cannot be carried from the motor section into the pump under any failure condition. The electric wires entered the motor through potted inlets, if the wire inlet was submerged, in normal condition or in case of a failure.

Centrifugal pumps were used rather than positive displacement pumps if necessary to preclude high-pressure buildup in case of line blockage. High-speed positive displacement pumps were not used when the pump element may run immersed

Capacitor type fuel quantity gages have complied with the fire protection requirements of MIL-G-8998.

Quantity indicators in tanks containing flammable fluids have been designed so that no “single electrical failure” in any part of the circuit, inside or outside the tank, could cause a spark or arc, with an energy greater than 0.2 millijoules, within the tank. Liquid level switches were in accordance with the fire protection requirements of MIL-S-21277. If transformers were used for power supply to the gages in the tank, electrostatic grounded shields were applied between the two windings, if a short between the primary and secondary winding could cause a spark or arc, with an energy greater 0.2 millijoules in the tank.

Electric components which were permanently or temporarily located in compartments containing flammable fluid components with potential leakage, or in compartments adjacent to fuel tanks, or in compartments into which leakage of flammable vapors from other compartments is likely due to lack of adequate sealing, should comply with the following requirements:

The following technical documents have been used in military aircraft:

Explosion proof

The electric components, including connectors, have been explosion-proof as defined in MIL-E-5272, Procedure IV. Procedure III of MIL-E-5272 is acceptable only for such components which cannot develop internal spark producing failures, such as loose wires and contacts, or other loose objects.

Overheat protection

Overheat protection has been provided for electric components, in case temperatures can cause ignition of the fluids involved under any potential condition of failure. The thermal protection has cut off the power to the equipment so that no point exposed to the fluids exceeds at any time a temperature which is 50ºF below the minimum autogenous ignition temperature of the fluids. The thermal protection has not been resettable in flight. Where resettable protection must be used, the thermal protections has been designed on the basis that it may be continuously reset as rapidly as is practicable after each time the power is cut off.

Short circuit

All bare conductors or other exposed current carrying parts has been adequately protected against short circuits caused by loose objects. This protection was obtained by locating them in such a manner that additional protection was not required, or by means of suitable coverings. Protection by location or covering was not sufficient for terminals, ground studs and similar components which can cause ignition by sparking or heating because of loose connections. Allowance was made for cumulative heating over extended periods and all affected materials were selected to prevent deterioration or electric breakdown under these conditions.

Wires

The installation and routing of electric wires has complied with the fire protection requirements of MIL-W-5088.

Flammable fluid systems and components have complied with the fire protection requirements of the following specifications:

Fuel Systems Aircraft, Installation and Test of, MIL-F-17874;

Fuel System Components, General Specification for, MIL-F-8615;

Fuel and Oil Lines, Aircraft, Installation of, MIL-I-18802;

Hydraulic System, Aircraft Requirements for, MIL-H-5440.

Electronic equipment have complied with the fire protection requirements of MIL-E-5400, and electric wiring has complied with the fire protection requirements of MIL-W-5088.

Installation of fuel and oil lines has complied with the fire protection requirements of MIL-I-18802.

Tank filler caps and adapters has complied with the fire protection requirements of MIL-C-7244. Pressure fueling adapters has complied with the requirements of MIL-A-6425. Fueling adapters were properly grounded to the airframe in accordance with MIL-B-5087

Gaseous oxygen systems has complied with the fire protection requirements of MIL-I-8683. Liquid oxygen systems have complied with the fire protection requirements of MIL-I-19326.

Electric components which are essential for safety of flight, or are required to perform emergency operations, have not been located in or close to a fire zone. If they must be located in or close to a fire zone for justifiable reasons, components essential for the safety of flight have been able to withstand a 2000°F flame of the type likely to be encountered in the area for at least 15 minutes. Components required to perform emergency operations have been able to withstand such a flame of 2000°F for at least five minutes, without failure.

Shock mounts for electric components located in potential fire zones have been all-metal.

Wire in fire zones which is essential for safety of flight or for emergency operations have been in accordance with MS 24284.

Electric components and wires have been located away from oxygen equipment. When such separation cannot be obtained for justifiable reasons, electric wires and wire bundles have been provided with frequent supports, including protective conduits if necessary, or other suitable means of support to prevent a free end of a broken wire from touching any oxygen tube. Electric wires have not been attached to oxygen components, unless required for electric operation or monitoring of the component.

The pressure in electrical and electronic components has not, when practicable, been above that of an adjacent compartment which contains volatile flammable fluid components with potential leakage, to compensate for the lack of complete sealing which may be expected after reasonable maintenance and service. Tests have been made to substantiate that flammable zones run at lower pressures than any adjacent ignition zone.

Nonmetallic material used in or close to electric components which can attain excessive temperatures due to resistance heating caused by a failure, should not ignite at the maximum temperature of a failed component. Flammable fluid has not been used in electric equipment such as ballasts in neon lights.

External power receptacles have been located as remote as possible from points of potential flammable fluid or vapor release, such as vent and drain exits. They have been located in areas of the aircraft where flammable vapors from leakage within the aircraft cannot accumulate, or they were enclosed in a vapor tight compartment.

Hermetically sealed batteries were used only with specific approval. Where used, they were provided with frangible safety blow-out plugs or the equivalent.

Batteries have had gasketed covers held down by reliable fasteners, in conjunction with the use of sealed type electric connections. Lead-acid batteries were vented overboard to a place where ignition or re-entry cannot occur. Nickel-cadmium batteries have been provided with pressure-relief vents to limit internal pressure build-up. Battery vent lines and fittings should be resistant to the electrolytes and their products of decomposition.

Safe cell temperatures and charging rates have been maintained when the battery is recharged (after previous complete discharge) at maximum regulated voltage, during a flight of maximum duration, under the most adverse cooling condition likely to occur in service.

Electro explosive systems

Since safe design of electroexplosive systems such as ejectors, igniters, destructors, flares, etc., is dependent upon proper design of the initiator system, the following design recommendations were directed toward initiator systems:

Specifications

Electric initiators have been designed in accordance with the fire protection requirements of MIL-I-23659.

Initiator systems

An initiator system consists basically of a fusible link (bridge wire), the external power supply and the triggering device which initiates the firing current. The fusible link generally ignites a small primer charge which in turn explodes an actuating powder charge. Sensitive, low electrical energy initiators has been avoided, whenever possible.

Shunt fuses

An electric shunt fuse connected across the bridge wire circuit has been included within the initiator circuit. This fuse was not more than one fifth of the resistance of the parallel bridge wire path and its blow-out rating was equip to the minimum all fire current of the bridge. A resistor may also be installed in series with the complete initiator to provide current limiting during firing and prevent opening the initiator wiring circuit breaker.

Bridge circuit

The bridge wire circuit was a two-wire, ungrounded system. Where a ground is necessary, the ground should be made at a single point only.

The external firing circuit wires to the initiator bridge wire was a twisted-pair cable, encased in a flexible metallic shield. This shield was covered with an insulating sleeve, but was electrically bonded to the disconnect plug shell at the initiator with a wire as short as possible. The twisted-pair firing cable to one initiator was not placed within the shielding braid of another initiator firing cable. Where an isolating relay is used in the firing circuit, it was located as close to the initiator as is practicable, and it opened both initiator leads.

Initiator shielding and grounding

The initiator was encased in a complete metallic shield container, with a metallic electric receptacle for external connections. The initiator case was thoroughly electrically grounded to basic metallic structure by means of the mounting installation.

Radio frequency filter

In addition to metallic shielding of the bridge wire and its twisted-pair shielded wiring, a radio frequency filter was included within the initiator circuit. The longer the twisted-pair shielded wiring, the more important the radio frequency filter becomes. The filter may be the conventional inductor-capacitor network or a “solid state attenuator” incorporated in the bridge wire leads.

Location of initiators and wiring

The wiring and the initiator have been routed separately from aircraft wiring, especially radio frequency coaxial cables and heavy ac power cables. The initiator and its wiring were located, insofar as practicable, within and close to the metallic skin or structure of the vehicle for shielding purposes. The initiator was not located adjacent to transmitting antennas in the aircraft.

Accessibility

All initiators were easily accessible and replaceable.

Exploding bridge wire initiating systems

Exploding bridge wire electric initiators employ bridge wires of much larger diameter adjacent to but not necessarily touching the normal charge of explosive. Since there is no heat sensitive explosive in contact with the bridge wire, any heating that may result from the passage of currents caused by stray voltages, electromagnetic radiation, or other accidental causes will have no effect on this type of initiator.

Bleed Air Subsystems

Ducts and their connections which terminate in the cabin or which are routed through the cabin have been made of aluminum or equally fire-resistant material. Air ducts passing through potential fire zones, when allowed to burn through, might give a fire the opportunity to travel from one fire zone to another or to the rest of the air vehicle, and they may also allow a high air mass flow to enter the potential fire zone and feed the fire. Such air ducts have been made of stainless steel or titanium not less than 0.015 inches thick, or equivalent material, where they pass through fire zones. Air ducts originating in fire zones have been made of stainless steel or titanium not less than 0.015 inches thick, or equivalent material, for a sufficient distance beyond the fire barrier to assure that any fire can be contained within the duct. For air ducts originating in potential fire zones, shutoff means has been provided.

Combustion air ducts have not communicated with the heating airstream unless it is demonstrated that flames from backfires or reverse burning cannot enter the heating airstream under any conditions of ground or flight operation, including conditions of reverse flow or malfunctioning of the heater or its associated components. Combustion air ducts have not restricted prompt relief of exhaust and backfires which can cause heater failure due to pressures generated within the heater.

Combustion and ventilating air intakes have been so located that no flammable fluids or vapors can enter the heating system under any conditions of ground or flight operation either during normal operation or as a result of failure.

Engine and combustion air inlets have been designed, whenever possible, so that air cannot be drawn from a compartment with potential flammable leakage during any ground or flight phase.

Low pressure in the air inlet ducts relative to pressures in adjacent compartments during ground runs and low flight speeds can cause ingestion of flammable leakage with resulting engine stall, flash-back of combustor flames through the compressor, and fire and explosion in the adjacent compartment. It also causes reverse flow of air in the compartment with the related problems of improper detector and extinguisher discharge nozzle location.

Hot bleed air and other hot gas ducts and their components have not been located in compartments containing flammable fluid components with potential leakage, or in compartments adjacent to fuel tanks, or in compartments into which leakage of flammable vapor from other compartments is likely, if the following conditions apply:

CONDITION 1: The maximum surface temperature of the bleed air ducts and components, under any normal or emergency condition, is equal to or higher than the minimum autogenous ignition temperature (MAIT) minus 50 Deg. F of the flammable fluids in question.

CONDITION 2: The maximum bleed air temperature under any normal or emergency condition is equal or higher than the minimum hot gas ignition temperature (MHGIT) minus 50 Deg. F of the flammable fluids in question.

If, for justifiable reasons, bleed air ducts and components must be located in such compartments, the installation of the ducts has complied with the following requirements, for above Conditions 1 and 2:

CONDITION 1: The ducts have been located as high within a compartment as practical, and away from potential flammable fluid leakage. The compartment has been drained, ventilated, and insulated as indicated in other sections of this document.

CONDITION 2: Bleed air ducts and components have been isolated by fluid and vapor tight, preferably permanent, barriers

Air bled from the engine to prevent compressor stall has been discharged directly overboard, and was not discharged inside any airplane compartment. Discharge into turbine and tailpipe compartments was permitted, except if water-alcohol was added to the compressor air for thrust augmentation upstream of the bleed air takeoff. The ducts for anti-stall bleed air discharge were made of steel, or equivalent material, within fire zones.

Oxygen Subsystems

Component temperatures

Oxygen components have been located in or close to potential fire zones, or in other areas where they could be subjected to temperatures in excess of those specified in the individual component specification, under normal operating conditions, or in case of a fire, hot duct rupture, etc. If such location is not possible permanently installed shielding and insulation, if necessary, has been provided to keep the component temperatures within specification values.

Portable oxygen containers

Portable oxygen containers were stored in areas where the likelihood of a fire is remote, or they were stored in enclosures which can withstand a fire likely to occur at their location, and they were insulated so that such fire will not cause discharge of oxygen from the container into the fire.

System layout

The layout of the oxygen system and the location of the components was such that all lines were as short as practical, and that high-pressure lines were held to a minimum length. Oxygen containers, however, were not be located immediately adjacent to the crew, and in combat aircraft they were located, whenever practical, so that they were protected against gunfire.

Flammable fluid components

Insofar as practicable, oxygen lines and components have not been grouped with lines and components carrying flammable fluids, and were not located above each other. When necessary to keep potential flammable fluid leakage away from oxygen lines and components, shrouding was used.

Component clearance

A clearance of at least two inches has been provided between oxygen tubing and components, and control cables and other flexible moving parts. A clearance of at least ½ inch was provided between oxygen tubing and components, and other parts of the aircraft under any condition of operation and accumulation of manufacturing tolerances, unless the oxygen lines and components were rigidly attached to these parts.

Propellers and turbine rotors

Oxygen containers were not be located within six inches of the plane of rotation of aircraft propellers or turbine rotors.

Lines and fittings

Aluminum or stainless steel tubing have been used in oxygen systems, and the connectors were an approved type for use in oxygen systems.

Container support

The oxygen container supports were designed to withstand the same inertia loads as the seats of the occupants. The container supports in combat aircraft were designed to prevent the container from tearing loose when hit by gunfire.

Filling provisions

The filler connections were located so there was no possibility of oil coming in contact with the filler valve. The filler connection was installed within a closed box behind a cover plate with a dirt and oil-tight seal.

Contaminants such as dirt, lint, metal chips, etc., were prevented from entering filler connections of the oxygen systems by means of fine mesh or sintered filters installed in the system.

Cleanliness

The entire oxygen system was completely free from oil, grease, and other foreign matter. Open ends of cleaned and dried tubing and components was plugged at all times. There was no unplugged opening in the installation at any time, except during attachment or detachment of parts.

Hazardous Subsystems

The systems treated or referenced in this section are potential fire and explosion hazards if not properly designed, located, or installed.

High speed rotating equipment

Recirculation fans or other high-speed rotating equipment have not contained magnesium parts.

Location

High speed rotating equipment such as starters, auxiliary power units (APUs), drive shafts, etc., were located, whenever possible, to prevent damage of flammable fluid components, explosives, oxygen containers, and in particular fuel tanks by flying fragments in case of disintegration of a rotating part.

Overspeed protection

If location recommended above was not possible for justifiable reasons, high speed rotating equipment, except main propulsion engines, was designed to incorporate either one of the following features:

Containment

Capability of containing all rotor fragments within the equipment under the conditions of the most adverse “single failure” which causes maximum overspeed at maximum operating temperature.

Rotor strength

Strength of all rotor parts to withstand a speed which produces 1.50 times the kinetic energy of a maximum overspeed which can be caused by the most adverse “single failure”, and at maximum operating temperature.

Aerodynamic speed limitation

Aerodynamic speed limitation such that failure of the rotor cannot occur at a speed producing 1.5 times the kinetic energy of the limit speed and at maximum operating temperature. If the equipment requires controlled ingestion of air for aerodynamic speed limitation, the equipment model specification should give all the requirements necessary for satisfactory duct design.

Friction braking

Speed limitation by friction braking between rotor and case such that failure of the rotor cannot occur at a speed producing 1.50 times the kinetic energy of the maximum limit speed, and at any operating temperature.

Speed limiting device

In order to limit the maximum over speed in the Containment or Rotor Strength sections, two reliable and independent speed limiting devices was considered. One of these devices may be the normal speed control and the other one a topping device with the sole purpose of preventing the equipment from exceeding a predetermined maximum speed. The topping device has incorporated a "self-exercising", or a testable feature to prevent sticking from inactivity. The speed limiting device has been located as close as practicable to the component which is to be protected against over speed by the device. Any electrical portion of the toping device was located or protected so that it will not be rendered inoperative by the lubricating oil of the equipment, under normal operating condition or in case of a "single failure".

Other hazards

High speed rotating equipment was carefully analyzed for other potential fire hazards such as ignition of flammable fluids by high case temperature due to normal operation or due to failure, such as oil starvation and bearing failure. Satisfactory protection was provided if such hazards exist. High speed rotating equipment was supported in such a manner that imbalance due to potential failures will not cause failure of the support with consequent fire potentiality.

High speed drive shafts were encased, if necessary to protect flammable fluid components, fuel tanks, explosives, oxygen containers, etc.

High pressure air systems

Specifications

High-pressure air systems have complied with the fire protection requirements of MIL-P-5518.

General

High pressure air compressor and related components utilizing lubricating oil as piston lubricant which ultimately is mixed with the compressor air can experience explosions with destructive results to the equipment and to adjacent components, if not properly designed.

Location

High pressure air compressors and related equipment have been located, whenever possible, to minimize damage of flammable fluid components, explosives, oxygen containers, and in particular fuel tanks, by flying fragments in case of any explosion.

Explosion hazards

High pressure air compressors and related equipment have complied with MIL-P-5518. An explosion hazard report should be submitted as required by MIL-P-5518. Particular attention should be given in this report to potential hazardous conditions caused by equipment malfunctions. The oil-air mixture in a compressor, which is pre-charged with compressed bleed air, may move from "too lean" to "explosive" when the mass airflow is reduced due to a severed compressor air intake line. The same result can be experienced when the lubricating oil flow to the cylinders of the compressor is increased due to a malfunction of the lubricating system. Breakdown of the cooling system due to a fan failure may also cause explosion when the air temperature exceeds the autogenous ignition temperature of the lubricating oil.

Support

Compressors and reservoirs for compressed air have been supported so that compressor unbalance caused by malfunction, or reservoir damage caused by gunfire, will not result in failure of a support with resultant fire potentiality.

Explosives

Specifications

Explosives have complied with the fire protection requirements of the following specifications:

Initiators, Electric, Design and Evaluation of, MIL-I-23659;

Design and Evaluation of Cartridges for, Cartridge Actuated Devices, MIL-D-21625;

Installation and Test of Aircraft Pyrotechnic Equipment, General Specification for, MIL-I-8672.

Location

Explosives have not been installed or stowed in the proximity of heat sources if these heat sources can cause ignition of the explosives under any normal condition, or if a “single failure” can cause ignition of the explosives. Explosives have not been installed or stowed in the proximity of potential fire zones. If explosives must be located close to real or potential heat sources for justifiable reasons, they were adequately protected by permanently installed insulation, or shields, or both.

Installation

Explosives can be a hazard to manufacturing and maintenance personnel. Designs have permitted installation of explosives as late as possible in manufacturing sequence, preferably at the flight line. Explosives have been interchangeable without force or rework.

Engine Starters

Specifications

Turbine starters have complied with the fire protection requirements of MIL-S-7848.

Overspeed Protection

Failure of a starter coupling to disengage after engine lightoff can cause over speed of the starter. Starter disintegration due to this type of failure and due to failure in the speed control mechanism has been prevented by over speed protection as indicated above.

Cartridge Starters

In addition to the above requirements, a cartridge starter has complied with the following:

Inadvertent Ignition

A cartridge starter should be suitably protected against inadvertent ignition of the cartridge. It should be possible to arm the starter only after securing the breech. It should be possible to disarm the starter at any time prior to actuation.

Gas Leakage

There should be no leakage of gases into the starter compartment or into any other compartment from any part of the starter during or following operation throughout the operating range.

Overpressure Protection

An overpressure relief device should be incorporated in the starter which will limit the maximum breech pressure in the event of abnormal cartridge burning. The device should bypass the turbine. The relief pressure should not exceed the breech proof pressure.

Cartridges

Cartridges should comply with the fire protection requirements of MIL-D-21625.

Gun Installations

General

Gun gases leaving the muzzle and leaking from the breech contain considerable quantities of unburned combustibles. Appropriate measures have been taken so that the gas-air mixture within the gun compartment does not fall within the explosive range.

Gun Gas Data

The maximum gun gas release rate into the gun compartment and the maximum content of combustibles by volume in the gas has been determined and specified by the gun manufacturer. The lower explosive limit of gun gas is approximately 9 percent (9%) by volume.

Ventilation

If ventilated was used for diluting the gas-air mixture in the gun compartment, air intake was located away from the gun muzzle to prevent gases from the muzzle from entering the ventilating air. Gun icing by ventilating air has been prevented. This can be accomplished with a ventilating system operating only while the gun fires. The ventilating airflow rate has been high enough to result in an average concentration of combustibles of 4.5 percent (4.5%) with good mixing, and 2.25 percent (2.25%) with less thorough mixing.

Fuel Tanks

Fuel tanks have not been located immediately adjacent to gun compartments; they were from such compartments by at least one liquid and vapor tight bulkhead in addition to the tank boundary structure.

Landing Wheel Brakes

Wheels which serve as housings for highly loaded brakes have been provided with pressure relief devices actuated by heat. Consideration should also be given to the use of a heat shield between the brake and the wheel. The purpose of these devices is to prevent tire explosion caused by brake overheating or by brake fire.

In addition, serious consideration has been given to a brake overheat warning system. Use of a brake warning system should be based on the type of vehicle, its intended usage, the characteristic of the brake, and the probability and the consequences of the hazards.

External Rockets

External rockets have been installed so that the rocket exhaust was not be a hazard to fuel tank vent lines. If fuel vent exits cannot be located at a safe distance from the rocket exhaust, the vent line exits were protected by flame arrestors or other effective means to prevent flame propagation into the tanks.

Surfaces of rocket exhaust impingement have been designed for heat and corrosion resistance. Protection was provided, if necessary, for flammable fluid components, fuel tanks, explosives, etc., located in compartments exposed to the exhaust wake.

4.3.8 Installation hazards reduction.

By analysis and inspection it should be verified that installation hazards reduction designs have been used to the fullest extent practicable to prevent the occurrence of fire and explosion due to the uncontrolled presence of __(TBS 1)__. The adequacy of the provided design should be verified by __(TBS 2)__.

VERIFICATION RATIONALE (4.3.8)

The use of these prevention designs to the fullest extent practicable is necessary to reduce the need for detection and control provisions. The adequacy of the provided designs must be verified to eliminate poor designs and avoid costly retrofits.

VERIFICATION GUIDANCE (4.3.8)

TBS 1: To prevent hazards resulting from component, line, wiring, etc. interference, line or wiring routing or line or wiring fabrication and installation should be verified by inspecting the various subsystem installations throughout the air vehicle ground and flight test program. Past recommendations have been to conduct these inspection at 50-hour intervals during the flight test program. When appropriate, additional inspections should be conducted after the following flight conditions and maneuvers:

a. Simulated and actual weapon delivery
b. Internal gun firing
c. Inflight refueling
d. Maximum positive and negative g maneuvers
e. Maximum roll and sideslip maneuvers
f. Maximum climbs and descents
g. Critical speed brake or thrust reverser actuations.

The adequacy of designs provided to prevent the spread, due to airflow, of fire along the air vehicle exterior from one subsystem to another may need to be verified by demonstration.

TBS 2: The required analysis and inspection should be done along with the analysis and inspection required by Installation hazards reduction and should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle.

a. The adequacy of designs provided to prevent normal subsystem operation from contributing to or resulting in fire and explosion hazards may need to be verified by demonstration. In the case of fuel dump systems it should be demonstrated by using dyed fluid that no fuel or fumes impinge on or enter any portion of the air vehicle and cause unsafe conditions under all normal flight conditions. Record data, including movies, during selected operating conditions.

b. The adequacy of designs provided to minimize fire and explosion hazards resulting from failure or accident may be verified by inspection, test or demonstration depending on the particular design. The test or demonstration may be required to show that flameholders have been excluded from powerplant installations and that flames from backfires or reverse burning cannot enter combustion heating airstream.

VERIFICATION LESSONS LEARNED (4.3.8)

When using dyed fluids for fuel impingement tests, visually inspect the air vehicle as part of the impingement determination. Do not rely solely upon motion pictures.

3.4 Subsystem characteristics

4.4 Subsystem characteristics

3.4.1 Landing subsystem

Reference appendix A.

4.4.1 Landing subsystem

Reference appendix A.

3.4.2 Hydraulic power subsystem.

Reference appendix B.

4.4.2 Hydraulic power subsystem.

Reference appendix B.

3.4.3 Auxiliary power subsystem.

Reference appendix C.

4.4.3 Auxiliary power subsystem.

Reference appendix C.

3.4.4 Environmental control subsystems.

Reference appendix D.

4.4.4 Environmental control subsystems.

Reference appendix D.

3.4.5 Fuel subsystem.

Reference appendix E.

4.4.5 Fuel subsystem.

Reference appendix E.

3.4.6 Aerial refueling subsystem.

Reference appendix F.

4.4.6 Aerial refueling subsystem.

Reference appendix F.

3.4.7 Fire and explosion hazard protection subsystem.

Reference appendix G.

4.4.7 Fire and explosion hazard protection subsystem.

Reference appendix G.

3.4.8 Electrical power subsystem.

Reference appendix H.

4.4.8 Electrical power subsystem.

Reference appendix H.

3.4.9 Mechanical subsystems.

Reference appendix I.

4.4.9 Mechanical subsystems.

Reference appendix I.

3.4.10 Cargo, aerial delivery, and special operations subsystem.

Reference appendix J.

4.4.10 Cargo, aerial delivery, and special operations subsystem.

Reference appendix J.

3.4.11 Vertical takeoff and landing – short takeoff and landing power drive subsystems.

Reference appendix K.

4.4.11 Vertical takeoff and landing – short takeoff and landing power drive subsystems.

Reference appendix K.

3.4.12 Propeller subsystem.

Reference appendix L.

4.4.12 Propeller subsystem.

Reference appendix L.

3.4.13 Pneumatic subsystem.

Reference appendix M.

4.4.13 Pneumatic subsystem.

Reference appendix M.

3.4.14 Additional subsystems and functions.

Reference appendix *X*.

4.4.14 Additional subsystems and functions.

Reference appendix *X*.

APPENDIX A

AIR VEHICLE LANDING SUBSYSTEM

REQUIREMENTS AND GUIDANCE

A.1 SCOPE

A.1.1 Scope.

This appendix provides the requirements, verifications, tailoring guidance, and background information for the Landing Subsystem provided for in Part 1 of this specification. The appendix has been developed and coordinated by technical personnel from the Air Force, Navy, and Army and has been approved as an official guide for use by Government personnel for assistance in tailoring the air vehicle subsystems specification for acquisition and model specifications. This appendix is a mandatory part of the specification. The information contained herein is intended for compliance.

A.1.2 Structure.

The appendix structure replicates the structure of the Air Vehicle Subsystems Specification except it places each corresponding section 3 requirement and section 4 verification together.

A.1.3 Appendix.

This appendix provides tailoring guidance and background information for individual paragraphs of the Air Vehicle Subsystems Specification. Guidance gives recommendations on how to tailor the specification paragraph. Where __(TBS)__ appears, the guidance paragraph provides recommended values or text that the using service may use to insert in the __(TBS)__. When contractors are expected to complete the __(TBS)__, the Guidance paragraph will so state. The Using Service makes the final decision on whom completes the __(TBS)__ in the specification. Finally, Lessons Learned are provided to give insight to past events that could impact the tailoring of the specification.

A.1.4 Deviations.

Projected designs for given applications which will result in improvement of the system performance, reduced life cycle cost, or reduced developmental cost through deviations from this guidance, or where requirements of the specification results in compromise in operational capability, should be brought to the attention of the using service.

A.1.5 Environmental impact.

Air Vehicle Subsystems will be designed such that their operation, maintenance, and repair may be accomplished without violating the most stringent environmental regulations applicable to locations where subsystems are used or supported. Compliance with environmental regulations will not prevent subsystems from achieving and sustaining mission performance capability. Materials, processes, and environmental control equipment necessary to meet these environmental requirements must currently be available in the Using Service's maintenance and supply system. The design will not use environmentally unsuitable materials such as ozone depleting fluorocarbons, chlorofluorocarbons, and halons, or highly volatile organic compounds in solvents and coatings during development, production, operation, maintenance, or repair. The Environmental Protection Agency maintains an online list of toxic chemicals and hazardous substances on its Ozone Layer Depletion Website at http://www.epa.gov/ozone/snap/ that should be consulted. The Significant New Alternatives Policy (SNAP) Program available thereon identifies substitutes for ozone depleting chemicals.

The contractor will conduct an environmental analysis of air vehicle subsystems.

A.1.6 Responsible engineering office.

The responsible engineering office (REO) for this appendix is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL.

A.2 APPLICABLE DOCUMENTS

A.2.1 Government documents

A.2.1.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this appendix to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

INTERNATIONAL STANDARDIZATION AGREEMENTS

NORTH ATLANTIC TREATY ORGANIZATION

NATO STANDARD AASSEP-1	Aircraft Jacking
STANAG 3098	Aircraft Jacking
STANAG 3278	Aircraft Towing Attachments and Devices

(Copies of these documents are available at http://nso.nato.int and www.ihs.com to qualified users.)

DEPARTMENT OF DEFENSE SPECIFICATIONS

JSSG-2006	Airframe Structures Joint Service Specification Guide
JSSG-2010	Crew Systems Joint Service Specification Guide
MIL-PRF-5041	Tires, Ribbed Tread, Pneumatic, Aircraft, General Specification for
MIL-B-8075	Brake Control Systems, Anti-Skid, Aircraft Wheels; Instruction for Preparation of Specifications of
MIL-L-8552	Landing Gear, Aircraft Shock Absorber (Air-Oil Type)
MIL-B-8584	Brake Systems, Wheel, Aircraft, Design of
MIL-S-8812	Steering System: Aircraft, General Requirements for
MIL-A-8860	Airplane Strength and Rigidity
MIL-A-8863	Airplane Strength and Rigidity Ground Loads for Navy Acquired Airplanes
MIL-A-18717	Arresting Hook Installation, Aircraft
MIL-L-22589	Launching System, Nose Gear Type, Aircraft
MIL-T-81259	Tie Downs, Airframe Design, Requirements for
MIL-PRF-83282	Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Metric

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-203	Cockpit Controls Location and Actuation of for Fixed Wing Aircraft
MIL-STD-805	Towing Fitting and Provisions for Fixed Wing Aircraft Design Requirements
MIL-STD-878	Method of Dimensioning and Determining Clearance for Aircraft Tires and Rims
MIL-STD-1568	Materials and Processes for Corrosion Prevention and Control in Aerospace Weapons Systems

DEPARTMENT OF DEFENSE HANDBOOKS

MIL-HDBK-1587	Materials and Process Requirements for Air Force Weapon Systems

(Copies of these documents are available online at http://quicksearch.dla.mil or from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia PA 19111-5094 USA.)

A.2.1.2 Other Government documents, drawings, and publications.

The following other Government documents, drawings, and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

AIR FORCE MANUALS AND DESIGN HANDBOOKS

AFM 86-3	Planning and Design of Theater of Operations Air Bases
AFM 86-8	Airfield and Airspace Criteria
AFM 88-6	Flexible Pavement Design for Airfields
AFML 70-7	Do's and Don'ts of Materials Applications
AFSC DH 1-6	System Safety
AFSC DH 2-1	Airframe
ARDCM 80-1	Handbook of Information for Aircraft Designers (HIAD)

(Copies of these documents are available to qualified users. Contact AFLCMC/ENRS, BLDG 28 RM 118, 2145 MONAHAN WAY, WPAFB OH 45433-7017 USA; DSN 674-5476; COMMERCIAL (937) 904-5476; ENGINEERING.STANDARDS@US.AF.MIL.)

USAF TECHNICAL REPORTS

ASD-TR-68-34	Evaluation of Aircraft Landing Gear Ground Flotation Characteristics for Operation from Unsurfaced Soil Airfields (Accession Number AD0843585)
ASD-TR-70-43	Aircraft Ground Flotation Analysis Procedures—Paved Airfields (Accession Number AD720273)

(Copies of these documents are available at www.dtic.mil to qualified users; Defense Technical Information Center, 8725 John J. Kingman Rd., Suite 0944, Ft. Belvoir VA 22060-6218 USA.)

A.2.2 Non-Government publications.

The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

SAE INTERNATIONAL

SAE ARP1107	Tail Bumpers for Piloted Aircraft
SAE AS50141	Tube, Pneumatic Tire, Aircraft

(Copies of these documents are available from www.sae.org; SAE International, 400 Commonwealth Drive, Warrendale PA 15096-0001 USA; and www.ihs.com to qualified users.)

AMERICAN SOCIETY OF MECHANICAL ENGINEERS

ASME B46.1 Surface Texture

(Copies of this document are available from https://www.asme.org; ASME, Three Park Avenue, New York NY 10016-5990 USA.)

A.2.3 Order of precedence.

Unless otherwise noted herein or in the contract, in the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

A.2.4 Streamlining.

The Air Vehicle Subsystems Specification has been streamlined. The documents listed in this appendix which are required for acquisition have the same status as those referenced directly in section 2 (first tier). All other documents referenced through tiering, may be used for guidance and information only.

A.3 REQUIREMENTS

A.4 VERIFICATIONS

A.3.1 Definition

A.4.1 Definition

A.3.2 Characteristics

A.4.2 Characteristics

A.3.3 Design and construction

A.4.3 Design and construction

A.3.4 Subsystem characteristics

A.4.4 Subsystem characteristics

A.3.4.1 Landing subsystem.

The landing subsystem covers the technologies, functions, interfaces, systems, and performance which provide the air vehicle with landing control and ground mobility. More specifically, this includes the design areas for landing subsystem flight and ground operation, structural support, and ground velocity and directional control. The landing subsystem provides the air vehicle with safe and maintainable capabilities of hold position, towing, taxi, takeoff, landing touchdown, balanced field, critical field length abort, and (emergency) arresting barrier compatibility.

A.3.4.1.1 Landing gear.

The landing gear subsystem shall provide a safe and reliable means of physically supporting the air vehicle structure (and any associated loads) during takeoff, landing, taxi, balanced field, and critical field length abort, hold position, and all other required ground operations at its intended operational sites. The landing gear also shall provide __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.1)

When an air vehicle is not in the air, some parts of the air vehicle, by necessity, touch the ground (or water, if intended to land on water). The parts of the air vehicle that touch the ground (or water) should be able to support the air vehicle so it remains airworthy and useful.

REQUIREMENT GUIDANCE (3.4.1.1)

When designing landing gear design for a particular air vehicle, one should take into account such factors as the intended landing surface and operational environment (carrier landings, unimproved runways), and air vehicle gross weight.

TBS: If the determination is made that the air vehicle will have some sort of landing gear other that just skids (as on a helicopter), then the requirement blank should be filled in with what sort of velocity and directional control is desired. That is, braking, braking control, steering control, If the air vehicle is a helicopter, and skid-type gear is to be used, a determination should be made whether to utilize standard or non-standard skid gear. Some factors to be used for this determination are:

a. Mission profile
b. Skid height
c. Crosstube flex
d. Skid wear
e. Standard or non-standard gear (See lessons learned.)
f. Deployment applications.

Extended landing gear should provide some amount of energy absorption to reduce the vertical velocity of the fuselage under crash conditions.

REQUIREMENT LESSONS LEARNED (3.4.1.1)

During conventional conflicts when deployment of helicopters on large transport-type air vehicles (C-141 or larger) are to be used, standard skid gear is adequate. During non-conventional conflicts such as guerilla warfare or terrorism, deployment on smaller transport air vehicles may be a factor thereby increasing restrictions on the helicopter to be transported. The Army had a requirement during the Middle East conflict to move small teams of armed reconnaissance helicopters rapidly to locations which would not accommodate large transport air vehicles. The skids on these helicopters were changed to an underslung crosstube design and a gear set allowing the helicopter to be lowered and raised as a unit to accommodate the restricted confines of a smaller transport.

A.4.4.1 Landing subsystem

A.4.4.1.1 Landing gear.

Analysis and tests shall be performed on the landing gear subsystem to insure structural integrity, endurance, and performance conditions are met.

VERIFICATION RATIONALE (4.4.1.1)

A landing gear design analysis may be accomplished to show that all operational requirements and conditions are adequately addressed for the air vehicle. Taxi, takeoff and landing tests are accomplished to ensure all operational performance is satisfactory to the user.

The purpose of landing gear tests is to demonstrate the landing gear meets the specified performance and interface requirements, such as specified extend and retract times, normal and crash loads, low observables, and compatibility with flotation and skis (if applicable).

VERIFICATION GUIDANCE (4.4.1.1)

The landing gear design analysis shows how the various landing gear subsystems work to accomplish the required action to assure the air vehicle operates satisfactorily while on the ground and in transition to and from the air. Flight testing and field-testing should be accomplished by the airframer and the eventual user to evaluate the landing gear subsystem suitability for the requested operational mission.

Typical measurements for landing gear include energy absorption, absorption capacity, and dynamic load characteristics of the landing gear. Landing gear subsystem qualification tests include drop testing, low- and high-speed testing, braking and brake lock testing, floatation testing, ski testing, retraction and extension testing.

VERIFICATION LESSONS LEARNED (4.4.1.1)

During air vehicle checkouts and flight testing many designs inconsistencies and design faults are discovered and corrected before the air vehicle goes into service.

A.3.4.1.1.1 Gear arrangement.

The landing gear for conventional air vehicles shall be arranged so that the airframe structure will not contact the ground during a ground turn producing __(TBS 1)__ lateral acceleration at the most critical operational center of gravity configuration.

The landing gear for Vertical Takeoff and Landing (VTOL) and rotary wing air vehicles shall also be arranged to prevent overturn during ground run-up of engines and during landing under the following conditions __(TBS 2)__.

REQUIREMENT RATIONALE (3.4.1.1.1)

Lateral stability of the air vehicle during ground operation is a primary factor in positioning of the landing gear. This requirement is necessary to insure acceptable ground operating characteristics to counter the natural tendency to use a narrow tread landing gear to minimize weight. Improvement of lateral stability characteristics after assembly of the air vehicle is very difficult and expensive.

REQUIREMENT GUIDANCE (3.4.1.1.1)

TBS 1 should be completed by analysis of ground handling requirements of the proposed air vehicle. A possible approach is to accomplish a dynamic analysis of similar existing air vehicle to determine lateral acceleration required for overturning. Operational experience can then be applied to determine suitability of this limit.

TBS 2 should be filled in with consideration given to the following:

It may be necessary to expand this requirement to adequately define overturn stability for VTOL air vehicles. Side load during landing of VTOL air vehicles may exceed that normally encountered during ground turns. Ground run-up of helicopters may also present an overturn stability problem. It is suggested the following words be used: "________". The blank should contain the most adverse condition(s) anticipated for normal operation.

Performance Parameters: The dominant parameters on this requirement are physical arrangement of the landing gear air vehicle, center of gravity location and strut-tire dynamic characteristics.

Background and Source of Criteria: The concept for this requirement comes from AFSC DH 2-1, and is described as turnover angle. Rather than identify a limit on turnover angle, the requirement is expressed in air vehicle performance. The 63° turnover angle limit in AFSC DH 2-1 was established to provide approximately a 0.5g side loads turning capability. This requirement was originated in 1950 or earlier. It should be noted that meeting the 63° limit does not assure a 0.5g turn capability due to shock strut and tire deflection.

REQUIREMENT LESSONS LEARNED (3.4.1.1.1)

Generally, the criteria applied at 0.5g side load are conservative. It is possible that this can be further studied and general criteria could be generated for each type or class of air vehicle. The combination of speed and turning radius, which approaches the limits on safe operation, should probably drive this requirement. Safety and operating restraints should become the driving force.

Air vehicle turning capability may be degraded by increased gross weight. Consideration should be given to growth potential during design of a new air vehicle.

This requirement should be examined during design of growth versions of existing air vehicles to determine if landing gear changes are required to maintain adequate turning capability.

A.4.4.1.1.1 Gear arrangement.

Air vehicle stability during turns shall be evaluated by a ground handling analysis substantiated by air vehicle taxi test as follows: __(TBS)__.

VERIFICATION RATIONALE (4.4.1.1.1)

An analysis supported by limited taxi data, permits exploration of the operational envelope without incurring risk of tip over and subsequent air vehicle damage. Since the criteria are based on maximum usage expectation, the results of the analysis will be used to provide operational limitations. That is, the limits on turning velocities, turning radius for various gross weights and configuration can be logically established.

VERIFICATION GUIDANCE (4.4.1.1.1)

TBS: The analysis should show the air vehicle tracking profiles for maximum steering angles and show that the air vehicle will not turnover or tip up during a turn at the maximum specified speeds over any given achievable turn radius. Taxi testing and flight test should verify the performance of the air vehicle over all the operational spectrum.

VERIFICATION LESSONS LEARNED (4.4.1.1.1)

Measured field data showed that for most operational high speed turns are at .2 g's or less. With the F-111 have some maximum turns at .25 g's. However the .5 g requirement (63° turnover) will often keep the air vehicle from catching a wing tip during a lateral skid that often occurs in a ground looping incident.

An additional 600 lbs of metal had to be added to the gear structure on the B-1 to get the struts far enough apart to meet this requirement. This was levied on the landing gear because the location of the wheel wells was established by the airframe structure design without consideration given this requirement.

A.3.4.1.1.2 Pitch stability.

The landing gears shall be arranged to provide pitch stability such that safe air vehicle ground control is maintained and no part of the air vehicle, other than the landing gear, contacts the ground under the following conditions: __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.1.2)

The most aft center of gravity should be far enough forward of the centroid of the main gear ground contact area that the air vehicle is stable statically and will not tip back on the tail.

REQUIREMENT GUIDANCE (3.4.1.1.2)

TBS in the requirement blank should take into account air vehicle center of gravity location, fore and aft pitch characteristics, aerodynamic tail power during takeoff rotation, strut-tire dynamic characteristics, and aft fuselage design such that tip back or ground contact is precluded.

This requirement includes conditions during engine run-up and during cargo handling fuel transfer. In the event the air vehicle design permits center of gravity excursions which preclude meeting this criteria, provisions should be provided to protect the air vehicle from damage due to uncontrolled ground contact. This is particularly pertinent with air vehicle utilizing variable sweep wing geometry during engine run-up. Ground contact is also a possibility due to landing or rotation for takeoff.

This requirement is a clarified statement of the arbitrary criteria for tip back previously described in AFSC DH 2-1. In that criteria the main wheel location was limited in a forward direction to a position where the angle between the most aft center of gravity, main wheel contact, and the vertical should be at least as large as the maximum tail down landing contact angle, limited by fully extended wheel contact and the tail bumper or aft fuselage. The intent was to try to insure that the air vehicle would rotate to a three point attitude upon contact with the ground. It was arbitrary criteria satisfied by geometric analysis.

REQUIREMENT LESSONS LEARNED (3.4.1.1.2)

Since the F-111 was the first production variable sweep wing air vehicle, the problems with pitch stability (tip back) were quite critical. Ground handling was most critical for the F-111B, aboard ship.

A classic example of critical center of gravity location was the C-54, which required a ground handling strut.

As a conservative rule of thumb, consider placing the main gear so that an angle between a line joining the center of gravity and the center of main gear contact with a vertical line through this contact is 15° with a most aft center of gravity configuration.

The B-1A experienced a tip back occurrence during an engine run-up with a faulty fuel transfer occurring at the same time causing damage to the tail cone.

A.4.4.1.1.2 Pitch stability.

Pitch stability shall be verified by (TBS 1) for the following conditions: (TBS 2) .

VERIFICATION RATIONALE (4.4.1.1.2)

Analysis of this condition can most economically be used to verify fore and aft stability. In the event the performance is marginal, the analysis can be supplemented by a demonstration of a critical condition on the air vehicle to increase the credibility and acceptability of the analysis.

VERIFICATION GUIDANCE (4.4.1.1.2)

TBS 1: A static center of gravity force moment analysis should be done to determine air vehicle ground stability during ground maneuvers, engine run-ups, towing, and jacking.

TBS 2: A dynamic performance analysis should cover all rotational conditions to ensure there is no gear dynamics that will cause over-rotation. The information used in these analysis should be supported by laboratory testing and verified by subsequent flight testing.

VERIFICATION LESSONS LEARNED (4.4.1.1.2)

(TBD)

A.3.4.1.1.3 Extended clearances.

Clearances shall be provided so that with the landing gear down and locked, and during any phase of the air vehicle ground operation, there is no contact between the landing gear and any other part of the air vehicle that results in degradation of life or performance of any air vehicle component. This requirement applies with the following conditions and restrictions: __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.1.3)

Experience has shown that failure to provide adequate clearance between movable parts of the landing gear and the fixed structure (including stores) will result in operational problems. Design of the air vehicles for minimum weight and frontal area encourages use of minimum clearance. While this may be adequate for operation of new equipment under ideal conditions, it may not be sufficient for operation of a worn system. This requirement is needed to force consideration of this problem.

REQUIREMENT GUIDANCE (3.4.1.1.3)

TBS should reflect sufficient air vehicle clearances that are influenced and controlled by tire growth characteristics, strut physical dimensions, strut-servicing limits tire production dimensional tolerances, gear structural deflections, and gear kinematics.

This requirement is intended to replace the clearance statements and diagrams of AFSC DH 2-1, AFSC DH 1-6, and MIL-STD-878. It is intended to expand to cover incorrectly-serviced hardware and the full range of dimensional tolerances.

REQUIREMENT LESSONS LEARNED (3.4.1.1.3)

In past designs, it has been determined that it is good design practice to leave clearance between the wheel, brake, and tire assemblies and the support structure or fairings. It was found that it is best to leave clearances, particularly around the tire, to accommodate growth, maximum production tolerances, and centrifugal forces for rotating tires. Special consideration should be given to installations utilizing a fork. Prime examples are the F-4 and F-105. Many aircraft have little or minimum clearance for the landing gear. Prime examples are B-52, F-111, F-15, EF-111 and other high-density aircraft.

A.4.4.1.1.3 Extended clearances.

Clearance between the landing gear and other air vehicle components shall be verified by (TBS)__.

VERIFICATION RATIONALE (4.4.1.1.3)

The method of verification will depend on the program. If a landing gear simulator is available, it may be suitable for verification of clearances. Measurement on the air vehicle will usually be required to verify the values used in the analysis

VERIFICATION GUIDANCE (4.4.1.1.3)

TBS should be filled as follows: Clearances between the landing gear and all other air vehicles structure and components should be verified by analysis based on clearances measured on the air vehicle and adjusted for tolerances, deflections, and wear. Ground clearance after tire failure and strut deflation should be determined by analysis. The analysis should include deflection and dynamic effects for the landing gear and airframe, and where applicable, account for traversing arresting cables. Clearances during arrestment should be demonstrated by air vehicle operation.

VERIFICATION LESSONS LEARNED (4.4.1.1.3)

The use of landing gear simulators on many systems have proved useful in establishing clearances for new and worn gear systems, and allowed fixes to be tested and verified before being applied on the air vehicle. However, simulators are expensive especially for large air vehicles and should be justified for verification of other performance requirements, not only this requirement.

A.3.4.1.1.4 Retraction clearances.

Clearances shall be provided on retractable landing gears so that with the landing gear in the retracted position and during any transition between the extended and retracted positions, there is no contact between the landing gear and any other part of the air vehicle, including landing gear fairing doors, that results in degradation of life or performance of any air vehicle component. This requirement applies with the following conditions or restrictions: __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.1.4)

This is to insure no interference between the landing gear components and the stationary structure or adjacent wheel well equipment.

REQUIREMENT GUIDANCE (3.4.1.1.4)

TBS should reflect the speed, temperature, altitude, operating condition of tires (stationary or rotating), air vehicle speed, operating mode of the air vehicle (takeoff, touch and go), and air vehicle altitude. It should consider malfunctions such as a flat strut.

Requirement influenced and controlled by gear kinematics, component dimensional tolerances, design of surrounding structure, gear gyroscopic loads and direction of reaction, and air loads.

There are numerous conditions that potentially cause interference. It is a new requirement and is not generally found in previous documentation.

Tire growth dimensions should be per the guidance of the Tire and Rim Association.

REQUIREMENT LESSONS LEARNED (3.4.1.1.4)

Gear interference while in transit between fully extended and fully retracted, and vice versa, can be attributed to numerous factors: oversize components, rotating parts, wear, kinematic stability, and design clearances. The most uncontrollable and potentially the most dangerous is a combination of rotating parts and structural stability in transit caused by gyroscopic loads. The YF-16 is the most recent example.

Part wear or improper servicing can place the gear in the improper position upon entering the wheel well. The F-15 is a recent example that required aircraft modification.

The C-5A aircraft has experienced clearance problems during inflight rotation and retraction of the main landing gear strut. These problems were a result of the rolling of the strut during rotation. Mechanical roll positions would not stop the roll moment caused by the side wind loads.

A thorough evaluation on the landing gear simulator can help prevent these incidents.

A.4.4.1.1.4 Retraction clearances.

Clearances between the landing gear and other air vehicle components shall be verified by (TBS) .

VERIFICATION RATIONALE (4.4.1.1.4)

If a simulator is provided (strongly recommended), it may be suitable for verification of clearances. Verification on the air vehicle will usually be required.

VERIFICATION GUIDANCE (4.4.1.1.4)

TBS is usually filled with analysis, with parameters verified by air vehicle measurements, followed with air vehicle demonstration during checkout and flight-testing.

VERIFICATION LESSONS LEARNED (4.4.1.1.4)

The justification of landing gear simulators on new programs has always been difficult due to program constraints. However, simulators have always proven themselves by uncovering many component and system problems and deficiencies before they happen in operation. It also provides a test bed to verify redesigns, fixes, troubleshooting procedures, system control logic, endurance, service life, checkout, and T.O. procedures.

A.3.4.1.1.5 Anti-rotation in retracted position.

(TBS) wheels shall be stopped from rotating during retraction or prevented from rotating in the retracted position.

REQUIREMENT RATIONALE (3.4.1.1.5)

This requirement is to identify the need to stop rotation of wheels after landing gear retraction. Wheel rotation may adversely affect air vehicle operation or cause pilot discomfort. Stopping rotation also minimizes air vehicle damage if the landing gear is retracted with a tire that has a loose tread.

REQUIREMENT GUIDANCE (3.4.1.1.5)

TBS should be filled in with “All” or “Main”. Normally, all wheels should be stopped. In some cases it may be cost-effective to stop only the main wheels.

Rotating mass and radius of gyration of the wheel, brake, and tire assembly are important parameters in assessing this requirement. Gear kinematics and retraction rates have an influence on the gyroscopic loads. Wheel well clearances are impacted by tire sizes and dimensional tolerances.

REQUIREMENT LESSONS LEARNED (3.4.1.1.5)

This requirement reflects the statement made in AFSC DH 2-1. It was originally included in ARDCM 80-1 (Handbook of Information for Aircraft Designers [HIAD]) as a result of fleet retrofit of the C-133 from trouble generated from free-rotating design.

In addition to the C-133, several other air vehicles have had to provide nose gear snubbers on a retrofit basis. As mentioned in the rationale, hazards of rotating nose wheels include: excessive vibration, electronic interference, and stones thrown from the rotating tire treads. The design solutions have ranged from fuselage mounted snubbers to simple cantilevered devices mounted on the doors. There have generally been no detrimental effects on the tires. It is recommended the rubbing be accomplished against the tires rather than against the wheel, which can suffer defacing damage.

Main gear snubbing is usually achieved by pre-braking associated with gear-up selection. This reduces or eliminates the gyroscopic loads. Generally, the pressure is relieved with the gear in the stowed position to preclude extension and touchdown with brake pressure applied.

A.4.4.1.1.5 Anti-rotation in retracted position.

Demonstration that the wheels do not rotate in the retracted position shall be shown by (TBS).

VERIFICATION RATIONALE (4.4.1.1.5)

If snubbing of all or some of the wheels is required. The effectiveness of the proposed snubber is best demonstrated with actual hardware. A landing gear simulator is a convenient device for this purpose, however, it is usually evaluated on the air vehicle. On the main gear, it is important to evaluate the sequence and timing between brake pressure application and cessation of wheel rotation.

VERIFICATION GUIDANCE (4.4.1.1.5)

The TBS should reflect a demonstration that the rotating wheel is stopped before fully retracted for braked wheels, or stopped when fully retracted for non braked wheels. Retraction should be commanded with the wheel rotating at a speed not less than 75 percent (75%) of the liftoff speed at maximum gross weight.

VERIFICATION LESSONS LEARNED (4.4.1.1.5)

(TBD)

A.3.4.1.1.6 Clearance with flat tire and flat strut.

In the event of flat tire and flat strut, the lowest part of the landing gear structure, door fairing, or air vehicle components, including external stores shall not be closer than ___(TBS)___ from ground.

REQUIREMENT RATIONALE (3.4.1.1.6)

The objective is to provide a clearance requirement to insure that no part of the air vehicle will engage the barrier cable installation when landing under the most adverse sequence of landing gear failures. By combining tire and strut failures, it will also insure that neither single failure will cause inadvertent engagement. The recommended ground clearance limit is six inches for safety considerations.

REQUIREMENT GUIDANCE (3.4.1.1.6)

TBS should reflect the minimum acceptable distance from the ground and or arresting cable installation to the lowest points on the air vehicle for all phases of its ground operation on through rotation. For this requirement, the wheel, brake and tire are not considered a part of the landing gear structure. It is also assumed that the wheel and tire are intact and that the rolling radius is the flat tire radius.

Air vehicle geometry, wheel, brake, tire sizing, and landing gear configurations are the controlling parameters in meeting this requirement.

REQUIREMENT LESSONS LEARNED (3.4.1.1.6)

This is an expansion of the existing requirement of AFSC DH 2-1 to include lessons learned on recent air vehicle accidents.

With the extensive use of arresting systems within the Air Force, most runways are equipped with arrestment cables at the ends of runways. Some runways also have midpoint barrier installations. Therefore, it is very important to not have a rigid member of the air vehicle extending low enough to engage the barrier cable in the event of a flat tire or a flat strut. The YF-16 was designed with a gear member extending low enough to engage the cable with a flat tire. This resulted in significant damage. Six-inch ground clearance under these circumstances should be a target for design.

A.4.4.1.1.6 Clearance with flat tire and flat strut.

Ground clearance after tire failure and strut deflation shall be determined by analysis.

VERIFICATION RATIONALE (4.4.1.1.6)

An analysis is the most economic approach to evaluating ground clearances for all the potential air vehicle configurations. An analysis would be required to determine the critical combinations if a test were selected for demonstration.

VERIFICATION GUIDANCE (4.4.1.1.6)

The analysis should take into account the ground clearance after a tire failure or strut deflation. The analysis should include deflection and dynamic effects for the landing gear and airframe, and where applicable, for the arresting cable.

VERIFICATION LESSONS LEARNED (4.4.1.1.6)

(TBD)

A.3.4.1.1.7 Gear stability.

Landing gear shall have natural or augmented damping so that the amplitude of any landing gear oscillations after __(TBS 1)__ cycles is reduced to __(TBS 2)__ or less of the original disturbance, with the following exceptions: __(TBS 3)__. The damping requirement applies to all initial displacements of the landing gear under the following conditions: __(TBS 4)__.

REQUIREMENT RATIONALE (3.4.1.1.7)

This requirement is necessary to establish an acceptable level of dynamic stability. The primary concern is the damping of steered landing gear to prevent shimmy. The same criteria also may be applied to other landing gear oscillations induced by air field roughness or brake system operation.

REQUIREMENT GUIDANCE (3.4.1.1.7)

TBS 1 and TBS 2 should be completed by requiring the amplitude be reduced to 1/3 of the original amplitude within three cycles. This has been recognized as standard by the airframe industry for damping of steered landing gear. Suitability for other oscillations has not been verified.

TBS 3 should permit some types of oscillation to be excluded from the general damping criteria. Examples include brake chatter and squeal and bogie beam pitching. The blank should include success criteria for each item excluded from the general requirement.

TBS 4 should be used to establish the range of operating conditions to be considered in application of the damping criteria. This should include air vehicle speed and weight conditions, type of airfield surface, and wear surfaces worn to the operational limit.

Gear damping characteristics are controlled by tire dynamics characteristics, landing gear component stiffnesses and damping characteristics, individually and "as installed." If friction damping is utilized, wear of the friction surfaces should be assumed and accounted for in the design. Air vehicle ground speed range defines the range of concern.

The landing gears (main and nose) should be free of detrimental oscillations induced by runway roughness, tire balance or design, brake vibrations or gear natural responses. The oscillations include fore and aft, torsional and vertical modes.

REQUIREMENT LESSONS LEARNED (3.4.1.1.7)

This is a tailorable statement for shimmy damping and other vibration, patterned after the requirement of MIL-S-8812. This requirement has been improperly placed in the Steering System design specification for years. It is a general landing gear requirement, steered and non-steered. It was improperly placed in the steering system specification because the nose gear shimmy damping is most frequently controlled by modification to steering system components and most shimmy occurs on the nose gear. Originally, the criteria was generated as a result of Dr. W. J. Moreland's study of shimmy and published in WADC TN 55-1 in 1955, and Journal of Aeronautical Sciences, Vol. 21, No. 12, Sec. 54. This was further expanded and studied by J. Edman of Bendix under contract to WADC and the results were published in WADC TR 56-197, dated July 1956.

Shimmy and various forms of gear vibration have historically been a serious landing gear problem. Nose gear shimmy has been a problem on the A-37, T-38, F-5, F-104, F-15, C-141A, and numerous other air vehicles. Solution of the problems include change of tires, balancing tires, adding friction dampers, changing hydraulic dampers, improving maintenance and servicing procedures, and changing materials.

There is industry evidence that main gear shimmy is most likely on dual wheel installations. A couple of commercial air vehicles have encountered such a problem. The solutions have been to add additional damping to the system.

Prevention of bogie pitch is generally a design problem of multiple axle (4 wheel and 6 wheel bogies), and by proper analysis and design, the problem is avoided.

Brake chatter and squeal are landing gear vibration phenomena, but the damping criteria proposed may not necessarily apply. The source of the vibration is the brake assembly. Therefore, system response and compatibility is a function of design of that component. See "Aircraft Landing Gear Brake Squeal and Strut Chatter, Investigation" by F. A. Biehl, The Shock and Vibration Bulletin, January 1969, for an explanation of the phenomenon and a method of analysis.

A.4.4.1.1.7 Gear stability.

Landing gear subsystem damping shall be verified analytically and substantiated by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.1.7)

Various component design parameters used in the shimmy analysis are estimated or calculated because the review is accomplished before the hardware is delivered on a development program. Therefore, it is necessary to verify the assumptions or calculations by system and component tests. Then the system response is verified by the ground vibration test of the installed gear. Frequently, the results are different from that which was estimated and the analysis should be modified accordingly to establish safety for first actual air vehicle operation. The blank should be filled with the minimum acceptable program to substantiate the stability analysis.

VERIFICATION GUIDANCE (4.4.1.1.7)

TBS: The vertical, fore and aft, and torsional damping should be verified by analysis. The parameter used in the analysis should be supported by test measurements of actual hardware and sir vehicle stiffness data.

VERIFICATION LESSONS LEARNED (4.4.1.1.7)

Many dynamic analysis are dependent on accurate determination of the landing gear and backup structure stiffness data, which is not always easy to obtain. Often ground vibration test results (GVT) are used to support the analysis. It is prudent to have an agreed to list of parameters and how they are measured or determined prior to the conduct of the analysis.

A.3.4.1.1.8 Alignment.

The landing gear shall be aligned relative to the airframe to minimize degradation of the tire, wheel, or brake life, resulting from misalignment throughout the life of the air vehicle.

REQUIREMENT RATIONALE (3.4.1.1.8)

This requirement is presented to reflect the desired performance.

REQUIREMENT GUIDANCE (3.4.1.1.8)

Gear design and material selection of the wearing elements are the parameters which control or influence the ability to meet this requirement. In particular the camber and caster of the gear should be such as to minimize the yaw and toe-in/toe-out of the wheel and tire assembly.

The geometry of the gear should not allow tire rollover or scuffing.

REQUIREMENT LESSONS LEARNED (3.4.1.1.8)

There have been cases where the gear design and installation practices allowed excessive misalignment on new gears as well as where the material selection allowed excessive wear, allowing excessive misalignment. Both resulted in a degradation in expected tire and wheel life.

Investigations into premature wheel failure and tire wear on both the F-15 and A-10 air vehicles indicated that the failures or excessive wear were due to improper gear alignment.

Provision of a 360° free swiveling capability best minimizes excessive wear due to tailwheel misalignment.

A.4.4.1.1.8 Alignment.

Landing gear alignment shall be determined analytically and substantiated by inspection.

VERIFICATION RATIONALE (4.4.1.1.8)

Reviews of design drawings and continual monitoring of the development are adequate to determine compliance with this requirement.

VERIFICATION GUIDANCE (4.4.1.1.8)

Throughout the design phase the gear alignment should be monitored through inspection of drawing and the production of the gear and airframe. The tire wear and wheel loads should be monitored during flight-testing and into initial field demonstration.

VERIFICATION LESSONS LEARNED (4.4.1.1.8)

(TBD)

A.3.4.1.1.9 Growth.

The landing gear structural arrangement and critical fuselage clearances shall permit a __(TBS) growth in the maximum takeoff weight without major airframe modifications or gear geometry changes.

REQUIREMENT RATIONALE (3.4.1.1.9)

Over the lifetime of most air vehicles, the maximum takeoff gross weight has significantly increased from the original design. To prevent major modifications to airframe, the wheel well should have sufficient volume (clearance) to install a stronger gear, wheel and brake, and tires.

REQUIREMENT GUIDANCE (3.4.1.1.9)

Consider strength criteria, gross weight, clearances, volume, gear location and design aspects, static and fatigue, and pin and lug sizing strut wall thicknesses.

TBS: As a minimum, allow for at least 25 percent (25%) growth in maximum takeoff gross weight.

There is a history of air vehicle development and difficulties in redesigning wheel well to accommodate larger gears.

REQUIREMENT LESSONS LEARNED (3.4.1.1.9)

The F-15, F-16, and B-1 had gear redesigns to larger size or load capability to accommodate air vehicle gross weight increases of 77 percent (77%), 78 percent (78%), and 32 percent (32%), respectively, from their original designs.

A.4.4.1.1.9 Growth.

Analysis shall be performed to determine maximum air vehicle growth capability as determined by the clearances and volume available within existing wheel well envelopes, the results of which shall be supported by inspection.

VERIFICATION RATIONALE (4.4.1.1.9)

An analysis of all critical growth loads, at all critical areas where interference with airframe structures may result, is required. The analysis should show that the dimensional growth of the landing gear structure will not exceed the established clearances. Inspection should be performed on the air vehicle to ensure the clearances used in the analysis are maintained.

VERIFICATION GUIDANCE (4.4.1.1.9)

The analysis should look into the volume and clearance between the gear and wheel well structure, as well with other gear components are such that the wall, pins, lugs and any other structural member may be increased such as to support the required increase in air vehicle gross weight. The analysis should include consideration for rework of joints and pins.

VERIFICATION LESSONS LEARNED (4.4.1.1.9)

During the design and verification phase the analysis and requirement is often deleted or ignored. This is due to pressures to achieve lower air vehicle weight and lower cost, which are in direct conflict with this requirement. Remember that history and air vehicle data shows that every production air vehicle has grown in weight after it has gone into service. This data may have to be presented to program management in order to maintain this requirement in contractual documents.

With existing computer analysis and Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) capabilities this can be readily accomplished with a good degree of confidence.

A.3.4.1.1.10 Service life.

With the stated exceptions, the service life shall be __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.1.10)

Design life of the landing gear subsystem is a significant driver of life cycle costs. This requirement is necessary to establish a minimum acceptable service life for design. This is to insure minimum cost, but acceptable utility of the completed system.

Consumable portions of the landing gear subsystem should be defined due to direct impacts to the logistics cost and support of the equipment. There are numerous design techniques and materials available that meet the design conditions that provide varying lengths of service life. Therefore, the objective of this requirement is to express the logistic needs of the system in a manner, which will influence the design, and material selected to produce the desired life.

REQUIREMENT GUIDANCE (3.4.1.1.10)

TBS should be filled in with:

a. Landing gear structure: TBS should be stated in terms of the minimum acceptable number of landings or years of service. The anticipated utilization of the system should be defined. It may also be desirable to reference or define the logistics support plan for the major landing gear components. The number selected for this requirement will usually be the same as used for the basic airframe service life.

b. If tires are used: TBS should be filled in with a service life, due to tread wear only based on a reference to Tire design load-speed-time figure for the air vehicle application, showing the number of air vehicle cycles required for a given tire diameter and speed rating range. This should apply during operation of the air vehicle during which the life requirement is to be applied.

c. If wheels are used: TBS should reflect an accelerated life performance of a specified number of miles at a specified overload. This allows a reasonable test program and produces a limited life wheel. The number selected is a function of the type of air vehicle on which it will be installed and the overall logistic plan.

d. If brakes are used: TBS should state how many landings that the heat sink material is capable of sustaining without replacement, the life capability of the structural member of the brake assembly, and a definition of the operational spectrum that the brake assembly will see in service. See section 6, “Component information,” for brake information.

e. If an arresting hook is used: TBS should state the required number of engagements the hook system will take before replacement as well as list the components that can be replaced sooner such as “ground contact” items.

f. If a drag chute is used: TBS should state that the life of the drag chute in number of deployments, how often it should be replaced, and the environmental operating conditions.

REQUIREMENT LESSONS LEARNED (3.4.1.1.10)

If damage tolerant criteria is used exclusively, it would eliminate the use of material such as 300M steel which does not have an inspectable flaw size used to verify the two-lifetime capability with a flaw. Therefore, if this type of material is to be allowed it will be necessary to maintain the four fatigue life requirements as dictated by Miner's rule that has successfully been used on B-1, F-16, F-15, and many other aicraft.

Service life of various landing gear components is a function related to various modes of failure. The primary modes and causes of failure include structural, corrosion, overload in performance, wear, inadequate design, erratic performance and abuse.

There are numerous examples of fatigue failures due to stress concentrations due to inadequate design. Emphasis should be placed on design details to avoid high KT. Fatigue failures have occurred on virtually every landing gear in the inventory, including B-52, B-66, KC-135, C-130, C-141, Century Series fighters, F-4, F-111, all trainers, and the A-37. Careful attention should be paid to lug areas and holes.

Choice of material for the application also has a significant influence on the success of the application. Selection of the wrong alloy and improper protection system can produce corrosion and stress corrosion failures. Stress corrosion failures of landing gear components has been particularly prevalent. Examples include B-52, KC-135, C-141, Century Series fighters, and F-4. Most of these failures were with aluminum parts heat-treated to the T6 temper. The alloys which were most susceptible were 7075 and 7079. A large portion of these failures occurred in components that had high-sustained stresses, such as outer cylinders which were pressurized. Stress corrosion failures with these alloys were not as prevalent when used as beam members in axial loading.

Many landing gear structural failures occur in overstressed parts. Examples of landing gears with overstress failures include virtually every air vehicle in the inventory. This appears be a very difficult deficiency to avoid. This may result from design errors or from subjecting the hardware to conditions not considered by the original design. Common design errors include failure to consider dynamic loading and secondary loading due to deflection of the landing gear or mounting structure. Any change in air vehicle operational needs during development should be reviewed for structural implications to avoid designed in deficiencies.

Numerous landing gear failures have been initiated by inadequate process and manufacturing control. Prime examples are the F-101 pin failures stemming from damage due to grinding of the chrome plating.

Frequently, major components are lost from the inventory due to insufficient material to permit rework dictated by corrosion or wear. This consideration and allowance should be included in the initial design. This consideration is best illustrated by the commercial landing gears for airline usage. The material for rework is mandatory for airline usage and should be seriously weighed for evaluation of Air Force applications. Only in cases of extreme weight criticality should this be waived.

Use of hard thermoplastic material in the construction of tubing clamps may result in chafing damage when dirt or sand enters the voids between the tube and clamp. Recommend the use of elastomeric material or other soft rubbery material in the construction of the clamp.

A.4.4.1.1.10 Service life.

Service life shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.1.10)

It is intended to verify this requirement in a manner consistent with the remainder of the structural verification program. Utilization of laboratory, flight tests, and service tests covers the total usage spectrum.

VERIFICATION GUIDANCE (4.4.1.1.10)

TBS should list the particular test and analysis for each individual consideration, since there will be different types of tests for landing gear structures, tires, wheels, brakes, drag chutes, and arresting hooks.

VERIFICATION LESSONS LEARNED (4.4.1.1.10)

Rarely is the spectrum developed and used in analysis and testing of the gear the one experienced in the field. The efforts in the integrity program is to provide recording and algorithms capabilities to obtain actual loading of the fleet air vehicles, combine this data in an analytical program to determine useful life remaining and overhaul criteria.

A.3.4.1.2 Ground operation

A.4.4.1.2 Ground operation

A.3.4.1.2.1 Ground flotation.

The landing gear shall have ground flotation capability to permit the air vehicle __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.2.1)

The purpose of this requirement is to insure that the load that the air vehicle applies to the airfield is compatible with the bearing strength of the airfield surface. Details of the requirement are very dependent upon the air vehicle mission and basing concepts. The primary consideration for a large cargo air vehicle, for example, might be to insure ability to operate on existing commercial jet air vehicle airfields without causing an unacceptable rate of pavement deterioration. Tactical cargo and fighter air vehicles, on the other hand, may need to be designed to perform a specified mission on an unpaved airfield.

REQUIREMENT GUIDANCE (3.4.1.2.1)

In many cases, this airfield compatibility is a primary system characteristic and is addressed in detail in the System Specification. If this is the case, reference to the System Specification will be sufficient. Some system documents, however, fail to define the requirement in adequate engineering terms. If this is the case, this requirement should be expanded to include the significant engineering parameters. The exact wording should be tailored for each system using the following parameters.

TBS should clearly state the user's mission requirements for the type of airfields he wants to operate on and should reflect the number of times he expects to perform these missions. The tire pressure should not exceed 300 PSI and the tire footprint area should be a minimum of 50 square inches for operation on bituminous surfaces.

The following should be considered in determining flotation equipment:

a. Air vehicle Gross Weight Condition
b. Air vehicle Center of Gravity Position
c. Type of Airfield Surface (Paved or Unpaved)
d. Strength of Airfield Surface
e. Level of Operation (Frequency or Total Number)
f. Tire Operating Limits.

It should be understood that flotation requirements are usually in conflict with brake sizing, wheel well volume, and location, and often affect the plane form shape of the air vehicle, as well as the number of tires and tire pressures used. This is a result of obtaining the largest tire profile at the lowest possible pressure with the biggest wheel spacing (on multiple wheel configurations) which force the air vehicle to give a large space to store the gear in during flight.

REQUIREMENT LESSONS LEARNED (3.4.1.2.1)

Flotation criteria were previously identified in AFSC DH 2-1.

Air Vehicle Conditions: In the case of paved airfields, it is usually best to specify the maximum gross weight that will be used for ground operation. Center of gravity position may not be too critical for paved airfields, however, specification as nominal, average or most critical makes the requirement more exact. The gross weight and center of gravity specified for unpaved airfield operation will usually be specified in terms of a specific mission condition. A specific weight should not be specified.

a. Type of Airfield Surface. The requirement should at least specify a paved or unpaved surface. Paved is considered to include rigid concrete surfaces, flexible asphalt surface and combination rigid and flexible surfaces. Unpaved means bare soil without vegetation with soil of any combination of sand, silt, or clay. Specification of landing mat or membrane surfaced airfields is not recommended. Experience has indicated that performance of these surfaces to applied loads is highly variable and difficult to predict. Also the type of surface in use at the time the air vehicle becomes operational may be much different than that in use at air vehicle conception. Landing mat and membrane development cycles are not keyed to air vehicle development.

b. Strength of Airfield Surface.

1. Paved Airfields - Possible approaches to this parameter include the following:

(a) Provide a list of the airfields to be used. This will require that a pavement evaluation report for each airfield be provided to the contractor. This is the most exact method, but may be difficult to accomplish due to lack of pavement evaluation data.

(b) Analyze the pavement evaluation reports of airfields to be used and develop a single chart to summarize most critical pavement characteristics. This has the same disadvantage as “a” but has an advantage in that it avoids the necessity for the Air Force to identify positively the final list of airfields to be used.

(c) Analyze an existing operational air vehicle and develop a rigid pavement and a flexible pavement requirements chart for operation at a condition comparable to the new air vehicle requirement. See “Aircraft Landing Gear Brake Squeal and Strut Chatter, Investigation” by F. A. Biehl, The Shock and Vibration Bulletin, January 1969, for an explanation of the phenomenon and a method of analysis to develop the chart. This approach has been used successfully. Although less exact, it permits establishment of a requirement without knowledge or examination of the exact airfields to be used.

(d) Specify that the airfields to be used are light, medium, or heavy load airfields as specified by AFM 88-6. The manual, in turn, then provides details of the pavement construction. A fallacy in this approach is that it assumes that all of the airfields will comply with AFM 88-6 criteria. In fact, very few military airfields comply entirely. Commercial and foreign airfields are constructed to different criteria.

(e) Specify the minimum Load Classification Number (LCN) of airfields to be used. The LCN method is an index approach used in many foreign countries to match air vehicle loading to airfield strength. Administrative limits prohibiting operation of air vehicle with LCN exceeding the airfield LCN are common. If the air vehicle is to be used extensively on airfields under foreign control, the LCN of the airfields to be used should be reviewed and an appropriate LCN specified. A detailed description of LCN can be found in ASCE Transportation Engineering Journal, November 1973, Page 785. The U.S. Army Corps of Engineers does not recognize the LCN approach as a valid method of pavement strength rating. Caution is advised in use of only the LCN approach if the air vehicle is to be operated in both foreign and U.S. military airfields.

(f) It should be noted that high tire pressures (greater than 300 PSI) used on recent air vehicles are inflicting irreversible damage to bituminous taxiways. Initial tire sizing is very important and should allow for future growth without causing pavement damage.

2. Unpaved Airfields:

(a) The strength of unpaved airfields is usually expressed in terms of California Bearing Ratio (CBR). The CBR is defined and measured in accordance with

MIL-STD-621. The U.S. Army Corps of Engineers recommends use of a CBR 4 for design because this is the minimum strength that is suitable for airfield construction. This concept assumes that an area will not be used for air vehicle operation unless it is suitable for operation of airfield construction equipment. Recently, joint Army and Air Force operational analysis has indicated that CBR 6 is a more practical limit to operation. A CBR 9 was used for C-5A and C-17 air vehicle development. This was selected solely on the basis that it appeared to provide the same bearing strength as the landing mat on CBR 4 originally specified. The latter requirement was abandoned because of the inability to predict accurately landing mat performance to repeated landing.

(b) An alternative to specification of CBR is to use a cone penetrometer reading known as Airfield Index (AI). CBR measurement is a tedious process not practical for extensive measurements during air vehicle test on unpaved surfaces. AI measurements can be made rapidly. Consequently, nearly all air vehicle test data is presented in terms of AI rather than CBR. AI and CBR correlation varies from soil to soil. This is because CBR is a measure of confined bearing strength of soil, whereas AI is a measure of bearing strength plus soil cohesion. Presently, flotation technology is in a state of transition from CBR to AI. CBR should be used until a suitable procedure for correlation of ground flotation to AI is published.

c. Level of Operation. The level of operation intended on a selected airfield type and strength is a significant factor. Short time overloads of paved airfields may be necessary or desirable. Specification of unlimited operation for cases that actually involved very limited use, results in extreme weight and cost penalty to the air vehicle. Design levels for normal operation on paved airfields may be selected from those specified in AFM 88-6. The level of operation on unpaved airfields should be determined by analysis of the mission to be performed. An alternative is to determine the estimated capability of an existing air vehicle on the specified unpaved surface and then relate the new air vehicle requirement to the capability of the existing air vehicle.

d. Tire Operating Limits. Frequently, it is desirable to establish a limit on the amount of tire deflection permitted to meet the ground flotation requirement. Most ground flotation analysis methods are very sensitive to tire deflection (under inflation). Theoretically, this provides the required flotation. In practice, it is not achievable because tires will not perform properly or have satisfactory life. A suggested limit is 40 percent (40%) deflection for bias ply tires. This should be adjusted, however, in the case of flotation requirements applied to destination conditions. For example, a cargo air vehicle may of required to deliver cargo to an unpaved airfield. Tire limits should be applied to the original takeoff conditions rather than the destination conditions. Enroute deflation to permit use of low pressure at the destination was applied to the C-5A aircraft. This approach is not recommended because it adds excessive complexity to landing gear and wheels.

A.4.4.1.2.1 Ground flotation.

The flotation capability shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.2.1)

Bases for the procedures are results of US Army Corps of Engineers test of pavement and soil sections. All tests were accomplished at low speeds with ground carts. The failure criteria for paved airfields are surface cracking. The failure criteria for unpaved airfields are three inches or permanent rutting. All tests on unpaved surfaces were accomplished by straight rolling on an unbraked wheel.

Verification of unpaved airfield flotation by demonstration or test is not considered practical. The primary problem is establishment of a safe airfield with uniform strength characteristics at the specified value. Flight test of the air vehicle on an unpaved airfield may be desirable to develop flight handbook procedures, and to qualitatively evaluate system suitability. This test, however, should not be established as a verification method for the stated flotation requirement.

VERIFICATION GUIDANCE (4.4.1.2.1)

TBS should be filled in with analysis using standard acceptable industry method for unprepared, semi-prepared, and prepared runway surfaces. The analysis should reflect the air vehicle mission requirements for the type of operation requested by the user.

VERIFICATION LESSONS LEARNED (4.4.1.2.1)

Analysis using the procedures contained in ASD-TR-70-43 for paved airfields and ASD-TR-68-34 for unpaved airfields or analysis in accordance with the LCN procedure of ASCE Transportation Engineering Journal, November 1973, or analysis from ICAO Airfield Design Manual was previously used.

The rigid pavement procedures of ASD-TR-70-43 evaluate concrete stress at the center of the slab due to a loading at the center of the slab. Air Force Civil Engineering, U.S. Army Corps of Engineers and Federal Aviation Agency rigid pavement design methods evaluate concrete stress at the edge of the slab due to a loading at the edge. This approach results in maximum stress up to 25 percent (25%) greater than the method used by ASD-TR-70-43. This increase is somewhat offset by assumption of level transfer to adjacent concrete slabs. In the event that ground flotation requirements are closely related to design of a specific pavement, it may be best to evaluate the landing gear design by the exact method of the appropriate agency.

It has been often noted that when more than one tire pressure is used to meet the flotation requirement, the user may be reluctant to change the tire pressure for any individual mission. Thus, it is more preferable to meet the requirement with the normal tire pressure.

The C-5 had and on-board inflation and deflation system to meet the flotation requirement, this was subsequently removed due to lack of use and unscheduled maintenance to fix leaks. Thus consider carefully the use of onboard inflation and deflation devices, and ensure they can meet maintenance requirements.

A.3.4.1.2.2 Ground handling

A.4.4.1.2.2 Ground handling

A.3.4.1.2.2.1 Jacking provisions and conditions

A.4.4.1.2.2.1 Jacking provisions and conditions

A.3.4.1.2.2.1.1 Axle jacking.

Axle jacking shall be capable of raising __(TBS 1)__ weight air vehicle high enough to perform required maintenance while exposed to __(TBS 2)__ crosswind from any direction.

REQUIREMENT RATIONALE (3.4.1.2.2.1.1)

This requirement establishes axle-jacking capability.

REQUIREMENT GUIDANCE (3.4.1.2.2.1.1)

TBS 1 should usually reflect the maintenance operations of the air vehicle dictate the need to jack a maximum design gross weight air vehicle.

TBS 2 lists a crosswind limit set at a value which can realistically be expected in service usage and when the user would expect to still be performing maintenance functions requiring jacking. Arbitrarily, this value should be 15 knots to be consistent with structural design criteria. The structural load factors will be defined by the applicable structures criteria document.

Air vehicle gross weight, center of gravity location, strength of the jack pad, and attachment are influences on meeting this operational need.

This requirement is an expansion of MIL-A-8860 criteria to include crosswind limits.

REQUIREMENT LESSONS LEARNED (3.4.1.2.2.1.1)

None.

A.4.4.1.2.2.1.1 Axle jacking.

Jacking capability and provisions shall be evaluated on the air vehicle during the flight test program to the specified limits of the system. Crosswind compatibility shall be verified by analysis.

VERIFICATION RATIONALE (4.4.1.2.2.1.1)

The risk and time associated with exposing valuable test air vehicle to high crosswinds during flight test is too high. Therefore, analysis of crosswind capability is satisfactory. However, it is important to demonstrate the basic axle jacking capability on the air vehicle to evaluate component compatibility and design capability.

VERIFICATION GUIDANCE (4.4.1.2.2.1.1)

Required jacking capability and provisions should be demonstrated on the air vehicle. Jacking should be demonstrated in the wind available, performance under the full wind velocity should be verified by analysis. Jacking demonstration should use an air vehicle configured to the most critical weight and center of gravity location. As a minimum the following demonstrations should be accomplished using only production support equipment: (1) Replacement of the main wheel, tire, and brake with tire inflated; (2) Replacement of nose wheel and tire with nose tire initially deflated; (3) Replacement of main wheel and tire with main tire initially deflated.

VERIFICATION LESSONS LEARNED (4.4.1.2.2.1.1)

If the air vehicle is to be operated in a worldwide environment, then the jacking interface need to meet the international requirements for international support equipment (such as NATO STANDARD AASSEP-1 and STANAG 3098).

A.3.4.1.2.2.1.2 Fuselage jacking.

See JSSG-2006, Structures Joint Services Specification Guide, "Maximum Airframe Jacking Weight" requirement.

A.4.4.1.2.2.1.2 Fuselage jacking

See JSSG-2006, Structures Joint Services Specification Guide, "Maximum Airframe Jacking Weight" verification.

A.3.4.1.2.2.1.3 Landing gear towing.

Interfaces shall be provided on the landing gear for pushing or towing the air vehicle at (TBS 1) gross weight up or down a (TBS 2) slope on a (TBS 3) surface.

REQUIREMENT RATIONALE (3.4.1.2.2.1.3)

This is to ensure the air vehicle and the landing gear subsystem can withstand the loads imparted while towing, and to ensure that the interface between the air vehicle and towing equipment are adequately defined.

REQUIREMENT GUIDANCE (3.4.1.2.2.1.3)

TBS 1 should reflect maximum design gross weight usage. The air vehicle should be able to be pushed or pulled over a required slope should that reflect the expected usage.

TBS 2 should typically be 3°-slope.

TBS 3 should address towing under maximum conditions should probably be limited to dry concrete surfaces, but any special case can be reflected in this requirement. Towing at angles other than straight-ahead is implied by the operational concept of the requirement. Towing provisions should be compatible with STANAG 3278.

Details of the tow bar and tow bar attachment, strength of the landing gears for horizontal loads, runway surface conditions, available coefficient of friction, and angle of load application have influence on meeting the requirements stated above. The detail characteristics of the towing vehicle also impacts meeting the requirement.

This requirement is clarification of criteria, which has been implied in MIL-STD-805 and MIL-A-8862. As stated, it is a new requirement even though a similar requirement has been individually applied to numerous air vehicles.

REQUIREMENT LESSONS LEARNED (3.4.1.2.2.1.3)

Compatibility with the nose gear steering system is a serious consideration. On some gears, towing is permitted to the limits of the powered system, but any additional input can result in damage to the steering system. This interface is very important.

Several gears have been damaged because the towing vehicle exceeded the limit drag force, sheared the safety pin, replaced the pin with a stronger material, then repeated the high drag force pull. Instead of shearing the pin, the excessive load is reacted by the nose gear and structural failure occurs. This recently occurred on the F-5.

Depending on the air base, frequent use of the tow bar is a possibility. Therefore, simple and reliable installation is a clear requirement.

Consideration should be given to the air vehicle brake modulating system to prevent overloading the nose landing gear and air vehicle backup structure when the air vehicle brakes are being used during towing. Of special concern is the use of on and off brake pressure at maximum towing speeds.

A.4.4.1.2.2.1.3 Landing gear towing.

Performance of the towing system shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.2.2.1.3)

Since there is considerable interface with the Aerospace Ground Equipment (AGE) and the air vehicle, this requirement is best verified with all the parts operating as a system on the air vehicle.

VERIFICATION GUIDANCE (4.4.1.2.2.1.3)

TBS: Towing capability should be verified by analysis, inspection of drawings and layouts, and a ground test demonstration with production and international support equipment. The demonstration should start with a stationary air vehicle and as a minimum include at least the following:

a. Towing at the maximum weight, with engines off, at most critical towing angle up the required slope.

b. Towing at maximum weight, with engine off, at most critical towing angles down the required slope.

c. Towing at angles outside of the powered steering range. Emergency fore and aft pulling provisions should be verified by analysis.

VERIFICATION LESSONS LEARNED (4.4.1.2.2.1.3)

Adequate provisions and documentation should be established to prevent any towing action that will cause damage to the air vehicle, steering system or the towing implements. If there are physical stops on the steering system, then either quick disconnected are need on the gear, or the ground equipment need to have shearpins or some other device to prevent overloading the gear if towing angle limits are exceeded.

A.3.4.1.2.2.1.4 Emergency towing.

The landing gear shall have the following provisions for emergency towing: __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.2.2.1.4)

There are options available for emergency towing of the main and nose landing gear. Normally, this requirement is used for identifying towing lugs or rings.

REQUIREMENT GUIDANCE (3.4.1.2.2.1.4)

TBS should reflect the expected gear towing in the fore and aft directions under the emergency conditions expected to occur in field usage. The interface should be compatible with available ground equipment, both domestic and international.

Details of the tow vehicle attachment, tow ring design details, strength of the gear, and operating terrain control meeting this operational need.

REQUIREMENT LESSONS LEARNED (3.4.1.2.2.1.4)

This requirement reflects the criteria of MIL-STD-805 and the implied performance of MIL-A-8862. It is a clarification.

Some recent large air vehicles have received a deviation to equipping each main gear with emergency towing lugs. However, provisions for installation are provided. The risk that is taken by this action is the availability of the lugs when the need arises. If the need for emergency towing arises in a relatively remote area, the probability of having tow lugs located in the proximity is low.

The probability of needing emergency towing capability is very high for each off-runway situation. If the air vehicle is remotely dispersed or an emergency is inadvertently encountered due to an incident, the use of lugs is very likely. This is assuming that the air vehicle is in an environment for which it is not normally intended to operate.

A.4.4.1.2.2.1.4 Emergency towing.

Performance of the main gear towing system shall be demonstrated on the air vehicle during the ground test program.

VERIFICATION RATIONALE (4.4.1.2.2.1.4)

The capability of using the main gear as a towing attach point to extract that air vehicle from certain undesirable positions should be specified in accordance to the user expectations.

VERIFICATION GUIDANCE (4.4.1.2.2.1.4)

Towing capability should be verified by analysis, inspection of drawings and layouts, and a ground test demonstration with production and international support equipment. The demonstration should start with a stationary air vehicle

VERIFICATION LESSONS LEARNED (4.4.1.2.2.1.4)

(TBD)

A.3.4.1.2.2.1.5 Towing interface.

The interface between the air vehicle and tow vehicle shall be as follows: __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.2.2.1.5)

This requirement is to define configuration or performance requirements to insure compatibility of the air vehicle towing fittings and the tow bar or tow vehicle. Other areas to be considered include steering of the air vehicle during towing and communications between the towing crew members.

REQUIREMENT GUIDANCE (3.4.1.2.2.1.5)

TBS should provide dimensions of towing fittings that are the subject of an international standardization agreement. Air vehicles intended for worldwide operation should comply to insure compatibility with towing equipment in various countries (that is, NATO STANAG 3278). Consider a requirement that the tow fittings be compatible with the appropriate standard tow bar. This requirement should be coordinated with ground equipment specification requirements.

Normally it should be required that the air vehicle be designed to permit the air vehicle to be steered by the tow vehicle, it may be desirable to require that this be done without disconnect of the air vehicle steering system.

Air vehicle size and weight, quantity of air vehicles to be built and type of operation (world-wide or local) are primary factors to be considered in establishment of this requirement.

REQUIREMENT LESSONS LEARNED (3.4.1.2.2.1.5)

Most of the items covered by this requirement were included in MIL-STD-805 and AFSC DH 2-1.

a. Most existing air vehicles can be towed without disconnecting the steering, provided that the normal steering range is not exceeded. Tow bar shear pins are provided to prevent damage in the event the steer angle is inadvertently exceeded. Experience indicates that these pins are sometimes replaced by high strength pins and nose gear damage results from exceeding the steering limit. The steering limit should be clearly marked on the air vehicle because it is too difficult for the tow operator to detect angle limits or see markings on the nose gear strut. Air vehicle markings should be at least 5° inside of absolute mechanical limits.

b. It is possible on most current air vehicle to disconnect the steering during towing so that the tow angle may exceed the normal steering angle. After disconnect of the steering system, it should be possible to turn the gear up to ±180° from the straightforward position. A lesser angle (±120°) may be sufficient for towing, but again could result in structural damage, if exceeded.

c. The method used to disconnect the steering is very critical. If frequently used, the resultant wear may increase free play to the point that nose gear shimmy becomes a problem. Failure to reconnect the steering or incorrect connections have been problems on some past designs. Automatic disconnect methods avoid most of these problems, but should also include a method to detect that the landing gear is out of the normal steering range and return it to the proper position for taxi. Particular attention should be given to proper detection of the 180° position because most landing gears are unstable if driven in reverse at high speeds.

d. Nose gear designs, such as the T-37, which require peculiar AGE, such as “stiff knees” during towing to preclude collapse of the gear have encountered difficulty. Such a design approach is currently considered to be undesirable. This was highlighted by AFLC/AFALD in their Lessons Learned.

e. It is difficult for tow vehicle operators to push back a tailless air vehicle. The absence of a long fuselage makes it difficult for the operator to sense his position relative to the centerline. This may be additionally problematic if the wheelbase/track ratio is low since the sensitivity to the tow bar angle is greater. Provide a visual indicator of angle on the nose strut that is visible to the tow operator. Something as simple as large tick marks painted at 60, 0, +60 on the upper strut and a single tick mark below the pivot could be sufficient.

A.4.4.1.2.2.1.5 Towing interface.

Towing interface shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.2.2.1.5)

Due to the complex interaction of the air vehicle and support equipment verification should be accomplished by demonstration.

VERIFICATION GUIDANCE (4.4.1.2.2.1.5)

TBS: Towing interface should be verified by analysis, inspection of drawings and layouts, and a ground test demonstration with production and international support equipment.

VERIFICATION LESSONS LEARNED (4.4.1.2.2.1.5)

(TBD)

A.3.4.1.2.2.1.6 Mooring provisions.

Mooring provision shall be compatible with __(TBS 1)__, and shall be capable of withstanding __(TBS 2)__ with all surfaces locked, at __(TBS 3)__ gross weight.

REQUIREMENT RATIONALE (3.4.1.2.2.1.6)

Landing gear should be compatible with standard mooring patterns. This is a performance requirement for the landing gear with mooring equipment attached. The amount of crosswind identified should be the same as that selected for structural design. Nominally, the value is 70 knots and it applies to any gross weight.

REQUIREMENT GUIDANCE (3.4.1.2.2.1.6)

TBS 1 should reflect the expected mooring arrangement that the landing gear will see in service.

Mooring patterns, mooring attachment details, mooring methods, and attachment strength control this requirement.

TBS 2 should reflect the mooring capability of withstanding a 70-knot wind from any horizontal direction, with all air vehicle surfaces locked.

TBS 3 should be filled in with all gross weight configurations, Preloading of the mooring provisions resulting from strut compression beyond the gross weight static position should be included.

Mooring fitting strength and mooring loads control meeting this requirement.

REQUIREMENT LESSONS LEARNED (3.4.1.2.2.1.6)

The strength requirement is derived from the legacy specification MIL-A-8865. This indicates mooring in a 70-knot crosswind. The MIL-A-8865 requirement is a direct derivative of MIL-A-8865, which requires mooring in a 75-mph wind.

Several recent air vehicles have waived the mooring requirements. But, this basically is a Using Command decision. If the mooring is not to be used to survive in adverse weather, it may be more expedient to dispatch to air vehicle to other bases rather than to take the risk of weather damage.

Generally, the gear design uses the same attachment for mooring and emergency towing. The towing lug makes a convenient attachment for a mooring cable.

The legacy MIL-T-21063 can provide tie down details. The inside diameters of tie down rings should not be less than one inch.

MIL-T-81259 provides standard mooring patterns.

If at all possible, the same attachment for emergency towing and mooring should be used on main gears to minimize the weight to accommodate this capability.

Caution should be used in nose gear mooring arrangements to avoid damaging control equipment when the mooring cables are installed.

A.4.4.1.2.2.1.6 Mooring provisions.

The mooring provisions shall be verified by __(TBS 1)__. Mooring conditions shall be verified by __(TBS 2)__. Design characteristics and component compatibility shall be evaluated.

VERIFICATION RATIONALE (4.4.1.2.2.1.6)

AGE - Air vehicle interface is best demonstrated on the actual air vehicle. Analysis cannot adequately evaluate this characteristic.

VERIFICATION GUIDANCE (4.4.1.2.2.1.6)

TBS 1: Mooring provisions should be verified by analysis, inspection of drawings and layouts, and a ground test demonstration.

TBS 2 should reflect the ability to moor the air vehicle in a demonstration using only production support equipment. Resistance to wind loads while moored, including preload of the shock absorbers, should be verified by analysis.

VERIFICATION LESSONS LEARNED (4.4.1.2.2.1.6)

(TBD)

A.3.4.1.2.3 Ground FOD.

Landing gear forward of engine inlets shall be designed and located to minimize FOD and water ingestion into the engine.

REQUIREMENT RATIONALE (3.4.1.2.3)

This requirement is presented to reduce detrimental engine performance due to water or other contamination thrown by the landing gear during ground operations.

REQUIREMENT GUIDANCE (3.4.1.2.3)

(TBD)

REQUIREMENT LESSONS LEARNED (3.4.1.2.3)

(TBD)

A.4.4.1.2.3 Ground FOD.

(TBD)

VERIFICATION RATIONALE (4.4.1.2.3)

(TBD)

VERIFICATION GUIDANCE (4.4.1.2.3)

(TBD)

VERIFICATION LESSONS LEARNED (4.4.1.2.3)

(TBD)

A.3.4.1.3 Structure

A.4.4.1.3 Structure

A.3.4.1.3.1 General provisions.

See JSSG-2006, Structures Joint Service Specification Guide.

A.4.4.1.3.1 General provisions.

See JSSG-2006, Structures Joint Service Specification Guide.

A.3.4.1.3.1.1 Material selection.

Material selection shall be made in accordance with _(TBS 1)_, except as modified by _(TBS 2)_.

REQUIREMENT RATIONALE (3.4.1.3.1.1)

Alloy selection, manufacturing processing, protective finishes, surface finishes, plating methods, and material properties are important factors in the success of the landing gear design. The major modes of failure for landing gear equipment are frequently structural and this is a very important consideration.

REQUIREMENT GUIDANCE (3.4.1.3.1.1)

TBS 1 should be filled in with requirements from MIL-STD-1568 and MIL-HDBK-1587.

TBS 2 should be completed by reference to the document used to tailor the standards.

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.1)

The material selection methods and corrosion control plans identified in MIL-STD-1568 and MIL-HDBK-1587 are a compilation of experience and lessons learned by the Air Force Materials Laboratory and the ASD/Industry counterparts. They evolved into AFML 70-7, "Do's and Don'ts of Materials Application." This unofficial documentation has been directly inserted in several recent development programs' System Specifications. It reflects much of the experience of the landing gear industry and lessons learned in landing gear service difficulties. Much of the criteria were contained in MIL-L-8552, Amendment 1, and reflect the former Aeronautical Systems Division/Ogden Air Logistics Center Task Group lessons learned.

a. There have been many lessons learned in landing gear material and processes. Ogden ALC personnel contributed significant improvements and observations in this area.

b. In addition to guidance provided in MIL-STD-1568 and MIL-HDBK-1587, the following items apply to landing gear design and processing as recommended practices:

c. Where steel forgings are used, use only vacuum arc remelt parts.

d. The preferred method of cold straightening of steel parts hardened to tensile strength of 200,000 psi and above would be to temper the parts while in a straightening fixture.

e. Magnetic particle inspection should be performed on all finished steel parts which are heat treated in excess of 200,000 psi ultimate tensile strength.

f. Many parts are received with forging laps or inclusions that were in the part at time of manufacture. These defects may not be detrimental to the service of the part; however, when the part is magnetic particle inspected at depot after service, inspectors cannot determine that these indications are forging laps and not fatigue cracks and, therefore, the part may be rejected.

g. Bushings should be limited to non-ferrous materials for the principal static and dynamic joints.

h. All joints should be bushed to facilitate depot rework.

i. Considerable numbers of problems have been experienced where bushing materials have been made from Teflon and phenolic type materials. These should not be used without verification of wear life expectancy or a rework procedure available for refurbishment of the bearing. Consideration should be given to the need and also to the placement of adequate grooves and their configuration for providing lubrication to all areas of the joint.

j. All surfaces, except holes under $^{3}/_{4}$-inch in diameter, of structural forging forged from stress-corrosion susceptible alloys which, after final machining, exhibit transverse grain exposed in the surface, should be shot peened or placed in compression by other suitable means.

k. All interior surfaces of hollow landing gear components, pins, and fasteners should have suitable corrosion protection to prevent degradation of capability.

l. Areas of components considered to be critical in fatigue should have a surface roughness in the finished product not to exceed 63 rhr, as defined by ASME B46.1, or should be shot peened, with a surface roughness prior to peening of not over 125 rhr.

Unmachined aluminum die forging should be approximately 250 rhr, except surfaces where flash has been removed.

m. Efforts should be made to reduce stress concentrations such as, using stress relief heat treatments (except aluminum alloys), try to optimize grain flow orientation, use “wet installed” inserts and pins and extensive use of surface cold working.

n. Avoid cross drilling of joint pins. Drilling operations result in material surface damage and stress risers that are difficult to control.

o. Consideration should be given to the location of drain holes to ensure they will properly drain and reduce the probability of corrosion.

p. The short transverse grain direction, if exposed, should not be subjected to any sustained tensile loads.

A.4.4.1.3.1.1 Material selection.

Material selection shall be verified.

VERIFICATION RATIONALE (4.4.1.3.1.1)

The landing gear becomes an integral part of the airframe structure and review of materials and processes is accomplished in the same manner as the rest of the structure.

VERIFICATION GUIDANCE (4.4.1.3.1.1)

Material selection should be in accordance with the required standards.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.1)

(TBD)

A.3.4.1.3.1.2 Roughness and runway repair profile criteria.

The landing gear shall operate without degradation of performance or service life on surfaces with the following roughness characteristics: __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.3.1.2)

The roughness of the surfaces to be used by the air vehicle is a major consideration in design of the landing gear. In all cases it provides the input for design of landing gear response to control ground loads to a level to provide the required air vehicle life. In the case of operation on unpaved airfields, it may also establish limits on landing gear arrangement and tire size to ensure that the air vehicle is not immobilized by the specified roughness.

REQUIREMENT GUIDANCE (3.4.1.3.1.2)

TBS should be filled in with one or two aspects of roughness. The first should be a discrete bump or dip criterion that establishes the maximum roughness to be encountered. The second is the frequency of occurrences of the various levels or roughness. The air vehicle gross weight condition and operating requirements should also be stated. In the case of paved airfields, this is usually all weights to maximum gross weight and all ground speeds to the maximum required for takeoff and landing. In the case of air vehicles to be operated from unpaved airfields, the gross weight is usually limited to that required for missions to be performed from unpaved airfield.

The paved airfield curve should be specified for all air vehicles along with a requirement for negotiation of one inch step bumps. The semi-prepared (matted soil) airfield curve and a two-inch step bump should be specified for most air vehicles to be operated on unpaved surfaces. The unprepared airfield curve and a four-inch step bump are considered severe and are rarely used.

For forward field operation, bomb damage repair criteria needs to be established. During the Have Bounce Program bump profiles corresponding to categories A, B, C, D, E, and I bumps were defined based on repair mat profiles. It was found that most existing air vehicles were limited to category A or B bump profiles. It was shown through testing that gear could be easily modified or designed to handle C, D, and even I bumps, if needed. It is recommended that for wartime operation over bomb damage repair, the gear be designed to category E bump criteria as a minimum to provide the quickest turnaround for the Rapid Runway Repair (RRR) group and for the most effective wartime operations.

Performance parameters include gross weight, ground speed, lift characteristics and frequency of operation on unpaved airfields.

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.2)

This requirement was previously stated in MIL-A-8862. The criteria are based on airfield roughness surveys conducted by the Air Force Flight Dynamics Laboratory in the early 1960’s. The Have Bounce Program defines repair profiles and provides the basis for RRR philosophies. Wartime operational scenarios should dictate the capabilities needed for operation.

Laboratory testing and on air vehicle demonstration has shown that the gear can be designed, without any significant impact to gear weight, to handle bomb damage repair profiles of 4.5 inches or more than the runway surfaces. The internal changes can be accomplished on existing gear designs or incorporated on new designs as required. By being able to handle greater bump heights the fatigue life of the gears and air vehicle structure are improved and the time to repair the runway to a condition to launch air vehicles is significantly reduced.

A.4.4.1.3.1.2 Roughness and runway repair profile criteria.

Performance during and after operation on surfaces of specified roughness shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.3.1.2)

Performance is a result of a complex interaction of air vehicle systems and the environment. Consequently, this requirement is best verified by air vehicle test. Testing can be accomplished on discrete bumps constructed to duplicate the specified roughness. Testing on a specified random roughness is usually impossible. An approach used in the past is to conduct taxi tests on two or three airfields to validate a dynamic response analytical model. The requirement is then verified by the validated analysis.

VERIFICATION GUIDANCE (4.4.1.3.1.2)

TBS should reflect an analysis of all expected bump and roughness profiles that the air vehicle will traverse, during ground operations up through rotations as applicable to the user mission requirements. The analysis should be substantiated with air vehicle operations over known bumps and repair profiles.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.2)

The significance of airfield roughness to performance of a given air vehicle is somewhat dependent upon the characteristics of the air vehicle. Analysis should be used to select most critical roughness for test. Usually a bump or dip wavelength critical for one design will not be critical for another.

Several simulated rough surfaces have been constructed at Edwards Air Force Base (AFB) for evaluation of existing air vehicles. These surfaces may not be suitable for test of a new design because they do not represent the most critical condition. Test on these surfaces, however, may be useful for validation of a dynamic response analysis model.

Portable surfaces to simulate roughness were constructed for evaluation of the C-5A air vehicle. These surfaces may be fastened to paved runways for taxi testing. These surfaces were in storage and available for use as of early 1977. The Air Force program manager at the Lockheed-Georgia Company should be contacted concerning availability of these surfaces.

A.3.4.1.3.1.3 Failure tolerance.

In the event of landing gear structural failure, the following failure modes shall be prohibited: __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.3.1.3)

This requirement is to establish limits on structural failure modes to minimize secondary effects.

REQUIREMENT GUIDANCE (3.4.1.3.1.3)

TBS should be completed by a statement of prohibited failure modes. It may also be necessary to further define the conditions of failure. As an example, a statement for a transport air vehicle might read, "pierce a crew station or passenger seating area, or result in spillage of enough fuel from any part of the fuel system to constitute a fire hazard. It should be assumed that failure occurs during takeoff or landing and that landing gear loads are acting in the upward and aft directions except when the air vehicle departs the runway."

Equipment affecting safety of flight, if located in the wheel well, should be protected from tire blowout.

Hydraulic brake lines located on or near the landing gear should be protected against tire disintegration related damage.

Landing gears should permit rapid replacement of main wheels, tailwheels, or nosewheels.

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.3)

There are numerous causes of gear structural failure and every precaution is taken to avoid such events. However, action can be taken by design to control the modes of failure. Every effort should be taken to keep failed landing gear components from the cockpit area, from severing hydraulic lines, or from penetrating the fuel tank areas. The results of such an inability are obvious. This occurred with the F-89 and commercially on the 747. Subsequent redesigns have corrected these modes of failure.

There was an incident with the KC-135 in which the bogie beam experienced a failure and the failed parts pierced the water tank adjacent to the wheel well. With proper control of failure modes, this could have been avoided.

The Navy has experienced numerous landing gear failures that struck the fuel tanks and caused fires. However, with proper precautions and cautions, this problem has been minimized.

A means should be provided (such as a large washer behind the axle nut) to ensure wheel retention on the axle in case of a bearing failure.

A.4.4.1.3.1.3 Failure tolerance.

Failure tolerance shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.3.1.3)

(TBD)

VERIFICATION GUIDANCE (4.4.1.3.1.3)

Analysis should permit a wide variety of options to be studied and evaluated.

TBS: An analysis of probable gear failure locations and surrounding air vehicle structure should be accomplished to minimize adverse effects.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.3)

In the past, the cost and risk were too high to permit evaluation by test or demonstration.

A.3.4.1.3.1.4 Strength.

The landing gear subsystem shall not __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.3.1.4)

The landing gear subsystem should be strong enough to support all the operational missions specified in the air vehicle specification for all environments and conditions it is expected to operate.

REQUIREMENT GUIDANCE (3.4.1.3.1.4)

TBS should be stated as follows:

a. Exhibit detrimental permanent set, yielding, or damage due to ground, flight, operational, and logistics limit load envelopes specified in the air vehicle specifications.
b. The structural components should not temporarily deform to the extent that functional performance is significantly affected within the flight and ground envelope conditions.
c. Catastrophically fail due to ground, flight, operational, and logistics ultimate load envelopes, at a 1.5 safety factor, or as specified in the structural loads documents.

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.4)

(TBD)

A.4.4.1.3.1.4 Strength.

The strength of the landing gear subsystem shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.3.1.4)

Verification of the yield and plastic deformation range of the structure should be such as to preclude such deformation would prevent landing gear subsystem from performing as commanded or required to complete the mission.

VERIFICATION GUIDANCE (4.4.1.3.1.4)

TBS should reflect the analytical and test method listed in the structural specifications for verification of air vehicle structure.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.4)

(TBD)

A.3.4.1.3.1.5 Durability.

The Landing Gear structure shall be designed for at least __(TBS 1)__ lifetime representative spectrums based on operational loads and the air vehicle service life.

The Landing gear systems shall be designed for at least __(TBS 2)__ lifetime representative spectrums based on operational loads and the air vehicle service life.

Landing Gear components shall be designed for at least __(TBS 3)__ lifetime representative spectrums based on operational loads and the air vehicle service life.

The Landing Gear actuation system, including the backup structure, actuators, doors and mechanisms, and locking details, shall be capable of __(TBS 4)__ retraction/extension cycles, of which __(TBS 5)__ (cycles shall include emergency extensions).

REQUIREMENT RATIONALE (3.4.1.3.1.5)

Landing gear subsystem should have design lifetimes to ensure the system will last the life of the air vehicle.

REQUIREMENT GUIDANCE (3.4.1.3.1.5)

TBS 1: For non-damage tolerant structure should be four (4), for structure design to damage tolerant criteria, should be two (2).

TBS 2: System life operation should reflect two (2) lifetimes of operation.

TBS 3: For components that are not considered limited life should be four (4) lifetime capable.

TBS 4: The actuations system and all its components should have the capability of 10,000 cycles.

TBS 5: 500 cycles of the number for TBS 4 are for emergency extensions.

The actuation number of cycles should take into account the number of touch and go cycles as well as the normal and emergency operation.

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.5)

(TBD)

A.4.4.1.3.1.5 Durability.

The durability of the landing gear subsystem shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.3.1.5)

Based on the latest structural design practices and determination of the operational cycles of the landing gear through all phases of air vehicle operations, the expected life of the gear and its systems should be determined.

VERIFICATION GUIDANCE (4.4.1.3.1.5)

TBS should be filled in with analysis, testing and material properties validation that supports the required life of the systems needed to meet air vehicle mission and life requirements.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.5)

(TBD)

A.3.4.1.3.1.6 Corrosion protection.

(TBD)

REQUIREMENT RATIONALE (3.4.1.3.1.6)

(TBD)

REQUIREMENT GUIDANCE (3.4.1.3.1.6)

(TBD)

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.6)

(TBD)

A.4.4.1.3.1.6 Corrosion protection.

(TBD)

VERIFICATION RATIONALE (4.4.1.3.1.6)

(TBD)

VERIFICATION GUIDANCE (4.4.1.3.1.6)

(TBD)

VERIFICATION LESSONS LEARNED (4.4.1.3.1.6)

(TBD)

A.3.4.1.3.1.7 Flat tire and flat strut operation.

In the event of a flat tire or a depressurized shock absorber, the gear shall be capable of __(TBS)__ without structural damage to the gear or the air vehicle.

REQUIREMENT RATIONALE (3.4.1.3.1.7)

The objective of the requirement is to establish performance capability of the landing gear under the emergency condition for a selected component failure, which has a reasonably high probability of occurring.

Consideration is also given to insure that sufficient ground clearance is maintained, particularly on air vehicles that have external stores and fuel tanks. It is possible to have ground contact with these stores while performing normal landing and takeoff operations.

REQUIREMENT GUIDANCE (3.4.1.3.1.7)

TBS should describe an average landing condition. For example, a flat strut-landing requirement could be a landplane-landing-weight air vehicle landing at 6-feet/second vertical contact velocity. It will also be necessary to identify ground-handling limits that might be expected under these conditions.

Air-oil characteristics of the strut, metering pin-orifice combination, wheel frangibility, and operating techniques have significant impact on this requirement.

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.7)

This is a new requirement not previously defined, prior to system development. This emergency capability has been implied and left to the undefined risk of the Using Commands. Some portion of the criteria has been contained in MIL-A-8862 for flat tire design load conditions. There has been a requirement for design strength dating back to ANC-2, but only an implied operational capability that has never been demonstrated.

Frequently, if the gear is not properly positioned upon touchdown, the necessary system actuations can be jeopardized. Landing with a flat strut, for example, may result in loss of anti-skid control. Without warning or prior notice, this type of system malfunction can lead to numerous difficulties.

In the event the condition is unknown to the pilot, no precautions will be taken, so a limit on performance is necessary to prevent loss of air vehicle.

A.4.4.1.3.1.7 Flat tire and flat strut operation.

Landing gear energy absorption performance with a deflated strut or flat tire shall be verified by (TBS) .

VERIFICATION RATIONALE (4.4.1.3.1.7)

Normally, this can be accommodated during the jig drop test program. It provides a controlled environment with no risk to an air vehicle. In the event difficulties are encountered when demonstrating this emergency condition, the laboratory is a more suitable environment. In the event that a test program is not planned, an analysis of the condition is the least that can be expected.

VERIFICATION GUIDANCE (4.4.1.3.1.7)

TBS should reflect verification by analysis and laboratory drop test.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.7)

It is difficult to laboratory test both the flat strut and flat tire test and insure there will not be any damage to the air vehicle. You can test to verify that there will be no damage to the gear during a flat strut landing, and that the wheel will not come apart when landed with a flat tire. However, it is too risky to demonstrate on the air vehicle and there will always exist a possibility that there may be some damage to the air vehicle when it operates with a flat strut or flat tires.

A.3.4.1.3.1.8 Energy absorption.

The landing gear subsystem shall absorb sufficient landing energy such that (TBS 1) is not exceeded under the following conditions: (TBS 2) .

REQUIREMENT RATIONALE (3.4.1.3.1.8)

This requirement is to establish shock absorption performance capable of meeting structural load criteria defined in the system structural criteria documents.

REQUIREMENT GUIDANCE (3.4.1.3.1.8)

TBS 1 should reflect the desired sink speed(s).

TBS 2 should be filled in with the air vehicle weight(s).

A number of sink speed and weight combinations can be specified to match a number of different operating conditions.

Normally, these requirements are established as 10 feet/second sink speed at landplane landing weight and 6 feet/second at maximum landing weight. If special system design conditions exist, they should also be reflected in these performance requirements as an addition to this criteria. In the past, a reserve energy criteria of 12.5 feet/second sink speed at landplane landing weight was imposed, with minor failures permitted. This represents a 50 percent (50%) margin in energy capacity since the velocity function is squared in calculating the absorbed energy.

The vertical travel of the wheels during operation of the shock absorber struts should be sufficiently long to insure that ground loads which are based on load factors determined by drop tests will not be appreciably more critical than other loading conditions for the carry-through structure.

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.8)

The sink speed or vertical energy requirements for shock absorber and landing gear design are currently defined in MIL-A-8863. The standard vertical contact velocity has grown from 9 feet/second to 10 feet/second at landplane landing weight. Both the contact velocity and the landing weight are frequent items of deviation and discussion. They should be established as a direct result of operational analysis of the intended air vehicle.

Recent examples of special consideration of sink speed included C-5A and Advanced Medium Short Take Off and Landing Transport (AMST). The C-5A rightfully assessed the operational concept and reduced the landplane landing weight contact velocity to 9 feet/second in lieu of the required 10 feet/second. This better meets the operational usage of the air vehicle and results in weight saving.

On the AMST, the operational concept of the air vehicle calls for flights in and out of short bare field runways in a hostile environment. Under these circumstances, the operational concept is to increase the sink speed to reduce the stopping distance. A design contact velocity for this condition will be established by analysis of the landing performance requirements. The C-17 air vehicle that came out of the AMST program was design to operate at 14.5 ft/sec-sec sink speed at mission weight for this very reason.

Another example of rational criteria is the use of higher sink speeds for trainer air vehicle. Since the operator is inexperienced, the probability of high speed contact is significantly increased. Therefore, the normal criteria is 13 feet/second sink speed or higher as determined by the user.

A.4.4.1.3.1.8 Energy absorption.

Landing gear shock absorption performance shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.3.1.8)

Normally, this requirement is satisfied by demonstration during a jig drop test. The test not only accesses the ability to absorb the vertical energy, it also serves the purpose of evaluation of rebound, spring rates, damping in both directions, and other dynamic characteristics.

There are several air vehicles that have flown on calculated metering pin-orifice combinations with relative success. Most Navy gears have calculated pins, but they are ultimately evaluated by dropping the total airplane in a fatigue drop test.

VERIFICATION GUIDANCE (4.4.1.3.1.8)

TBS should be accomplished by analysis and laboratory testing, with demonstration during flight testing.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.8)

(TBD)

A.3.4.1.3.1.9 Ride quality.

The landing gear subsystem shall provide a ride such that the vertical accelerations at the pilot's station shall not exceed __(TBS 1)__ on a __(TBS 2)_.

REQUIREMENT RATIONALE (3.4.1.3.1.9)

Objective of the requirement is to establish quantitative ride quality requirements which can be verified. Runway roughness has long been recognized as impacting the peak design loads and the fatigue life of the basic airframe structure. Ride quality relates to pilot comfort and his ability to function in the cockpit dynamic environment induced by ground loads and air vehicle response.

REQUIREMENT GUIDANCE (3.4.1.3.1.9)

TBS 1 should be filled by insertion of the acceptable acceleration limits.

TBS 2 runway surface roughness should be specified in detail and should match up with the structural ground roughness criteria specified in the air vehicle specification.

As a minimum, the criteria should be based on pilot functional capability. In other words, criteria should reflect the maximum levels of oscillation at which the pilot can continue to perform required control functions. Air crew physical comfort should also be considered.

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.9)

The prime example of problems for which this criteria is intended is the XB-70. The location of the cockpit relative to the nose gear amplifies the vertical travel of the nose gear shock strut. The problems that the designer is trying to avoid are primarily physiological. The environment has been known to be so hostile that the pilot was unable to read the instruments or to provide vocal communication.

There are numerous solutions to the problem of ride quality. The most common of recent times has been to use dual chambered shock struts. This design solves the ride quality problem, but introduces severe landing gear maintainability problems. In the F-4, C-5A, and F-15, it has been difficult to seal the high pressure chamber and there is no way to determine the status of the cylinder without disassembly. Development of adequate servicing and inspection techniques has been difficult. The FB-111 uses dual pistons, but has a single air chamber. It has been a relatively good performer in the field.

A.4.4.1.3.1.9 Ride quality.

Ride quality shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.3.1.9)

An analysis permits evaluation within the full operational spectrum. However, in order to obtain confidence in this review, it is necessary to verify discrete points by actual taxi test on the airplane over a known runway profile.

VERIFICATION GUIDANCE (4.4.1.3.1.9)

TBS: Ride quality should be verified by analysis, substantiated by component laboratory testing and demonstrated on the air vehicle during flight testing.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.9)

(TBD)

A.3.4.1.3.1.10 Landing gear servicing.

The ___(TBS)___. types of landing gear servicing shall be accomplished without removal of components or jacking of the complete air vehicle.

REQUIREMENT RATIONALE (3.4.1.3.1.10)

This requirement is to insure that consideration is given to maintenance requirements in design of the landing gear installation and fairing. Designs that require air vehicle jacking and strut removal not only increase maintenance costs but also increase the possibility of maintenance accidents.

REQUIREMENT GUIDANCE (3.4.1.3.1.10)

TBS should be filled with at least the following: “gas charging, oil replacement, and inspection for proper servicing.”

Internal shock strut design, which impedes fluid flow and location of the drain, are the major considerations in meeting this requirement.

It should be possible to fully re-service each shock-strut with both fluid and nitrogen in not more than 30 minutes.

It should be possible to determine the amount of extension for all struts without removing any cowling or without using a measuring device other than a scale. A scale integral with the strut is desirable.

If serviced with fluid, the shock absorber struts should utilize the same type of fluid as used in the air vehicle hydraulic system. On Navy air vehicles without a hydraulic system, MIL-PRF-83282 is preferred.

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.10)

This requirement was previously contained in MIL-L-8552 and represents an application of lessons learned and an attempt to standardize maintenance procedures. This is part of the overall effort to improve air vehicle maintainability.

The maintenance of shock absorbers is a very important factor in achieving desired performance and life. Strut servicing with fluid and charging agent should be as simple as possible under all load conditions to insure that line maintenance personnel accomplish the required functions.

Most struts require complete removal or pulling of the piston to drain the fluid. The hazards of oil spillage should be readily apparent. Recent efforts have been made to attempt to influence designers to provide drainage capability without removal. This requirement is intended to continue this pursuit.

Strut filling is another important function which is potentially compromised on most designs. There is no way of telling fluid level without complete deflation and refilling. It is unfortunately easier to add nitrogen and adjust the extension rather than to assess the fluid level. This results in inadequate fluid for metering during energy absorption. This then can result in excessive load, and possible structural damage.

A.4.4.1.3.1.10 Landing gear servicing.

Landing gear servicing shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.3.1.10)

Initially design features such as servicing will be reviewed by routine engineering discussions and inspection of drawings. After the air vehicle is in flight test status, maintenance function will be evaluated on a routine basis.

VERIFICATION GUIDANCE (4.4.1.3.1.10)

TBS should be filled in with inspection, demonstration and substantiated during flight testing. This should take into account all servicing actions.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.10)

(TBD)

A.3.4.1.3.1.11 Repeated operation.

The landing gear subsystem shall be capable of performing its required shock absorption function within __(TBS 1)__ after positioning for landing and shall not prevent accomplishment of (TBS 2)__ successive landings with __(TBS 3)__ between landings.

REQUIREMENT RATIONALE (3.4.1.3.1.11)

Unless care is exercised in design, the internal shock absorber chamber arrangement can impede fluid flow. Assemblies with this characteristic have difficulty in performing the basic energy absorption function upon extension if they have been stowed with the centerline above horizontal and the fluid is required to flow from chamber. The purpose of this requirement is to establish a time limit consistent with system needs for fluid flow between chambers to insure proper metering during energy absorption. The consequences of improper flow are foaming, improper metering, and cavitation. All of which result in excessive load and potential structural failure. It is recommended that the blank have two minutes inserted if no specific system requirements are identified or are unidentifiable.

REQUIREMENT GUIDANCE (3.4.1.3.1.11)

TBS 1 should reflect the minimum time from when the strut is fully extended to touchdown.

TBS 2 is the number of time landing or touch-and-go's are performed within a given operation or training missions.

TBS 3 gives the minimum amount of time that expires between any set of landing or touch-and-go.

This requirement is intended to define the energy absorption capability for touch and go landings. The most severe succession of consecutive landings, which can reasonably be expected in service, should be identified for design. It is recommended that successive design conditions such as landplane landing at 10 feet/second, level landing attitude, be identified within a five minute time period.

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.11)

Internal strut design with proper drainage routes controls this capability. Whether or not the strut fluid foams upon extension controls whether there is sufficient fluid beneath the orifice to insure that only fluid is metered during the energy absorption stroke.

This performance characteristic was previously identified in MIL-T-6053. It represents a condition that can be developed when the air vehicle is used in training by landing with a series of touch and go landings. If the internal shock absorber design permits foaming of the fluid during the metering process, the second landing will encounter a portion of the energy stroke where gas will be metered through the orifice instead of oil and the peak loads will be very high.

Fluid flow between chambers should be carefully considered in the internal strut design.

It would be beneficial to study design details of existing struts that are stored above the horizontal and successfully meet the extensive time requirements without any adverse effects.

There are various circumstances which affect the metering characteristics of a gas-oil shock absorber. Included among these are: The ability to recirculate the oil, rebound characteristics of the strut, and temperature. Recirculation and rebound are a function of internal design and the temperature impacts the air curve from which the taxi loads are determined. Higher temperature will result in noticeable load increases. The source of temperature increase can be changes in the ambient air or internal strut friction.

A.4.4.1.3.1.11 Repeated operation.

Repeated operation shall be verified __(TBS)__.

VERIFICATION RATIONALE (4.4.1.3.1.11)

The laboratory drop test is the best method of demonstrating this requirement because the exact condition of installation and performance can be duplicated and controlled. It is significantly less expensive than trying to measure the loads and analyze the effects of this condition on the air vehicle during the flight test program.

VERIFICATION GUIDANCE(4.4.1.3.1.11)

TBS should reflect the number of successive drops to be done in a row with a specified minimum time between them. For those struts that are stored past horizontal, thus having air-oil inversion, it may be desirable to conduct an analysis and laboratory demonstration to ensure the oil drains into the proper chamber in time.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.11)

(TBD)

A.3.4.1.3.1.12 Friction control.

Shock absorber friction in the landing gear subsystem shall not cause __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.3.1.12)

This requirement is intended to minimize operational problems due to high mechanical friction of the shock absorber. Mechanical friction may cause severe operational problems in strut servicing and weapons loading. Quantitative requirements are not well defined because this characteristic has not been considered in detail on past designs It is suggested that detailed study of a proposed air vehicle may result in suitable quantitative requirements. Areas of study could include strut extension as a function of strut pressure changes and change in elevation of external stores stations when weapons are loaded.

REQUIREMENT GUIDANCE (3.4.1.3.1.12)

TBS should specify as a minimum: "adverse effects in shock absorber servicing, air vehicle landing and taxi, and mission loading or unloading."

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.12)

Static strut function on the A-10 air vehicle created a hazardous condition for weapons loaders in that at a certain load the strut would suddenly break away causing a significant change in elevation of the weapons loading point.

During some landings on early F-15 aircraft, one strut would stroke before the other due to differences in mechanical friction. The resultant asymmetric loading prevented the other strut from stroking for several seconds. The air vehicle ground rollout was in a skewed attitude adversely affecting control during this time.

A.4.4.1.3.1.12 Friction control.

Shock absorber friction control shall be verified by <u>(TBS)</u>.

VERIFICATION RATIONALE (4.4.1.3.1.12)

Careful analysis and design best meet this requirement. Except for some bearing material and seal changes, little can be done with existing hardware that proves unsuitable. Nevertheless, final proof of suitability is a demonstration on the air vehicle. In some cases specific tests such as weapons loading, fueling, or servicing may be specified in detail to verify the function characteristics.

VERIFICATION GUIDANCE (4.4.1.3.1.12)

TBS should reflect inspection of drawing and layout to support an analysis of strut friction and ratcheting effects on air vehicle operations. The analysis may be supported with laboratory testing of bearing. The final verification should be operational demonstrations on the air vehicle for those critical stroking situations.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.12)

(TBD)

A.3.4.1.3.1.13 Repairability.

Where joints and wear surfaces are required, they shall accommodate reparability by __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.3.1.13)

Experience has shown that it is essential that a means be provided to permit rework of landing gear joints and wear surfaces. Failure to establish such a requirement results in high operating costs because expensive landing gear forgings must be replaced when contact surfaces are corroded or worn out of tolerance. Landing gear functional and structural requirements do not insure that parts can be refurbished.

REQUIREMENT GUIDANCE (3.4.1.3.1.13)

This requirement is primarily intended to prevent scrapping of major landing gear forging due to normal wear and corrosion.

TBS should be completed by the following statement: “providing a minimum of 0.060 inch allowance on the diameter of each pinned joint and a minimum of 0.030 inch allowance on each non-circular wear surface.” Allowance means that up to this much material may be removed for insertion of bushings or other repair. Deletion of this requirement should be considered for prototype and other limited life air vehicles.

Small linkage parts that are more economical to replace than repair should be excluded from the requirement. A suggested statement is: “This requirement should not apply to any component such as small linkage parts that are more economical to replace than repair.”

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.13)

This requirement is intended to reflect the detail requirements currently documented in AFSC DH 2-1, AFSC DH 1-2, MIL-L-8552, and lessons learned on recent systems and commercial experience of airlines.

There are numerous air vehicles which have experienced wear in the joints. Examples would include KC-135 bushed axle and beam, B-52 pistons, and C-141 axle bogie beam fretting. Therefore, to save the expense of repair or replacement, it is vital to allow enough material for rework.

Joint designs have proved to be extremely critical in maintaining hardware in the fleet. Lessons learned include use of positive lubrication for all joints, static and dynamic. All joints should be bushed. Avoid all pressed fit or matched fit joints. These features have contributed to great cost at the depot level during overhaul. They should be considered in the original design recognizing the service life commitment of "Roughness and runway repair profile criteria" in this appendix.

Commercial airline usage has made extensive use of lubrication and replaceable bushings to achieve extended use of major landing gear components. It is impossible to legislate against corrosion or wear; you can only design for minimized detrimental effects.

Extreme difficulty has been encountered in the use of keyways and threaded parts on the B-52. These have been the source of stress concentration and have resulted in numerous field failures from fatigue cracking.

A.4.4.1.3.1.13 Repairability.

Repairability shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.3.1.13)

Close engineering monitoring of design details during the development program is the only effective means of transfer of lessons learned. These lessons learned come from Using Commands and AFLCMC Engineering monitors.

VERIFICATION GUIDANCE (4.4.1.3.1.13)

TBS should be filled in with inspection of engineering drawings and analysis.

Strength and life analysis should be accomplished on the rework capability designed into the joints to ensure that the gear performance capability is not compromised when the joints are reworked.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.13)

(TBD)

A.3.4.1.3.1.14 Empennage protection.

Empennage protection, if used, shall be provided by __(TBS 1)__ and shall incorporate the following features: __(TBS 2)__.

REQUIREMENT RATIONALE (3.4.1.3.1.14)

This requirement is aimed at protecting the empennage from damage during ground usage when the brakes are applied while the air vehicle is rolling backwards or the air vehicle is over rotated on take-off or landing, or during shipboard towing operations for all allowable sea state conditions.

REQUIREMENT GUIDANCE (3.4.1.3.1.14)

TBS 1 should be filled in with the appropriate empennage protection device.

TBS 2 should reflect the expected performance of the empennage protection device for those mission profiles that the air vehicle will see. It should list the number of times the bumper will be used and type of operation, such as passive bumper versus an extendable bumper.

Special control features include: retraction, automatic extension based on throttle setting and gear position, emergency extension capability, and position indication.

Depending on the characteristics which are identified in the blank, various parameters influence and control this requirement. System design, component design details and system interfaces are general areas of control.

Tail bumpers are frequently safety features that represent protection of more expensive and delicate airframe hardware that is jeopardized by extreme tail down landings, abrupt rotation on takeoff and ground maneuvering.

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.14)

This is a new requirement, not previously documented in design requirements. Since these special features impact the cost, it is necessary to state the requirements in the original documentation. Most of the special features are Using Command preferences and they should be consulted extensively on these requirements. Since they are cost drivers, the user should be apprised and be willing to accept the impact on reliability and maintainability.

Tail bumper design is a direct function of the protection to be provided. A simple ground handling protection device can be simply a hard point to prevent ground contact of the rest of the airframe. It would be infrequently encountered and usually be a simple manual device. If the protection desired come from overrotation on takeoff or high attitude landing, the device becomes in fact an energy absorber. If the strikes are frequent enough, the designer should consider a replaceable contact.

Another feature that is optional is the ability to position the bumper from the pilot's station. Retractable bumper wheels or skids should extend during regular and alternate or emergency extension of the landing gear. A position indicator should be provided. If aerodynamic degradation occurs from having the bumper permanently extended, consideration should be given to providing a retractable feature.

If the bumper is contacted on takeoff or landing, there is a firm need to isolate the hydraulic system to prevent spikes of peak pressure being applied to the system.

The unit should be readily inspectable.

SAE ARP1107 is a useful reference for recommended practice for design and installation of tail bumpers.

A.4.4.1.3.1.14 Empennage protection.

Empennage protection shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.3.1.14)

The need for a bumper should be determined before an air vehicle is produced. Analysis is the only logical means to evaluate the full range of operational capabilities. The effectiveness of the bumper to provide the intended protection should be evaluated on the air vehicle. It can be accomplished as part of the routine observations. Some effort should be made to record frequency of strike to assist in evaluation of the operational adequacy.

VERIFICATION GUIDANCE (4.4.1.3.1.14)

TBS should be filled in with dynamic analysis of the air vehicle. The empennage protection operation and controls should be evaluated by air vehicle test.

Dynamic analysis should be conducted of all air vehicle ground and rotational operations to determine the need and the type of bumper.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.14)

(TBD)

A.3.4.1.4 Velocity and directional control

A.4.4.1.4 Velocity and directional control

A.3.4.1.4.1 Braking.

Braking shall be provided with the capability to __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.4.1)

This requirement is necessary to establish performance requirements for the braking system.

REQUIREMENT GUIDANCE (3.4.1.4.1)

TBS should be filled in with the level of performance expected. Differential control of braking is a desirable feature to permit the pilot to use the brakes for directional control. Anti-skid control should be considered, but may be optional. There may be reason to have both a secondary and an emergency braking system.

Consideration should be given to a protection circuit or indication to the pilot of an incipient skid so as to minimize the potential of a tire blowout.

REQUIREMENT LESSONS LEARNED (3.4.1.4.1)

This is a reflection of the criteria previously stated in MIL-B-8584, AFSC DH 2-1, and AFSC DH 1-6. It reflects the lessons learned from WWII aircraft and has been standard criteria for over ten years. The only recent innovation has been the use of anti-skid control on emergency brake systems and the double redundancy of dual actuation lines for normal and emergency systems.

A.4.4.1.4.1 Braking.

Braking shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.4.1)

Since the requirement is for a level of performance, the only suitable demonstration is for the total system.

VERIFICATION GUIDANCE (4.4.1.4.1)

Brake performance should be verified by analysis and laboratory tests. System performance should then be substantiated during flight testing.

VERIFICATION LESSONS LEARNED (4.4.1.4.1)

(TBD)

A.3.4.1.4.2 Directional control.

Directional control provided by the landing gear shall be as: __(TBS 1)__. Ground directional control characteristics shall permit the pilot to control the air vehicle under the following crosswind conditions: __(TBS 2)__.

REQUIREMENT RATIONALE (3.4.1.4.2)

Specific performance will be allocated to the landing gear steering, braking, propulsion and flight control systems. Two major requirements to be defined are: the expected performance during takeoff and landing, crosswinds and ground maneuvering of the air vehicle for other reasons. Both should be defined because the allocation to the landing gear steering system will be different for each case. The requirement to meet both is usually a steering system design driver.

REQUIREMENT GUIDANCE (3.4.1.4.2)

TBS 1 should reflect the air vehicle ground maneuverability of the air vehicle for all phase of ground operations. Normally for high speed small steering angles are required, where as for taxi and ground apron operations large steering angle control is needed. The system design and air vehicle control should be designed to reflect full operational capability to the users requirements to complete his mission. The following should be considered in determining the appropriate directional control:

a. Air vehicle geometry

b. Landing gear geometry

c. Width of runways and taxiways

d. Type of airfield surface (wet or dry)

e. Cargo handling (loading dock compatibility)

f. Takeoff and landing speeds

g. Thrust reversal

h. Crosswind.

TBS 2 should specify the crosswind condition limits under which the pilot should be able to control the air vehicle.

Since it is a full system requirement, the capability of the steering system is combined with various other techniques to identify the directional control capability desired for the total air vehicle.

REQUIREMENT LESSONS LEARNED (3.4.1.4.2)

a. A method frequently used to specify the ground maneuvering requirements is to establish the maximum width permitted for the air vehicle to make a 180° turn on a dry pavement without use of differential braking. This characteristic is usually presented in the flight handbook for each current air vehicle.

b. In some cases, obstacle clearance by the air vehicle may be more restrictive than pavement width available for ground turning. The flight handbook also normally provides characteristic data for current air vehicle.

c. Excessive reliance should not be placed on use of differential braking for ground maneuvering. Minimum radius turns using this approach are difficult to accomplish with precision. Also, this condition frequently results in the most critical landing gear loads. If used extensively, this will result in landing gear reliability problems. Directional control by differential braking is very unsuitable for air vehicle operation on soft surface airfields because it causes extreme surface damage. Turnaround requirements should not be so restrictive that they can be met only by a pivot turn.

d. If it is expected that the air vehicle will have a reverse thrust capability, it may be desirable to establish a direction reversal requirement more severe than can be accomplished by a normal 180° continuous turn. Operation of C-130, YC-14 and YC-15 air vehicle has shown that direction reversal by several movements of the air vehicle, including backing of the air vehicle, is a practical operation. Pilot experience has shown that the number of movements should be restricted to three.

e. Air vehicle ground directional control is usually severely degraded if the airfield surface is icy, wet or soft. This should not be ignored. However, establishment of a requirement for ground maneuvering on anything other than a dry concrete surface should be avoided. Experience has shown that verification of compliance on any other surface is impossible due to difficulty of accurate control of the many test variables.

f. Airfield geometry for standard construction is controlled by the following manuals. These may be useful in establishment of requirements:

1. AFM 86-3, Planning and Design of Theater of Operations Air Bases
2. AFM 86-8, Airfield and Airspace Criteria.

Some systems have tried to maintain a steering tolerance of .2°, which has proven to be very difficult to rig and maintain.

Overall landing gear arrangement and basic ground stability are significant factors in crosswind operating performance. This requirement should be compatible with the ground stability requirement.

Flight test experience has revealed that shock strut characteristics can influence crosswind-landing response. High breakout loads of the strut combined with aerodynamic characteristics of the air vehicle may result in failure of the air vehicle to attain a wings-level attitude during rollout. This may appear to the pilot as poor directional control.

This requirement should apply to operation on dry concrete airfield surfaces only. Crosswind performance is degraded on low coefficient of friction surfaces. However, verification of a stated requirement on such surfaces is difficult. Flight test evaluation on adverse surfaces should be accomplished for flight handbook data.

Systems to preposition landing gear for crosswind takeoffs and landings have been used on some air vehicle to improve crosswind-operating characteristics. Recent examples are the B-52 and C-5A. These systems are recommended only when justified by analysis of air vehicle handling qualities and pilot workload for crosswind operation.

A.4.4.1.4.2 Directional control.

Directional control performance of the landing gear system shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.4.2)

Due to the many variables involved in the air vehicle ground directional control characteristics, the only suitable verification method is test of the complete air vehicle. This normally is accomplished in three stages. The first is an evaluation for typical operation. This is a continuous process throughout the flight test program. The second is a planned evaluation for minimum radius turns on a dry paved surface. This is accomplished not only to evaluate the minimum radius turns that can be achieved by various pilot techniques, but also to measure resultant structural loads. The third phase, which will vary between air vehicle programs, is evaluation of directional control under adverse conditions. Adverse conditions can include wet surfaces, soft surfaces or failure of some air vehicle systems.

VERIFICATION GUIDANCE (4.4.1.4.2)

TBS: Performance of the ground control of the air vehicle should be demonstrated during taxi and flight testing for all operational missions and ground maneuverability.

VERIFICATION LESSONS LEARNED (4.4.1.4.2)

Verification of the steering system's ability to hold the air vehicle to 25 ft within 1000 ft is difficult to demonstrate on the air vehicle due to crown of the runways, alignment of the air vehicle to the centerline or line of reference, and centering of the steering system. More consideration is needed on how to verify whether the air vehicle can hold a straight line track as it travels down the runway. (Modify to not include numbers.)

A.3.4.1.4.3 Emergency directional control.

Emergency ground directional control provided by the landing gear, if required, shall be provided with the following characteristics: __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.4.3)

Some type of emergency directional control system should be provided to permit completion of the design mission or safe recovery of the air vehicle after failure of the normal directional control system. The design approach to provide an acceptable capability is highly dependent upon success criteria established by this requirement. It may be possible to meet the requirement with existing normal systems, or it may be necessary to provide secondary or redundant steering systems. In many cases, differential braking may qualify as the emergency directional control system.

REQUIREMENT GUIDANCE (3.4.1.4.3)

TBS should be filled in with consideration given to the following performance requirements for the emergency directional control system:

a. The emergency directional control system should permit the air vehicle to complete the operational mission after failure of the normal directional control systems. Completion includes recovery of the air vehicle to the base of origination without damage due to failure of the normal directional control system.

b. After failure of the normal directional control system, it should be possible for the air vehicle to maintain a path along the centerline of the runway (±10 feet) after landing (Sea level, Standard day).

c. The emergency directional control system should permit the air vehicle to maneuver from the soft surface runway without assistance from external power or equipment. Maneuver includes the ability to turn 180° in a maximum width of 100 feet.

d. No single point failure should cause loss of ground directional control.

The following parameters should be considered: air vehicle weight, air vehicle speed, type of runway surface (hard and soft), and control precision

REQUIREMENT LESSONS LEARNED (3.4.1.4.3)

(TBD)

A.4.4.1.4.3 Emergency directional control.

Emergency ground directional control characteristics provided by the landing gear shall be verified by: __(TBS)__.

VERIFICATION RATIONALE (4.4.1.4.3)

Verification is to ensure that emergency directional control is achieved.

VERIFICATION GUIDANCE (4.4.1.4.3)

TBS should reflect verification by analysis of system operation after the insertion of failures, either single point or normal control systems. The analysis may be supported by bench testing of system components with induced failures and air vehicle tests.

VERIFICATION LESSONS LEARNED (4.4.1.4.3)

With the advent of digital control systems, verification of failures and emergency systems has been a multi-phase verification. With computer simulations modeling various failures, watch the computer logic response. Then this is backed up with some "iron-bird" type of simulation to see if the hardware responds properly with the response of the software code for the inserted failure modes.

A.3.4.1.4.4 Braking and skid control

A.4.4.1.4.4 Braking and skid control

A.3.4.1.4.4.1 Braking control interface.

Braking control shall be applied by the following means: __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.4.4.1)

Rather than define the classical method of applying brakes through the rudder pedals, this requirement is adjustable for the situation. If the mission(s) or the state-of-the-art dictate a change in concept, the blank should reflect the desires.

REQUIREMENT GUIDANCE (3.4.1.4.4.1)

TBS should reflect the braking control method used. If no new method is used then the phrase, "foot pressure on the tip of the rudder pedal" should be inserted.

If foot pressure on the tip of the rudder pedal is used, the following should be considered:

a. Maximum breakout force at the tip of the pedal
b. Minimum force for full braking
c. Maximum force.
d. Maximum breakout force
e. Maximum force for full braking
f. Maximum travel
g. Travel for initial braking
h. Deceleration rate/application force gradient (mean)

i. Deceleration rate/application rate tolerance.

REQUIREMENT LESSONS LEARNED (3.4.1.4.4.1)

This requirement reflects the criteria previously contained in MIL-B-8584. The intent was to standardize the brake application methods so that transition by pilots from one air vehicle to another will not result in confusion in the event of an emergency, which requires fast application of brakes. The initial source of the requirement is not known.

Refer to JSSG-2010 for further information on brake activation controls. This is a critical control and the use of a non-standard activation method should not be permitted without consulting with the crew systems design group.

Brake controls should be provided to both the pilot and co-pilot. In any position of the foot there should not be a tendency for the pilot to apply brake effort unintentionally during the normal use of the rudder pedals or during arrested landings. Equal positive action of the brake system should be provided when the air vehicle is moving forward or aft with the same effort on the brake pedal or brake-operating control.

Some foreign air vehicles utilize a hand lever for brake application.

Pedal position for pilots of varying heights and leg lengths can be a problem.

The MIL-B-8584 paragraph on “Power operated systems, Types II and III” calls for landplane landing weight pedal brake force of 65 to 85 pounds. This has been found to be too high for comfortable pilot control. The forces were reduced to the 35 to 65 pound range for the B-2 and 50 to 75 pound range for the C-17. It is recommended that the pedal force for landplane operation be between the 35-65 pound force range. It may be desirable to restate the requirement to read: "Brake pedal forces shall not to exceed 60 lbs for a 10 ft/sec squared at landplane landing weight deceleration, and 150 lbs for maximum braking.”

A.4.4.1.4.4.1 Braking control interface.

Braking control interface shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.4.4.1)

Since braking control suitability is subjective, the evaluation is qualitative and subject to personal preferences. A mock-up or actual air vehicle should be used for preliminary evaluation. Final review is subject to program limitations.

VERIFICATION GUIDANCE (4.4.1.4.4.1)

TBS should be filled in with mock-up evaluation, air vehicle taxi and flight testing.

VERIFICATION LESSONS LEARNED (4.4.1.4.4.1)

(TBD)

A.3.4.1.4.4.2 Alternate independent braking.

Separate and independent braking shall be provided with the capability to __(TBS 1)__ with __(TBS 2)__ failures.

REQUIREMENT RATIONALE (3.4.1.4.4.2)

This requirement is necessary to establish performance requirements for the alternate braking system. An alternate braking system is nearly always required. Experience indicates that an alternate system is essential to provide adequate safety and reliability.

REQUIREMENT GUIDANCE (3.4.1.4.4.2)

TBS 1 should be filled in with the level of performance expected. Normally, the stopping performance should be equal to that provided by the normal system. Differential control of braking is a desirable feature to permit the pilot to use the brakes for directional control. Anti-skid control should be considered, but may be optional. There may be reason to have both a secondary and an emergency braking system which should be specified: “A secondary braking system, separate and independent of the primary system, should be provided. The backup system should have braking capabilities equivalent to the primary system. An emergency braking system should be provided with sufficient capability to perform a maximum energy stop with pilot metered braking.” Such a design concept may be need to preclude any single failure causing loss of normal brake functions.

TBS 2 should define the number of non-structural failures.

Consideration should be given to a protection circuit or indication to the pilot of an incipient skid so as to minimize the potential of a tire blowout.

The design and marking of the alternate brake control should be coordinated with the crew system design group.

REQUIREMENT LESSONS LEARNED (3.4.1.4.4.2)

This is a reflection of the criteria previously stated in MIL-B-8584, AFSC DH 2-1, and AFSC DH 1-6. It reflects the lessons learned from WWII air vehicle and has been standard criteria for over 10 years. The only recent innovation has been the use of anti-skid control on emergency brake systems and the double redundancy of dual actuation lines for normal and emergency systems.

There are various approaches to emergency brake system design. In the 1950 time period, it was common practice to provide emergency braking from an auxiliary air bottle. These designs had limited capacity, utility, and effectiveness. They did not operate through the anti-skid control system and there were often blown tires with the use of this type of emergency brake system. They had separate lines to a shuttle valve at the brake. Since this was a different media than the normal system, extensive system bleeding was required after their use.

Another disadvantage of the air bottle emergency system is the limited capacity. If the pilot "pumps" the brakes, he will deplete the system and could have insufficient capacity to complete the stop.

Another recent design approach to emergency brake design is to provide dual lines to the brakes from different hydraulic systems. Each system has the capability to stop the air vehicle. The F-111, B-1, and F-16 utilize this approach.

Usually with pilot directed brake pressure, there is little or no sense of deceleration or "feel" for tire skidding. The problem is further aggravated by the pressure differential between the normal and emergency braking systems for the same pedal deflections. One successful method was a "foot thumper" which caused a small pin in the brake pedal to "thump" the pilot's foot when the tire started into a skid, thus allowing the pilot to back off the pedals. This also assisted the pilot in metering the pressure up to the point of skidding, thus providing a means of achieving maximum deceleration without a blowout in emergency conditions.

Since the normal and emergency brake systems may not provide comparable pressure to the brakes for the same pedal position, it is desirable for the condition of the wheel to be indicated in the cockpit. This is necessary because in most air vehicles the pilot does not have a "feel" of locked wheels or air vehicle deceleration in the cockpit. A foot pulsar has been used in one case to fulfill this need.

The logic of the anti-skid allowed brake pressure only when both Main Landing Gear (MLG) and Weight On Wheels (WOW) switches indicated weight on (Touchdown Protection). But the MLG strut design allowed enough strut deflection during taxi turns to trip the WOW switch off, causing the anti-skid to go into touchdown protection mode.

A.4.4.1.4.4.2 Alternate independent braking.

Alternate braking shall be verified by flight test.

VERIFICATION RATIONALE (4.4.1.4.4.2)

The requirement is for a level of performance, thus, the only suitable test is of the total system.

VERIFICATION GUIDANCE (4.4.1.4.4.2)

The alternate brake performance should be verified by analysis and laboratory tests. System performance should then be substantiated during flight-testing.

VERIFICATION LESSONS LEARNED (4.4.1.4.4.2)

(TBD)

A.3.4.1.4.4.3 Skid control.

Skid control shall be tuned for optimum performance on a __(TBS)__ surface, considering both braking and cornering forces throughout the control speed range.

REQUIREMENT RATIONALE (3.4.1.4.4.3)

There has been a tendency within Industry to attempt to achieve a minimum stop distance on a dry runway, and then to assume a factor to be applied to predict wet stop distances (FAA). This is demonstrated most safely and under more controlled conditions. However, the real need of the system is to have the skid control system to be tuned on the surface where the greatest need exists. Therefore, every attempt should be made to tune the production adjustments or the anti-skid brake control system for a wet runway, where the performance is most critical. The brake and skid control system should provide differential braking control, locked wheel protection, touchdown protection, parking brake function, anti-spin on retraction, and hydroplaning protection. In addition, the brake and skid control system should permit holding the air vehicle at a full stop and locked wheel pivot turns.

REQUIREMENT GUIDANCE (3.4.1.4.4.3)

Stopping distance is not the only factor to be considered. Cornering power is equally important on runways experiencing adverse weather. Crosswinds may dictate that differential controls to assist steering are equally important to stopping performance. This should be considered equally in tuning the system.

TBS: the anti-skid system should operate satisfactorily under the following conditions:

a. Prevent tire flat-spotting and never permit a completely locked brake within the control speed range when the brake will respond to control.

b. From maximum ground operation speed to the lowest speed compatible with ground handling, not to exceed 10 knots.

c. Should not induce airframe dynamic instability, gear walking, gear chatter.

d. Tuned for optimum performance on a wet runway, a dry runway, and combination of wet and dry surfaces, considering both braking and cornering forces, throughout the control speed range.

e. At temperatures from -65°F to +160°F.

f. When conditions are imposed which duplicate the environment of sea coast regions.

g. Environmental conditions of 100 percent (100%) humidity, including conditions in which condensation occurs in the form of water or frost.

h. When subject to pressure variations associated with altitude ranging from 1300 feet below sea level to the maximum operational altitude of the air vehicle.

i. Under conditions consisting of blowing sand and dust particles as encountered in desert areas.

j. Environmental conditions such as explosive atmosphere, translational accelerations, acoustical in the region where the hardware is mounted, vibrations, shock, and fungus.

REQUIREMENT LESSONS LEARNED (3.4.1.4.4.3)

This criterion is generally stated in MIL-B-8075. Difficulty has been encountered on numerous systems where the anti-skid control system components are adjusted to provide minimum stop distance on a dry concrete surface. Then the wet runway performance is left to chance and is frequently less than optimum. The requirement for consideration of wet system adjustment was not introduced into specification language until 1971. Prior documentation reflected ancient state of the art design and evaluation. Coordinate the anti-skid activation controls and location with the crew station group.

In tuning an anti-skid system or adjusting the response rates for production, there is significant risk in tailoring the system for dry runway performance. The available coefficient is relatively constant with a dry surface as compared with a wet surface. Therefore, system response or sensitivity can be improperly placed from dry runway testing. This usually is the direct result of establishing guaranteed stop distances on dry surfaces, but not requiring specific performance on wet. It is extremely difficult to define a wet surface and to control it in flight test for demonstration. It is dependent upon the surface (micro-texture), the runway construction, and the rate of water input.

Factors to be considered in anti-skid tuning and operation are features such as locked wheel protection and interaction if the brakes are paired, touchdown protection to prevent lock-up or flat spotting upon initial contact with the runway, and the degree of sophistication desired. Anti-skid systems vary in performance from anti-locked wheel devices to approaching automatic braking systems. Some commercial and T-43 brakes are automatically applied without pilot effort and function to a pre-selected deceleration rate.

There are several basic design approaches to anti-skid system in terms of hydraulic control. One is paired wheel control and another is individual wheel control, with various combinations of each. For single wheel gear air vehicle such as used on fighters, more use has been made of paired wheel control. This decision is made primarily for dynamic stability and ground control reasons. If release and reapplication of brakes on one side of the air vehicle at a time can induce control problems, paired wheel control should be considered. However, individual wheel control is more efficient from a stopping efficiency point of view, because each braked wheel is producing all the torque that is possible. With paired wheel control designs, caution should be used in valve selection to insure retention of differential braking capability in crosswind situations. Some systems reduce both wheels to a common threshold pressure and offset the differential pressures that the pilot thinks that he is applying. Other paired wheel control valves operate like individual wheel control systems.

A.4.4.1.4.4.3 Skid control.

Skid control shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.4.4.3)

Ultimately, the final production tuning should be done on the air vehicle, but there are various approaches to preliminary evaluation. These include computer simulation and working simulators. The verification should be tailored to reflect the economic coordinated method used for other systems.

VERIFICATION GUIDANCE (4.4.1.4.4.3)

TBS should be filled in with "The brake and skid control system performance, including efficiency and compatibility with interfacing subsystems, shall be initially evaluated by computer simulation analysis; final verification shall be performed by air vehicle test subsequent to final production tuning. Tuning performance verification shall include operation on a wet runway and shall be accomplished with an instrumented air vehicle. The effects of system malfunction shall be evaluated by analysis and validated by computer simulation. The operating characteristics of the anti-skid system and design features of the system shall be verified by inspection."

Verification of the anti-skid should include the following:

a. Freedom from air vehicle dynamic instability due to anti-skid brake control operation will be demonstrated on the air vehicle throughout the forecasted air vehicle operation spectrum.

b. Document all test conditions, test equipment, and test procedures for component preproduction tests.

c. Analysis of brake control system performance under various anti-skids, air vehicle (including wing lift), runway surface conditions, brake system inputs should be considered.

d. Analysis of the effects of various system part failures should be considered. Those failures not adequately covered by analysis should be simulated by appropriate laboratory tests.

e. Operational checkout procedures should be developed to detect all failures.

VERIFICATION LESSONS LEARNED (4.4.1.4.4.3)

(TBD)

A.3.4.1.4.4.4 Skid control with power interruption.

During interruption of power to or malfunction of the skid control the system shall __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.4.4.4)

It is the intent of this requirement to state how the system responds to circumstances of power interruption or system malfunction. It indicates the reaction that is most acceptable for system design.

REQUIREMENT GUIDANCE (3.4.1.4.4.4)

TBS should be filled by specifying an acceptable means for responding to power interruption or system malfunction. For example, “return to pressure as metered, with adequate pilot notification.” Or “metered brake pressure is dumped and the braked wheels are free rolling until the alternate brake system is activated.” There may be other logical choices of action for system power interruption or malfunction that should also be considered.

REQUIREMENT LESSONS LEARNED (3.4.1.4.4.4)

The source of this requirement is MIL-B-8075. A requirement similar to this has been in force since the anti-skid systems first were introduced into USAF aircraft around 1954-55. The failure response mode has been questioned on numerous occasions and user preference appears to be the criteria that should be applied.

On fighter air vehicle or relatively simple multi-tired gear designs, most systems revert to manual upon system failure with suitable notification to the pilot. On complex systems, such as the C-5A, the affected wheel and brake assembly is isolated and the remainder of the system continues to function with anti-skid control.

If the gear was not retracted on a touch-and-go, the anti-skid should be capable of resetting its touchdown protection circuit to provide touchdown protection for each subsequent landing regardless of gear cycling.

A.4.4.1.4.4.4 Skid control with power interruption.

The effects of power interruption and system malfunctions shall be verified by: __(TBS)__.

VERIFICATION RATIONALE (4.4.1.4.4.4)

There are numerous means of evaluation of anti-skid system malfunction. These include failure mode analysis under the reliability program, simulator studies on the full scale landing gear mock-up, and flight test evaluation. The flight test portion is normally on a routine monitoring.

VERIFICATION GUIDANCE (4.4.1.4.4.4)

TBS should specify that computer simulations and analysis, with the results being substantiated by on air-craft demonstration and checkout of system switching logic parameters.

VERIFICATION LESSONS LEARNED (4.4.1.4.4.4)

Often test sets will not detect all types of failures and causes. Generally, the using activity observes the test set or warning light and, if functioning, will assume the unit is acceptable when in fact those lights only indicate failures of a specific type. Operation instructions, including failure modes and effects, are desirable.

A.3.4.1.4.4.5 Anti-skid engagement and disengagement.

A means shall be provided, if required, to engage or disengage the anti-skid.

REQUIREMENT RATIONALE (3.4.1.4.4.5)

This requirement is to provide a means for the pilot to override anti-skid system operation. It permits the pilot to select normal braking without anti-skid as an alternative to emergency braking. This is desirable if the emergency system has limited capacity or is difficult to control.

REQUIREMENT GUIDANCE (3.4.1.4.4.5)

The anti-skid override is usually accomplished by removing power from the anti-skid control box. The control for this can vary from a circuit breaker to a switch (stick or panel mounted) to a complex control and warning system (semi-automatic shut down). The control should be as simple as possible. Braking force should be that commanded by the pilot. The pilot should be provided with a warning that the anti-skid has been disabled."

REQUIREMENT LESSONS LEARNED (3.4.1.4.4.5)

The criteria for pilot control is a restatement of requirements previously stated in specification MIL-B-8075 and AFSC DH 1-6.

In the past it has frequently been desirable to shut off anti-skid during taxi to prevent unexpected brake release. The argument against the control is that it leads to inadvertent operation without anti-skid. Also, if the pilot is given several alternatives, he may try all of them and overrun the runway. (direct selection of an emergency system may provide a shorter total stop distance).

Most older air vehicle utilize an on-off switch for the anti-skid control system. Without anti-skid protection it is much easier to flat spot or blow out the tire. The heavier the air vehicle the more likely the pilot will not know he is locking up a wheel until the tire blows. With digital technology it is easy to design two or more equivalent braking control systems that switch back and for between them almost instantaneously without the loss of any braking performance. Therefore, strong consideration should be given to determine whether the pilot can operate without anti-skid. If not, then the requirement is to design a redundant braking system that switches automatically and let the pilot know that it has switched.

A.4.4.1.4.4.5 Anti-skid engagement and disengagement.

The means to engage and disengage the anti skid shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.4.4.5)

To ensure that the switching logic works appropriately for all the condition that the system is engaged and disengaged.

VERIFICATION GUIDANCE (4.4.1.4.4.5)

TBS should reflect verification by computer simulations and the results substantiated by on air vehicle checkouts and flight testing. The anti-skid control and switching logic should be modeled on the computer and applied to a laboratory simulator.

VERIFICATION LESSONS LEARNED (4.4.1.4.4.5)

(TBD)

A.3.4.1.4.5 Nose wheel steering

A.4.4.1.4.5 Nose wheel steering

A.3.4.1.4.5.1 Steering characteristics.

Nose wheel steering shall have the following characteristics: __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.4.5.1)

Usually some form of nose gear steering will be required to provide adequate directional control. If this should be the case, it may be desirable to specify some characteristics. This is required to standardize controls and insure that air crew procedure is similar to previous air vehicles to minimize air crew transition training.

REQUIREMENT GUIDANCE (3.4.1.4.5.1)

TBS should be filled in with consideration given to the following:

a. Steering control force

b. Steering rate

c. Ability to track a straight line

d. Steering deadband

e. Method of control (rudder pedals or wheel)

f. Indicators (strut marking, warning lights)

g. Self-test provisions

h. Shimmy damping. Shimmy damping should be provided at all times, including with or without steering engaged, and during power system failures. Shimmy damping should be maintainable without dependency on replacement of normally wearing parts.

i. 360° swivel. Should provide 260° full swivel of the nose landing gear wheel without disconnection of or damage to any air vehicle component.

j. Power Recovery of the nose landing gear wheel to the commanded position should be possible from any wheel angle within the powered steering range.

k. System stability should be controlled to the commanded position without hunting, chatter, or instability under all conditions when installed and operating on the air vehicle.

l. Positive trail should be provided to allow recovery to neutral from any powered steering angle when the system is disengaged during taxi.

m. Nose wheel centering should be automatically provided when the nose wheel is airborne.

n. Static nose wheel steering should be provided to give sufficient torque to turn through the full steering range statically at the maximum weight with brakes applied on dry pavement, on unprepared site of some specified CBR and with tires initially frozen to the ground.

Coordinate the activation and location of the steering controls with the crew station group.

REQUIREMENT LESSONS LEARNED (3.4.1.4.5.1)

This requirement is to provide a method of including specific design characteristics that have previously been directed by MIL-S-8812, MIL-STD-203, and AFSC DH 2-1. System rate and response characteristics have not been quantitatively stated in the past, but rather have been controlled by test pilot consensus. In the future, it may be desirable to establish quantified requirements to permit more orderly development of the system. The type of control (rudder pedal or wheel) has been dictated in the past by MIL-STD-203. Steering indication systems and built-in test have been given little consideration in the past.

Past air vehicles have generally been designed to the following criteria:

a. The steering system should be designed with sufficient output torque to permit turning the steered wheels through the full range without the aid of motion or the air vehicle or engine thrust or auxiliary power. The steering capability should be available throughout the design temperature range of the air vehicle, and with the most critical combination of weight and center of gravity at engine idle thrust and a design coefficient of friction of 0.80 at the tire ground interface. The tires should be inflated in accordance with applicable servicing instructions, and all brakes may be assumed to be released unless normal engine idle thrust is sufficiently high to cause motion.

b. Testing has indicated that the actual maximum tire to ground friction coefficient may be less than 0.8. Air vehicles that have little or no capability to turn the nose gear with the air vehicle static have generally been unacceptable and required redesign to increase steering torque.

c. Flight and laboratory tests indicate that excessive nose gear steer angle during takeoff and landing, particularly on slippery surfaces, is likely to result in over control by the pilot. If excessive steering angle is used, the turning force may be less than the maximum available. This has caused several air vehicle accidents. Consideration should be given to restriction of steer angle during takeoff and landing to preclude this problem.

d. Development of suitable steering rate and control force have been problem areas on several recent air vehicle developments (C-141, F-15). Frequently, the problem involves excessive deadband in the control, control hysteresis, or poor pedal geometry. Careful analysis of initial flight test results is recommended to insure timely detection and correction of problems. Quantitative control criteria to avoid problems by good design are desirable but not available.

e. Deflection of cables, pulleys, pulley mounts, and pulley mount back up structure is a frequent cause of poor response in systems with mechanical control.

f. Military Standard 203 (MIL-STD-203) required use of hand wheel steering in cargo air vehicles. This is desired because it permits smoother operation during taxi, providing a better ride for passengers. Recent work with prototype air vehicles indicates that perhaps the advantages of the steering wheel are not clear cut for tactical cargo air vehicles. At the present time it is probably best to leave the type of steering control unspecified.

g. Some air vehicle steering systems have a method to show the pilot the nose gear steering angle. One evaluation reveals that such indicators are seldom used and may be of little value. On some air vehicles it may be desirable to indicate that landing gear are not centered. Indicators on the landing gear showing steering angle are useful for rigging of the steering system.

h. The caster axis for wheel swivel or rotation should be vertical.

i. Ensure the free-play, friction, and steering load path are design to be stable.

Damping should be provided to preclude shimmy through the speed range for wheel ground contact.

Damping provisions should be in accordance with MIL-S-8812.

Unless otherwise specified in the detail specification, nosewheel steering should be provided in accordance with MIL-S-8812.

If at all possible, avoid putting the steering actuator on top of the strut, try to keep the steering power as close to the torque arms as possible. This minimizes the effect of freeplay, wear, and friction in the shimmy tendency of the gear.

See the structure section on shimmy to keep the trail distance between 1-5 inches for better chance to have a stable design.

Avoid designs where the gear has to be rotated to be stored.

Avoid designs where unequal or unsymmetrical loading goes into the gear.

For design's that exhibit shimmy it has been found that hanging a mass damper on the strut, in particular forward of the gear, has been able to move the shimmy onset speed to a level higher than air vehicle rotational speed.

A.4.4.1.4.5.1 Steering characteristics.

Steering characteristics shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.4.5.1)

Performance Of the steering system is the result of the complex interaction of air vehicle subsystems and geometry. Flight test of the complete air vehicle is considered the only valid verification method. Usually, this can be accomplished concurrently with flight performance testing. However, it may be necessary to augment testing by formal test or demonstration of the adverse steering conditions. Engineering analysis during development is desirable to insure successful test. However, it is not required for verification.

VERIFICATION GUIDANCE (4.4.1.4.5.1)

TBS: Steering characteristics should be verified by an analysis, flight test and a formal demonstration of the steering system operation with the static air vehicle should be accomplished to determine compliance with factors that cannot be verified by flight test. Configuration design requirements should be verified by inspection of engineering drawings and hardware.

The verification should cover at least the following: Compliance with system performance and control requirements including power recovery, torque output, and control stability should be verified by analysis and ground test. Adequate positive trail and 360° swivel should be verified by demonstration on the air vehicle. Configuration design requirements, including centering should be verified by inspection of drawings and hardware, and demonstration on the air vehicle (on jacks). The effects of system failure should be verified by analysis.

VERIFICATION LESSONS LEARNED (4.4.1.4.5.1)

(TBD)

A.3.4.1.4.5.2 Response to nose wheel steering failure.

No single or multiple failures of the nose wheel steering control, including hydraulic or electrical power, shall cause the air vehicle to depart the runway.

REQUIREMENT RATIONALE (3.4.1.4.5.2)

This requirement is to influence the contractor in selection of the type of steering system to be used and the degree of redundancy to be provided when there is loss of the steering function. It should be tailored to recognize the importance of steering to the particular air vehicle.

REQUIREMENT GUIDANCE (3.4.1.4.5.2)

In the event of nose wheel steering, including a power system failure, the steering system should provide for automatic or manual switching to a backup system or deselection to a free caster mode in sufficient time to avoid departing the runway

The following should be considered:

a. Maneuverability of the air vehicle without steering
b. Operating environment
c. Performance of similar air vehicle.

REQUIREMENT LESSONS LEARNED (3.4.1.4.5.2)

This item reflects criteria previously identified in MIL-S-8812. Requirements on failure mode and effect were introduced into this document in 1975 and they represent input from industry.

Some air vehicle incorporate dual sources of steering power. This should be considered for air vehicles that must have operable steering to maintain control for takeoff and landing. It may also be desirable for air vehicle that cannot be taxied by use of differential brakes and thrust. Secondary systems should be pilot selectable after the air vehicle is on the ground and should not degrade braking performance.

A.4.4.1.4.5.2 Response to nose wheel steering failure.

Adequate response to nose wheel steering failure shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.4.5.2)

This requirement usually will be such a low rate of occurrence that demonstration by flight test is not practical. Verification should be by use of a failure mode analysis combined with historical failure - rates of similar equipment. In some cases, it may be difficult or impossible to determine the result of some component failures. The effects of such failures should be investigated by simulation on a laboratory simulation of the system or on the air vehicle.

VERIFICATION GUIDANCE (4.4.1.4.5.2)

TBS should be filled in with analysis, computer simulations, systems checkout and demonstration on the air vehicle to ensure proper system response to failures of the nose wheel steering system and power supply.

VERIFICATION LESSONS LEARNED (4.4.1.4.5.2)

(TBD)

A.3.4.1.4.5.3 Emergency steering.

In the event of failure of primary nose wheel steering, emergency nose wheel steering, if required, shall be provided with the following characteristics: __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.4.5.3)

If a nose wheel steering system is required to provide adequate directional control, consideration should be given to directional control in the event of failure of the system.

REQUIREMENT GUIDANCE (3.4.1.4.5.3)

TBS should define unique requirements. Possible characteristics include: pilot or automatic selection of an alternate power system, indication or primary failure, type and amount of steering to be accomplished, emergency steering should not degrade normal or emergency brake system performance.

REQUIREMENT LESSONS LEARNED (3.4.1.4.5.3)

A requirement for emergency steering capability has been a requirement of MIL-S-8812 since 1969. However, most military air vehicles achieve emergency directional control with differential brakes or rudder control.

a. Emergency systems that operate by providing a second source of hydraulic pressure should be designed with care to prevent creation of additional critical failure modes. Emergency steering should be designed so that it does not degrade normal or emergency braking.
b. The question of automatic or pilot selected emergency steering should be carefully considered. Automatic selection reduces pilot workload and provides minimum transfer time. Pilot selection, on the other hand, reduces the possibility of depletion of the emergency system before the critical operating period. All hydraulic selector valves should be designed so that fracture of the valve body will not result in loss of both steering systems.
c. Steering systems that use two sources of power for normal operation have been used to fulfill this requirement. Consideration should be given to whether operation with one system failed will provide sufficient steering torque for emergency operation.

d. Use of differential braking for directional control is often considered a suitable substitute for an emergency steering system. This may not be a suitable approach for air vehicle with complex landing gear arrangements, narrow landing gear tread, or unpaved airfield operating requirements.

A.4.4.1.4.5.3 Emergency steering.

Emergency steering shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.4.5.3)

Performance of the emergency steering system is the result of a complex interaction of air vehicle subsystems and configuration. Suitability can be determined only by test of the complete air vehicle.

VERIFICATION GUIDANCE (4.4.1.4.5.3)

TBS should be filled in with analysis and a flight test. Adequacy of the emergency steering system should be verified by analysis and tested on the air vehicle.

VERIFICATION LESSONS LEARNED (4.4.1.4.5.3)

(TBD)

A.3.4.1.5 Actuation control

A.4.4.1.5 Actuation control

A.3.4.1.5.1 Retraction and extension actuation interface.

A means shall be provided to actuate retraction and extension of the landing gear.

REQUIREMENT RATIONALE (3.4.1.5.1)

The intent of this requirement is to identify the technique required for landing gear actuation.

REQUIREMENT GUIDANCE (3.4.1.5.1)

Normally the gear actuation should be accomplished by actuation of a standard gear handle. This requirement should be coordinated with crew systems.

REQUIREMENT LESSONS LEARNED (3.4.1.5.1)

(TBD)

A.4.4.1.5.1 Retraction and extension actuation interface.

Retraction and extension actuation interface shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.5.1)

Normally, the suitability of the design, location and operation of the landing gear control can be evaluated by inspection of engineering drawings, crew station mock-ups, or actual hardware. Unusual designs may require pilot evaluation during flight test or formal demonstration to verify suitability.

VERIFICATION GUIDANCE (4.4.1.5.1)

TBS should be filled with inspection of drawings.

VERIFICATION LESSONS LEARNED (4.4.1.5.1)

(TBD)

A.3.4.1.5.2 Gear door actuation and locking.

If required, fairing door actuation and locking shall be __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.5.2)

The objective of the requirement is to establish the relationship and mechanical interface of the gear and door actuation and locking system. Usually, this statement will be completed by the phrase: “automatically sequenced with the landing gear actuation.” The intent here is to minimize aircrew workload and to standardize aircrew procedures. In some special cases, however, it may be desirable to provide controls for separate operation of the fairing doors. An example would be to open doors that are normally closed for ground operation.

REQUIREMENT GUIDANCE (3.4.1.5.2)

TBS should be filled with “automatically sequenced with the landing gear actuation. Retraction or extension of any single landing gear shall not depend on satisfactory operation of any other landing gear.“

REQUIREMENT LESSONS LEARNED (3.4.1.5.2)

This item was previously contained in AFSC DH 2-1 and AFSC DH 1-6. The requirement dates back to ARDCM 80-1 or HIAD in the 1955 time period.

a. Landing gear and door sequencing is frequently a major source of problems in development of a new air vehicle. The best approach is to minimize or eliminate sequencing by elimination of landing gear fairing doors, or by connecting the doors directly to the landing gear. Serious consideration should be given to statement of this design approach as a part of this requirement.

b. Current air vehicle use one or more of the three basic types of sequencing: mechanical, hydraulic, or electrical. Mechanical consists of use of links, bellcranks, and torque tubes to transfer landing gear motion to door drive motion. Hydraulic includes use of priority valves, actuator internal porting, or mechanically actuated valves to operate door actuators at a proper time in the landing gear operation. Electrical consists of detection of landing gear and door positions by electrical switches to enable control of relays or solenoid operated hydraulic valves to apply power in the proper sequence.

c. F-5, F-15, and T-38 type aircraft include separate door controls so that doors can be opened for ground maintenance. This introduces several design problems. The first is that it may present operational problems if doors are not returned to proper position before flight. The actuation sequence and in-flight performance should not be degraded by this maintenance error. As an alternative, the error should be correctable by the pilot while the air vehicle is in flight. Separate operation of doors also results in a need for door ground locks to prevent inadvertent ground operation while personnel are in the wheel wells. Control switches should be located so that the operator is clear of the door operation, but so that he can readily determine that all personnel are clear of the doors.

d. Proper operation of some sequencing methods is very dependent upon hydraulic pressure, hydraulic flow, dynamic loads, and aerodynamic loads. It is essential that it be possible to check the system for proper operation with the air vehicle on jacks. Ground checkout set up and test procedures should be developed that adequately simulate the in-flight operation. If this is not possible with the proposed design, the design should be changed to provide a practical operational air vehicle.

e. Proper timing of landing gear door locks to the door drive system is a frequent problem area. Usually, some type of time delay is used to insure door unlocking is complete before doors are powered open. Time delay systems are not fail safe and sometimes will not perform properly at extreme temperatures. Door unlock detection systems avoid these problems, but add significantly to control circuit complexity.

f. The effect of landing gear and door actuation dynamics on proper sequencing of door locks is frequently overlooked. Rebound of the door from the closed position may prevent proper locking. Oscillations may combine with control circuit characteristics to cause buzz or chatter of doors and locks. This can be avoided by decelerating the door near the closed position and by use of a time delay to insure that door closed and locked force is maintained for seven to ten seconds after initial indication of locking.

g. Nose door has locks on the door as the result of a late design change to an aft retracting nose gear configuration. Low observability requirements led to more locks than on other air vehicles. Compounding the rigging problem is the flexibility of the composite door.

h. When loads are high on all doors increases the criticality of the latch sequence timing. The fall out of this is very tight rig requirement. Unfortunately, the adjustments are made on the connecting rods which have threads that are too coarse for the required levels of accuracy. High loadings on the hooks and rollers led to galling problems which was addressed by changing the coatings on the surfaces.

A.4.4.1.5.2 Gear door actuation and locking.

Landing gear door actuation and locking shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.5.2)

Proper operation of the landing gear and doors is the result of a complex interaction of air vehicle subsystems, dynamic and aerodynamic loading. It can be evaluated only by flight test of the air vehicle. Preliminary verification by analysis, laboratory test of a simulated system, and with the air vehicle on jacks, is highly recommended to minimize flight test time and cost.

VERIFICATION GUIDANCE (4.4.1.5.2)

TBS should be filled with inspection of drawing and hardware followed with demonstration on the air vehicle during checkouts and in flight testing.

VERIFICATION LESSONS LEARNED (4.4.1.5.2)

(TBD)

A.3.4.1.5.3 Single failure criteria.

No single point nonstructural failure, including power interruption or unmated connector, shall prevent gear extension or cause mis-sequencing.

REQUIREMENT RATIONALE (3.4.1.5.3)

This requirement is needed to ensure that the landing gear will extend and lock with a single point nonstructural failure, including power interruption or unmated connector.

REQUIREMENT GUIDANCE (3.4.1.5.3)

The design should be such that there is no single failure in the power and electrical portion of the actuation system that will prevent the extension of the landing gear.

REQUIREMENT LESSONS LEARNED (3.4.1.5.3)

The past approach was to specify a general level of redundancy and to prohibit or require certain design features. Requirements were contained in AFSC DH 2-1.

Consideration should be given to the fact that air vehicle with multiple landing gears may be able to land with one landing gear retracted. This may require modification of this requirement statement. Landing with one assembly retracted will impose some weight limit and may require special techniques. Operating limits should be evaluated by analysis to insure that they provide a useful emergency capability. Flight test to evaluate technique should be accomplished. This approach was successfully used in development of the C-5A aircraft.

A.4.4.1.5.3 Single failure criteria.

It shall be verified that no single point nonstructural failure, including power interruption or unmated connector, shall prevent gear extension or cause mis-sequencing by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.5.3)

The acceptable level of failure is normally so low that verification by test is not practical. The requirement should be verified by failure mode and effects analysis of the extension system combined with historical failure rate data for similar components. In some cases, it may be necessary to accomplish laboratory testing to verify failure modes and effects, and to establish failure rate data for new design components.

VERIFICATION GUIDANCE (4.4.1.5.3)

TBS should be filled in with inspection of drawing, design logic and schematics to eliminate single failure points. Extension with failures induced should be verified by demonstration, either on the air vehicle or on a simulator if available.

VERIFICATION LESSONS LEARNED (4.4.1.5.3)

(TBD)

A.3.4.1.5.4 Actuation reversal.

Reversal of the landing gear control during actuation shall result in the landing gear going to the last position selected.

REQUIREMENT RATIONALE (3.4.1.5.4)

This requirement is to ensure that consideration is given to system operation if the command is changed before the system completes an earlier command. In some cases, however, it may be necessary to use some other scheme to avoid system design problems. Then the requirement should be changed accordingly.

REQUIREMENT GUIDANCE (3.4.1.5.4)

This requirement is to ensure that the landing gear actuation system will not “hang-up” under any motion of the control handle and prevent the gear from finally going to the last commanded position.

REQUIREMENT LESSONS LEARNED (3.4.1.5.4)

This requirement is from the AFSC DH 2-1.

It may not be possible to meet this requirement with a system fairing door actuation. F-15 experience indicates that this is the case for a design that requires that fairing doors be closed after extension of the landing gear.

All systems should be analyzed in the design stage to determine if there are any critical time periods that a control reversal will create a problem. Consideration of dynamic loads and time delay functions of the system may be required for an accurate analysis.

Control reversal characteristics after single component failures in complex electrical control and indication systems should also be reviewed. Failure of a single switch may not only give an indication that the landing gear is not in the position selected, but also disrupt normal sequencing.

It may be proposed that this requirement be modified to establish a time limit on reversal or that the landing gear immediately go to the last position selected. The concern is that a landing gear that must go fully to the first position selected will take excessive time to reach the last position. Modification of the requirement in this form should be resisted because it may complicate the design and increase cost excessively.

A.4.4.1.5.4 Actuation reversal.

The ability of the landing gear during actuation to go to the last commanded position shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.5.4)

Control reversal characteristics of the actuation system may be very dependent upon system dynamic, hydraulic supply characteristics and aerodynamic loads. Verification of the characteristics should, therefore, be accomplished by flight test of the air vehicle.

VERIFICATION GUIDANCE (4.4.1.5.4)

TBS should be filled in with landing gear simulator and demonstrated on the first air vehicle prior to first flight. Usually, this is accomplished as a part of the subsystem functional test after initial assembly. A retest of control reversal characteristics should also be accomplished with the air vehicle on jacks whenever test air vehicle are modified by components that affect the retraction or extension sequence.

VERIFICATION LESSONS LEARNED (4.4.1.5.4)

(TBD)

A.3.4.1.5.5 Airspeed operational criteria

A.4.4.1.5.5 Airspeed operational criteria

A.3.4.1.5.5.1 Retraction.

Retractable landing gear shall retract into an aerodynamically faired enclosure and the fairing doors if used, shall close and lock without damage at all airspeeds up to (TBS 1) for flight at (TBS 2) within a time no greater than (TBS 3) .

REQUIREMENT RATIONALE (3.4.1.5.5.1)

This requirement is to establish the range of airspeed for retraction of the landing gear and to define the flight conditions at which the limits apply. Usually, minimum airspeed for retraction is not a problem. Landing gears usually retract with the air vehicle static on jacks. In special cases, such as use of an air turbine to power gear retraction, it may be desirable to specify a minimum airspeed for operation. A possible selection is "minimum flying speed." The maximum airspeed is frequently a design driver in sizing of retraction or door closing actuators. The value selected usually will depend upon the type and performance or the air vehicle. It may also be established indirectly to be compatible with landing gear extended limit speed or landing gear extension limit speed. A possible approach is to specify that the maximum airspeed must be compatible with air vehicle performance and mission requirements. In some cases, the Using Command may specify a minimum value based on operational experience. Conditions for application of limit speeds should be defined. This should include temperature (usually 59°F), altitude (usually sea level), air vehicle attitude (side slip, yaw, pitch, roll) and possibly configuration.

A time limit should be put on retraction so as to reduce drag for take-off and minimize the transition time between clean and dirty.

REQUIREMENT GUIDANCE (3.4.1.5.5.1)

TBS 1 should reflect the maximum air speed required for operation.

TBS 2 should define the environmental conditions and the air vehicle maneuvering limits for the operation of the actuation system.

TBS 3 should be filled in with a time compatible with air vehicle performance, but no greater than ten seconds.

REQUIREMENT LESSONS LEARNED (3.4.1.5.5.1)

Aerodynamic loads on the landing gear and doors are frequently difficult to predict. Errors to 100 percent (100%) have been experienced. This may result in severe restrictions of the landing gear limit speed compared to the planned value. The retraction system should be instrumented for load and air load surveys accomplished early in the flight test program.

External stores on some air vehicle may significantly change aerodynamic loads on landing gear doors. Performance should be evaluated with various external stores configurations.

Retractable landing gear should be designed to ensure proper wheel alignment during retraction and stowage.

For large air vehicles where feasible, a clear vision panel or a positive mechanical indicator should be provided that may be used to verify the gear position as indicated on the gear indicator panel.

Hydraulic linear actuators should be preferred over hydraulic rotary actuators for landing gear and door actuation.

When electronic proximity switches are used, the larger model proximity switch should be preferred over the smaller model.

Landing gear door lock actuators should be mounted on the airframe and the lock stirrup should be mounted on the gear doors, and not vice versa.

A solid state automatic gear sequencing control system should be used only if it has adequately built-in test equipment to check out the principal components of the control system. Indicator lights on the control box should also indicate the progress of the gear actuation sequence from retract to extend, and vice versa. Low temperature frequently, severely degrades operating time due to increased viscosity of hydraulic fluid and lubricants. Rotary drive systems seem more susceptible to this problem than linear actuators. Examination of system performance after cold soaking is very important because maximum air vehicle take-off performance occurs at low temperature.

Loss of an engine or hydraulic system may severely degrade operating time. This should be examined by analysis and flight test to confirm that it does not create a hazardous flight condition.

Very short operating time usually results in severe dynamic loads on the actuation mechanism and points of attachment to the landing gear and doors. Mechanism acceleration and deceleration loads may greatly exceed aerodynamic and inertia loads determined by analysis. Failure to consider this fact has resulted in early failure of mechanisms on flight test air vehicle. Strain gage instrumentation of the mechanism during initial checkout and flight test is recommended to confirm that dynamic loading is acceptable.

A.4.4.1.5.5.1 Retraction.

Retraction requirement shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.5.5.1)

Normally, the suitability of the retraction system to function properly can be determined by direct observation of flight test results. Loads instrumentation may reveal, however, that although the function is proper, retraction mechanism stresses are too high for reliable operation.

VERIFICATION GUIDANCE (4.4.1.5.5.1)

TBS should be filled in with analysis and by flight test.

Initial design should be supported by air loads analysis, the results should then be substantiated by flight testing that include the establishing of maneuvering limits at the specified air speed.

VERIFICATION LESSONS LEARNED (4.4.1.5.5.1)

It has been found in several cases that the air loads seen on the air vehicle differ significantly from that calculated. This has often required the air vehicle to do certain series of yaw movements to get gears down and locked.

It has also been seen that for high accelerating air vehicles that they can exceed the operational limits speed of gear retractions during a max performance takeoff. Thus in determining the maximum operational limit of the actuation system will take into account air vehicle acceleration speeds after lift off and allow a pad if retraction time is compromised (longer than expected).

A.3.4.1.5.5.2 Extension.

Retractable landing gears shall extend and lock and the fairing doors if used, shall be positioned as required for landing without damage at all airspeeds from (TBS 1) to (TBS 2) for flight within a time no greater than (TBS 3) .

REQUIREMENT RATIONALE (3.4.1.5.5.2)

This requirement is to establish the minimum acceptable range of airspeeds for extension of the landing gear and to define the flight conditions at which the limits apply.

Previous requirements were based on structural design criteria of MIL-A-8862. This contained four conditions to be considered to determine actuation speed for the landing gear. Usually, this was discussed with the contractors prior to contract award and a general agreement reached on a specific airspeed for design. Frequently, the actual basis for the design criteria was comparison with similar type of air vehicle or previous experience of the contractor.

A time limit should be put on extension so as to minimize the time necessary for return to base and between clean and dirty.

REQUIREMENT GUIDANCE (3.4.1.5.5.2)

TBS 1 should be filled with the minimum air speed which should usually be “0” to avoid excessive design reliance on air loads to extend the landing gear. This also enables checkout of the landing gear with the air vehicle on jacks. From a practical operational limit, this block could also state, “minimum flying speed.”

TBS 2 should be filled with the maximum airspeed for landing gear extension should be the minimum acceptable to perform the required mission.

This block should be completed as necessary to define the flight condition at which the limit speed applies. This should include temperature (usually 59°F), altitude (usually sea level), and possibly flight attitude (roll, pitch, yaw).

TBS 3 should be filled in with a time compatible with air vehicle performance, but no greater than 15 seconds.

Retractable landing gear should be designed to ensure proper wheel alignment during and after extension.

REQUIREMENT LESSONS LEARNED (3.4.1.5.5.2)

Application of the criteria contained in MIL-A-8862 may not result in adequate or reasonable landing gear limit speeds.

Although it is desirable to have the landing gear operate in a direction that enables the air load to assist extension, normal and emergency extension should not depend on this air load for proper operation. Use of a landing gear that requires some minimum airspeed for operation should be avoided because it presents maintenance difficulties (hard to functional test and adjust), and may be sensitive to lubrication, wear and air vehicle maneuvering.

Many factors other than normal landing gear operation may be significant in selection of the maximum landing gear limit speed. Examples include: use of the landing gear as a high speed air brake and air traffic control rules for operation near airports. The limit should be set only after careful analysis of the total mission of the new system.

Low temperature frequently, severely degrades operating time due to increased viscosity of hydraulic fluid and lubricants. Rotary drive systems seem more susceptible to this problem than linear actuators. Examination of system performance after cold soaking is very important because maximum air vehicle take-off performance occurs at low temperature.

Loss of an engine or hydraulic system may severely degrade operating time. This should be examined by analysis and flight test to confirm that it does not create a hazardous flight condition.

Very short operating time usually results in severe dynamic loads on the actuation mechanism and points of attachment to the landing gear and doors. Mechanism acceleration and deceleration loads may greatly exceed aerodynamic and inertia loads determined by analysis. Failure to consider this fact has resulted in early failure of mechanisms on flight test air vehicle. Strain gage instrumentation of the mechanism during initial checkout and flight test is recommended to confirm that dynamic loading is acceptable.

A.4.4.1.5.5.2 Extension.

Extension requirement shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.5.5.2)

This requirement can be verified only by flight test because proper operation is the result of complex interaction of the air vehicle aerodynamics, dynamics, and system design.

VERIFICATION GUIDANCE (4.4.1.5.5.2)

TBS: Landing gear extension should be verified by analysis. Flight-testing should test to the calculated speed limits and the results of these tests should be compared to the analysis and the analysis should be corrected accordingly.

VERIFICATION LESSONS LEARNED (4.4.1.5.5.2)

(TBD)

A.3.4.1.5.6 Operation with loss of door.

Loss of any landing gear fairing door used shall not result in __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.5.6)

This requirement is to insure that the design approach minimizes the effect of loss of a fairing door. The primary intent here is to discourage routing of hydraulic lines and wires on the doors. Alternate design approaches that have been used, include use of hydraulic fuses on lines that are routed on doors. Expansion of the requirement statement to include consideration of door loss detection may be desirable.

REQUIREMENT GUIDANCE (3.4.1.5.6)

TBS should be filled with the statement should be completed by the phrase: “loss of the actuation power system.”

REQUIREMENT LESSONS LEARNED (3.4.1.5.6)

Routing of hydraulic lines and electrical wires on fairing doors can cause severe problem with landing gear operation if the doors are lost in flight. Usually the landing gear remains operable after door loss if drive power to the actuator and control logic is maintained. Problems were experienced during flight test of C-5A air vehicles, because both electrical and hydraulic lines are mounted on the landing gear doors.

Mechanical linkages and cables should not be located on fairing doors because they are subject to binding due to deflections of the door caused by aerodynamic and inertia loading. Rigging of door locks with complex mechanisms mounted on the doors may be very difficult because the in-flight dimensions cannot be duplicated on the ground. Problems with door mounted mechanisms were encountered on the B-57 air vehicles.

Control logic with the lost door should be reviewed to confirm that it does not prevent landing gear extension. Normal extension is preferred, however, emergency extension after door loss is acceptable.

A.4.4.1.5.6 Operation with loss of door.

Operation with loss of door shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.5.6)

If a door loss-operating requirement is imposed, it should be verified by analysis. The intent is to insure consideration of safety aspects rather than positive demonstration of a mission capability. Flight demonstration is not worth while because of the many possibilities of the mode of door loss. In some cases it may be desirable to cycle the landing gear with the air vehicle on jacks and the doors removed or disconnected to confirm proper control logic.

VERIFICATION GUIDANCE (4.4.1.5.6)

TBS should be filled with analysis of gear operation with loss of door and analysis of effects of in flight loss of gear doors.

VERIFICATION LESSONS LEARNED (4.4.1.5.6)

(TBD)

A.3.4.1.5.7 Emergency extension.

A separate emergency extension system shall be provided with the capability to __(TBS 1)__. It should extend the landing gear in not more than __(TBS 2)__ seconds at all airspeeds from (TBS 3)__ to __(TBS 4)__.

REQUIREMENT RATIONALE (3.4.1.5.7)

The intent of this requirement is to indicate that an emergency extension system is required and to define characteristics of the system.

REQUIREMENT GUIDANCE (3.4.1.5.7)

TBS 1 should state be independent of the normal system except for components stressed by ground loads.

TBS 2 should specify the time required to get the gear down and locked with the emergency system.

TBS 3 should specify the minimum airspeed the emergency system should function successfully; usually 0 to accommodate on jacks operation.

TBS 4 should reflect the maximum air speed that the emergency extension system will need to operate. This value needs to allow enough speed to safely control the air vehicle in all phases of landing.

The time and speeds are not usually the same as those required for normal gear extension.

System and linkage design details, lock designs, method of emergency extension, redundancy of system with power sources influence this requirement. This item reflects the criteria previously stated in AFSC DH 1-6 and AFSC DH 2-1. It has been a standard input for over 20 years.

When a strut compressing mechanism is used, means should be provided in the wheel well to preclude jamming of the gear in case of compressing mechanism failure.

A direct mechanical linkage should be provided to release the uplocks for emergency gear extension unless otherwise specified in the detail specification. It should not be necessary for the crewmembers to physically hold the emergency extension control in the actuated position. Where possible, interior fuselage and compartment doors should be provided to permit direct in-flight access to gear uplocks by a crewmember.

REQUIREMENT LESSONS LEARNED (3.4.1.5.7)

The limit airspeed for emergency extension should be the same as the normal extension limit speed to simplify emergency procedures. During a C-5A air vehicle accident, the landing gear did not fully extend because the emergency extension gear limit speed was exceeded. At the time, the C-5A emergency extension limit speed was significantly lower than the present limit.

Experience indicates that the most desirable design is one that provides for free fall of the landing gear after manual release of the uplocks and door locks. Frequently, this approach cannot be used due to the geometry of the landing gear and doors. Alternate power systems of various types are in current use but all have some inherent problems as discussed below.

The emergency landing gear control should be located near the normal control unless specific approval is granted for an integral control. Whenever cockpit space is at a minimum, consideration should be given to integrating the emergency landing gear control with the normal control. The design should preclude interaction between normal and emergency operation. Failure of the normal landing gear control should not preclude subsequent successful actuation of the emergency landing gear subsystem. The emergency landing gear control should be as specified in MIL-STD-203.

Manual uplock release - free fall systems. A major problem with these systems is degradation of performance due to inadequate lubrication and corrosion. It should be possible to functionally test such systems on the ground. As in the case of normal system operation, excessive reliance should not be placed on assisting air loads. Actuation forces should be carefully considered to be sure that they remain within capability of the air crew. Proper rigging and resetting of the system after use frequently presents a maintenance problem. Complex resetting procedure may seem acceptable for use after real emergencies but normally become intolerable because of the need for periodic checkout of the system. Consideration should be given to the effect of normal retraction after use of the emergency extension system.

Typical actuation endurance testing with 10 percent (10%) of the extensions being emergency extensions may drive the design of system components unnecessarily. The life of a typical bomber could see less than 100 emergency cycles. Some extend by having the tires knock the doors out of the way, with composite doors 500 impacts versus 100 impacts can cause a considerable weight difference and strength difference. Consider the appropriate number of emergency extension cycles for endurance, instead of arbitrarily assigning 10 percent (10%) of the cycles.

The actual time for emergency extension of the landing gear includes the time required to confirm that, the landing gear is down and locked. Air vehicle accidents have occurred because aircrew attention was directed for long periods of time trying to confirm that the emergency system has operated properly.

Operating time for manual emergency extension systems that include a set of controls for each landing gear assembly should be based on the assumption that landing gear will be extended in sequence (one at a time) rather than simultaneously.

Emergency extension system operating time may be significantly degraded by operation at low temperature. Performance at low temperature, including cold soak of the mechanism, should be investigated.

Performance of emergency extension systems is sometimes severely degraded by certain hydraulic system configurations. Measurements should be made using hydraulic return pressures and hydraulic porting typical of that expected for actual emergencies. Do not assume that the normal hydraulic actuation system is devoid of fluid. Many landing gear emergency extensions are accomplished as a precautionary measure rather than due to a confirmed fluid loss failure in the landing gear hydraulic system.

A.4.4.1.5.7 Emergency extension.

Emergency extension shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.5.7)

Verification of emergency extension system characteristics should be accomplished during flight because air loads and the interface with other air vehicle systems cannot be accurately simulated.

VERIFICATION GUIDANCE (4.4.1.5.7)

TBS: The verification of the emergency extends system should include an air load analysis which is supported by simulator testing and flight testing. If simulator testing is too expensive then means to test the emergency extend system adequately on the air vehicle both on the ground and in the air should be accomplished.

VERIFICATION LESSONS LEARNED (4.4.1.5.7)

On some air vehicles, additional flight hardware was added to block the normal extend system so the emergency system was the only operating system. Addition flight hardware may be added to ensure that the gear would be extended if the emergency system failed the extension testing, or did not have the hydraulic power to get the gear down especially if the gear has to extend into the air stream.

Providing correct air loads on simulators have not been very successful. They have often been in the wrong direction and the max loads have often been at the wrong gear position and door position.

The flight test used to verify performance of the emergency extension system should accurately reflect the most critical probable failure conditions. For example, depressurization of the hydraulic system may not accurately simulate failure of a landing gear sequence valve. Hydraulic flow with a blocked valve may cause much higher extension loads than experienced with a depressurized hydraulic system. Critical failure modes should be accurately simulated.

A.3.4.1.5.8 Actuation indication

A.4.4.1.5.8 Actuation indication

A.3.4.1.5.8.1 Gear position status indications.

An indication shall be provided to show gear position.

REQUIREMENT RATIONALE (3.4.1.5.8.1)

This requirement is provide an indication of the position and status of the landing gear. This is required on air vehicle with retractable landing gear to enable the pilot to know that the landing gear is in the position required for the intended operation. Also, the system may warn the pilot of unsafe conditions and permit him to select the proper corrective action.

REQUIREMENT GUIDANCE (3.4.1.5.8.1)

A means to indicate normal gear position, disagreement between the gear control and the gear position, and gear unsafe conditions should be provided. See Crew Systems Specification Guide for position indicators and standard lighting configurations.

REQUIREMENT LESSONS LEARNED (3.4.1.5.8.1)

This requirement was formerly contained in AFSC DH 1-6 and MIL-STD-203 also contained a requirement that the indicator(s) be located on the instrument panel or adjacent to the landing gear control lever visible to the pilot(s) in his (their) normal position(s).

a. The general requirement for an indicator has existed in some form for at least 25 years.

1. Normally, an indicator should be provided for each separate landing gear assembly. The pilot usually needs to know which landing gear is not in the position selected to properly plan the corrective action.

2. The gear indicating system should not indicate a “safe-gear-locked-position” prior to actual locking or positive engagement of uplock or downlock mechanism. Landing gear indicators are usually lights or electromechanical devices. Usually a green light is used for each landing gear to indicate that it is down and locked. Red lights are sometimes used to indicate that landing gear or doors are not up and locked. In some cases, no indicator is provided for up and locked, however, and unsafe uplock condition is indicated by the warning system (red light in gear handle plus an aural warning). Electromechanical indicators have been used in many air vehicles. These usually show green wheels for gear down, a barber pole design for in-transit and “up” for landing gear up and locked.

3. Indicator systems that use lights should include two bulbs in each indicator with a light test function either as an integral part of the indicator or as a part of the air vehicle lighting system. When two bulbs are used, be sure that it is possible to detect that one bulb is burned out. F-15 air vehicle experience indicates that bulbs should be separated under the common lens to insure that failed bulbs can be detected.

4. Indicator lights and panel lighting should be designed with replaceable bulbs. A sealed lighting system used on the C-5A air vehicle proved troublesome. Bulb replacement required removal of the entire landing gear control. Replacement of the landing gear control required a complete functional check of the landing gear retraction system. The functional check required that the air vehicle be jacked. What seemed like a good idea at component level had a major impact on system maintenance manhours. Landing gear indicator panel lighting should be accomplished with easily accessible bulbs or light emitting elements that will permit easy replacement without removal of the panel or removal and disassembly of the panel. This requirement should stand regardless of the alleged guaranteed life of the bulbs.

5. Switches used to indicate an uplock or downlock position of the gear should be activated directly by the locking means

6. Indicators should function from a positive signal rather than lack of a signal. Negative logic can, for example, result in a broken wire giving a false down and locked indication.

7. Landing gear control circuits, indicator circuits, and electrical and magnetic proximity sensors should be separated insofar as possible. This minimizes the possibility of sensor-to-sensor inductive interference that will not only prevent landing gear

operation but could also give false indications of the malfunction. When gear geometry does not allow sensor separation, interference properties should be investigated to determine if sensor isolators are needed. Also, separation of the circuits usually prevents compromise of emergency circuits. Use of common components would result in simultaneous deactivation of the indication systems.

8. Indicator operation after a single failure of the nominal extension system should be carefully considered. An incident was experienced on the initial F-15 design wherein a single failure resulted in a down and locked indication when the landing gear was up and locked. A switch failed causing the landing gear to try to extend while still uplocked. Deflection caused by the force against the uplock caused an indicator switch to make contact. The combination of failed switch plus the false actuation of the second switch resulted in a false indication.

9. If at all possible, some type of backup system of indication should be provided. Usually viewing windows can be provided on cargo air vehicle so that uplocks and downlocks can be inspected directly. Some type of simple marking system should be used for the downlock locked indication. Frequently, a diagram of proper position is placed near the viewing window so that the air crew can quickly judge the position. On some air vehicle it is also desirable to mark the downlock so that it can be observed from a chase air vehicle. Other devices such as mechanical indicators and mirrors have been used on air vehicle to permit the pilot to check gear position if he suspects indicator system malfunction. The use of fiber optic scopes to inspect the position of the landing gear in flight has been unsatisfactory to date.

10. The original nose landing gear position indicator used on C-141A air vehicle was actuated by a switch in the over center drag brace link. Slight movement of the landing gear in the retracted position could result in a false indication that the landing gear was extended and locked. This feature resulted in an air vehicle accident. The deficiency was eliminated by installation of a switch to detect that the landing gear is extended.

11. All switches should be designed and installed to be readily accessible and easily adjusted or rigged and removed and replaced. Switch mounting and installation should be adequate to ensure proper switch actuation under all landing gear loads and deflection. Proximity switches have proven to be highly reliable, easy to troubleshoot and do not require the frequent rigging and adjustments associated with mechanical switches as long as the initial design locates the switches and targets in stable areas of the landing gear linkages. Mechanical switches should have a high-force actuator-return-spring or be provided with a direct double-acting mechanical linkage. This prevents mechanical switches from sticking in one position due to contamination or friction.

12. For certain locations on the gear, it may be desirable to install connectors on the proximity switches. This would reduce maintenance time if chafing or wire bundle failures are a problem. Note: if connectors are used on the switches, ensure they are designed to be compatible with the EMC/EMI requirements.

13. The squat switch should be located and should be of such a design that the “weight-off” condition is not indicated until the wheel is off the ground.

b. The following detailed requirements have been applied to most current air vehicles. The results are generally satisfactory. Use of a similar requirement and approach aids air crew transition to a new air vehicle design.

1. Provide a Type MA-1 audio warning signal (refer to MIL-DTL-9320) that automatically actuates when the following conditions exist simultaneously:

(a.) The air vehicle is below a preset altitude.

(b.) The IAS of the air vehicle is less than a preset value.

(c.) In turbine engine air vehicle, the throttle is less than a predetermined power setting. In reciprocating engine air vehicle, the throttle is less than normal cruise position.

(d.) The landing gear is not down and locked.

2. Provide a radially mounted wheel-shaped landing-gear control knob. Ensure that the internal red warning light automatically lights when any gear is not exactly consistent with the position selected for the landing-gear control, or if any of the gear is retracted. Additionally, ensure that this light illuminates when the audio signal occurs. Install the red warning light on an automatic dimming circuit. Provide a test switch that tests the landing-gear audio and warning light circuit.

Recently, difficulty was experienced with the F-105 control handle. The detent had worn to such a state that adequate warning was not provided. This indicated that periodic inspection is required.

A.4.4.1.5.8.1 Gear position status indications.

Gear position status indications shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.5.8.1)

Proper operation and suitability of the indicator system can best be determined by normal use during the flight test program. In some cases it may be desirable to perform a specific demonstration of operation when specific malfunctions to the landing gear are simulated. If a landing gear retraction simulator is available, it is highly recommended that the various failure modes be investigated on the simulator.

VERIFICATION GUIDANCE (4.4.1.5.8.1)

TBS: The verification of the landing gear indication should be by inspection of drawing and logic schematics. The verification of operation should be demonstrated on the air vehicle both on jacks during checkouts and in flight-testing.

VERIFICATION LESSONS LEARNED (4.4.1.5.8.1)

Consideration should be given to conducting an icing test where the landing gear subsystem will successfully operate after there is an ice build-up and freezing of the hydraulic locks. The gear should successfully retract and extend, verify that any ice build-up on door or locks will not prevent extension.

Conduct simulator testing to verify that the braking inertia loads encountered while stopping the wheel from spinning during retraction are not exceeding the design limits and concur with the analysis.

Conduct simulator testing to determine minimum accumulator pressure needed to extend and lock the gears successfully under all conditions.

It is significantly more difficult to verify operation at -65°F than it is at -40°F.

A.3.4.1.5.9 Landing gear position restraint

A.4.4.1.5.9 Landing gear position restraint

A.3.4.1.5.9.1 Gear position restraint.

A means shall be provided to maintain each landing gear in the selected position.

REQUIREMENT RATIONALE (3.4.1.5.9.1)

The intent of this requirement is to ensure that the gear will stay in the final selected position without any power for all air vehicle operations within its mission profiles.

REQUIREMENT GUIDANCE (3.4.1.5.9.1)

The objective of the requirement should be to establish performance for gear positioning. "Locks" should be considered for maintaining each landing gear in the selected position.

Where doors are used in conjunction with landing gear, the method used to restrain the landing gear in the selected position should not result in extension of the landing gear due to gapping or loss of a landing gear door.

REQUIREMENT LESSONS LEARNED (3.4.1.5.9.1)

AFSC DHs 1-6 and 2-1 formerly stated the requirement for automatic operating positive mechanical locks. These requirements were based on ARDCM 80-1 (HIAD) that were generated primarily on lessons learned.

a. Use of actuation force or blocking of the actuation pressure to retain the landing gear in the retracted or extended position is considered an unacceptable approach. Such designs are subject to failure due to power failure, leakage, or excessive deflection. Inadvertent gear extension at high speed has caused major air vehicle accident. This requirement should specify that positive mechanical locks be used to maintain the landing gear in the extended or retracted position.

b. Landing gear and door locks should be designed for proper rigging while on the ground. Rigging of uplocks and downlocks should be by simple adjustment and not require devices with close tolerance adjustments. Some designs have been used in the pasts that require compensation for the fact that alignments of parts of the lock are dependent upon the amount of airload applied. These designs require considerable flight test effort to develop suitable rigging procedure. Frequently, the problem is not recognized and severe flight test delays result. In most cases, the problem can be avoided by mounting major lock components on fixed structure and providing guides to direct moving parts to the proper position.

c. Landing gear uplocks should not be mounted in a manner that requires that the shock absorber be properly serviced for the lock to operate correctly. A recent incident with a fighter air vehicle revealed that not only will the lock not lock but also the lock parts may jam and prevent landing gear extension.

d. Landing gear downlocks should be designed so that ground loads does not stress them. Downlocks subjected to ground loads are exposed to a severe fatigue stress environment that may be highly dependent upon lock rigging. Durability testing on a single landing gear may not accurately reflect operational design life. If the design dictates that the downlock must carry ground loads, it is recommended that the lock be non-adjustable.

e. Hydraulic pressure variations due to surges or thermal expansion have caused locks to unlock. Locks sometimes work properly for normal operation but malfunction when used for emergency extension because subjecting both sides of the actuator to return pressure results in a tendency to unlock. The actuators should be installed so that if both sides of the piston are pressurized, the resultant force tends to lock the actuator towards the commanded position. In designs where pressure works on both sides of the actuator insure that time delays and system logic are such to cause the gears or doors lock in the commanded position. The use of landing gear simulators is strongly recommended in proving the logic and capability of such a system.

f. Locks should be designed so that if actuation force is applied with the lock engaged the lock does not unlock and neither the lock nor the actuating mechanism is damaged.

g. Some ground load conditions may result in deflections that tend to unlock downlocks. An analysis should be performed to determine if limit load conditions will result in excessive deflection. The analysis should include unusual loading conditions such as extreme landing attitudes and reverse braking.

h. Electrically operated locks should be designed so that no single electrical failure will result in the lock unlocking.

i. Locks should be designed with no water traps. Ice build-up should not prevent operation. Testing may be required to verify that actuator force or ice breaker design is adequate.

j. Uplocks should be designed so that flight inertia loads of the landing gear do not load the actuation mechanism.

k. Landing gear subsystems should be designed so that small errors in servicing will not cause gear malfunctions.

l. The use of shims for adjustments between any switch, brackets and gear structure decreases the reliability and maintainability of the landing gear subsystem.

m. The uplocks should hold the individual gears in the up and locked position independent of door locks.

n. Failure of door locking linkages or extension devices should not preclude emergency unlocking and extension of the landing gear.

Slight 5 to 7 percent (5-7%) over inflation of the F-111 gear struts will prevent the main gear from locking in the retract position.

The F-111 landing gear strut servicing procedure used air pressure in conjunction with strut extension for proper inflation of the shock struts. The strut extension is measured in one-eight inch increments and the air pressure is held to plus or minus 25 pounds per square inch. The gage used for this procedure has a range of 0-4000 pounds and the dial face is marked in 100-pound increments which makes accurate air servicing very difficult and almost impossible to meet the plus or minus 25-pound requirement.

Do not use air for inflation, for under certain conditions an explosive mixture can be formed, resulting in a "dieseling" effect. Nitrogen will prevent this potential problem.

This requirement should not prohibit use of systems that depend on the landing gear uplocks to keep doors closed. These systems have been used on fighter air vehicle, F-4 for example, with considerable success. An inherent disadvantage of this approach is that door linkage must be rigged to provide proper preload of the door. The preload should be enough to prevent door gaping due to air loads but not so high as to cause structural damage. The major advantage of this approach is that it simplifies the actuation sequence and mechanism.

The number of actuators required to operate door and landing gear locks should be minimized. Failure of an actuator normally disables the actuation system and may cause severe damage. Only electrical or hydraulic interlocks can avoid this. Experience has indicated that these interlocks frequently cause more failures and maintenance problems than the basic system. Use of a small number of actuators often results in a complex mechanism. Once developed, however, such systems provide better operational service.

A.4.4.1.5.9.1 Gear position restraint.

The means to maintain gear in the selected position shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.5.9.1)

Suitability of the lock system should be evaluated by flight test. Evaluation of performance under extreme conditions such as load or low temperature may require that a laboratory test be performed. In some cases, design analysis may be sufficient to show that the lock performance is not adversely affected by the specified conditions.

VERIFICATION GUIDANCE (4.4.1.5.9.1)

TBS should be filled with analysis, laboratory tests (simulators), taxi and flight-testing, failure modes and effect analysis, supported with laboratory testing or on air vehicle testing as appropriate.

VERIFICATION LESSONS LEARNED (4.4.1.5.9.1)

(TBD)

A.3.4.1.5.10 Ground safety restraint.

Ground safety provisions shall be provided to prevent retraction without damage to the air vehicle or ground safety provisions under any of the following conditions: __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.5.10)

There have been numerous incidents of inadvertent or uncoordinated gear retractions during landing gear maintenance which have resulted in personnel injury. Therefore, operational needs exist to provide a design which precludes this characteristic.

REQUIREMENT GUIDANCE (3.4.1.5.10)

TBS should be filled with the following: Inadvertent gear handle actuation, transient, taxi, take-off, landing, hydraulic or electrical signals, EMI, physical impact of gear linkages or other should be included in the blank.

Unique landing gear ground locks should be stowable on the air vehicle.

REQUIREMENT LESSONS LEARNED (3.4.1.5.10)

Previously, ground lock requirements were contained in AFSC DHs 2-1 and 1-6. These documents identified the need for inclusion of such a device in the design but they did not attempt to identify the conditions under which the lock would continue to provide safety. This will be a new requirement.

a. Landing gear lock should be designed so that they may be installed and removed regardless of the load on the landing gear. This is required so that locks can be used for normal operation to maximum weight and with the air vehicle on jacks.

b. Doors that are power activated for ground maintenance access should be provided with separate ground locks for installation with doors open. It may not be necessary to use these locks for normal flight operations.

c. Pins used to hold a ground lock in place should be permanently attached to the lock to minimize the possibility of the pin being improperly installed.

A.4.4.1.5.10 Ground safety restraint.

The effectiveness and adequacy of the ground safety locks shall be verified during flight test.

VERIFICATION RATIONALE (4.4.1.5.10)

Design aspects of the ground lock can be evaluated by inspection of the hardware. Functional suitability can be evaluated as a part of the overall flight test evaluation of the air vehicle.

VERIFICATION GUIDANCE (4.4.1.5.10)

During ground operation in flight testing the use of ground safety restraints should be demonstrated and proved to be adequate.

VERIFICATION LESSONS LEARNED (4.4.1.5.10)

(TBD)

A.3.4.1.6 Ground operation interface.

The landing gear shall be capable of providing flotation, high frequency ground roughness accommodation, controllable frictional drag at the ground for stopping, stopping energy absorption, a side load at the ground as a function of yaw angle, and low friction drag for take-off and landing.

REQUIREMENT RATIONALE (3.4.1.6)

The objective is to provide a capability compatible with the air vehicle operation and performance for all taxi, turns, takeoff, and landing operations at the critical gross weights and velocities that do not exceed air vehicle structural or operational limits. Emergency conditions should also be considered, such as aborted takeoffs and maximum landings. If aerodynamic

heating exceeds 160°F during flight, this should be considered.

REQUIREMENT GUIDANCE (3.4.1.6)

Performance parameters:

a. Air vehicle configuration
b. Flotation
c. Load - This parameter will be dependent upon A.3.4.1.3.
d. Growth allowances
e. Runway considerations
f. Speed - maximum ground speed, rotation speed, brake application speeds.

g. Taxi distances and turning requirements

h. Environmental heating - Aerodynamic heating level, time at high speed, equipment mass and air flow may be significant parameters for the design. This may dictate high temperature compounding.

i. Temperature

j. Air vehicle design weights.

The environment developed by the wheel-brake-tire combination should be accounted for in the design conditions of the wheels.

See sections A.3.4.1.11 and A.4.4.1.11 for Component information if tires, wheels, and brakes are used.

REQUIREMENT LESSONS LEARNED (3.4.1.6)

This requirement reflects the concept generated in MIL-PRF-5041, AFSC DH 2-1, and AFSC DH 1-6. This is an Industry accepted practice for military and commercial tire development.

A.4.4.1.6 Ground operation interface.

Ground operation interface shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.6)

This is to ensure that the ground operation interface requirement is verified.

VERIFICATION GUIDANCE (4.4.1.6)

TBS should be filled in with analysis, ground and flight test as appropriate.

This should take into account the static and dynamic loads, speeds and time at loads for worst case operational conditions, as well as normal operating conditions.

VERIFICATION LESSONS LEARNED (4.4.1.6)

If tires are used:

The use of a laboratory dynamometer to evaluate the tire, wheel and brake performance characteristics permits evaluation to the limits of the tire, wheel and brakes capability with low risk. The design conditions are carefully controlled and are repeatable. The Industry has always utilized this method of evaluation prior to installation on an air vehicle to determine performance limits and to establish safety of flight. It is significantly more economic than any other verification method. The tire, wheel and brakes will also be observed and evaluated during the routine flight test program.

A.3.4.1.7 Restraint capability.

The landing gear shall provide restraining force to hold the air vehicle static on a dry paved surface during application of __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.7)

This establishes the need to hold the air vehicle static for functions such as engine run-up.

REQUIREMENT GUIDANCE (3.4.1.7)

TBS should reflect the thrust level of engine run-up during which the air vehicle is required to remain static, such as 100 percent (100%) military power.

REQUIREMENT LESSONS LEARNED (3.4.1.7)

Depending upon Using Command practices, this requirement may vary. Most jet air vehicles do not generally park with brakes locked and run-up all engines to military power. However, the requirement should be tailored for the Command requirements.

The ability to meet these requirements is a function of the size and design of the rolling components selected. If there is not enough tire contact area, holding the brakes locked will still result in skidding the tires. The ability to develop a tire drag force is a function of the applied load and the tire to ground coefficient of friction. The contact patch may have some effect, but that should be included in the assumptions used to select the coefficient of friction.

Depending on the type of brake used on the design, the brakes may or may not remain locked at full actuation pressure. With steel brakes, the static coefficient of friction between the brake disks is much higher than that generated during braking, and holding wheel locked is relatively easy. With carbon brake disks and friction material, the static and dynamic coefficients of friction are very close to one another and more effort would be required to keep the disks from rotating.

It is not clear whether it is best practice to let the operational practice drive the hardware design or whether the hardware design should drive the operational practice. This should be a joint engineering/Using Command decision.

A.4.4.1.7 Restraint capability.

Total air vehicle stopping performance and the ability to hold the air vehicle static during engine run-up shall be evaluated by air vehicle test as follows: __(TBS)__.

VERIFICATION RATIONALE (4.4.1.7)

Even though the static coefficients of the brake are evaluated in the laboratory during development testing, it is best to evaluate the system performance on the air vehicle.

VERIFICATION GUIDANCE (4.4.1.7)

TBS should reflect a demonstration on the air vehicle. On some air vehicle the thrust is sufficient to move the air vehicle even with the wheel locked up. This is not a failure of the brake system as long as the brakes can keep the tires from rotating. It would be prudent to release brake once the air vehicle begins to move to prevent flat-spotting the tires.

VERIFICATION LESSONS LEARNED (4.4.1.7)

A number of air vehicles have start to move are the end of the runway when the throttles are advanced and before they get to 100 percent (100%) power. In these cases the pilot should release the brakes and begin it takeoff roll. This should not be considered a failure of the braking system as long as the wheel did not begin to rotate first.

A.3.4.1.8 Auxiliary deceleration devices

A.4.4.1.8 Auxiliary deceleration devices

A.3.4.1.8.1 Arresting hook systems

A.4.4.1.8.1 Arresting hook systems

A.3.4.1.8.1.1 Air vehicle arrestment performance.

The arresting hook system shall be capable of decelerating __(TBS 1)__ air vehicle to a stop by engaging __(TBS 2)__ arrestment system at __(TBS 3)__.

REQUIREMENT RATIONALE (3.4.1.8.1.1)

This is a performance statement for the arresting hook system. The legacy arresting hook specification MIL-A-83136 can provide additional guidance.

REQUIREMENT GUIDANCE (3.4.1.8.1.1)

TBS 1 should define the maximum weight or configuration of the air vehicle to be arrested.

TBS 2 should list the intended arresting system. If this value is not known, use the BAK-13, which produces the highest hook load.

TBS 3 should list the speed of engagement blank and define the energy to be absorbed. If the total energy of the system exceeds the barrier capability, the limit speed at the design gross weight selected should be used.

The arresting system and air vehicle should withstand engagement loads with all tires contacting the ground, initially with zero deflection of the tires and landing gear shock absorbers, for an air vehicle at landplane landing design weight and approach speed.

Barrier system design and limits hook compatibility, air vehicle configuration, and engaging speeds control this requirement.

The verification aspects are defined in AFSC DH 2-1. The original emergency tail hooks were retrofitted on MIL-A-18717, was used to establish criteria. Through the efforts and cooperation of Industry, MIL-A-83136 was published in August 1968. Recently, errors were found in the load data used for design compatibility with the BAK-12 barrier system, and efforts were being made to update the criteria.

REQUIREMENT LESSONS LEARNED (3.4.1.8.1.1)

The spring type hook shanks have exhibited numerous problems both during testing and operation in the field. If a spring tube shank is used, consideration should be given to its bending mode after contacting a protrusion on the runway or at barrier engagement, as missed engagements are common place because of hook bounce when the vertical load at the attach point is very high.

A.4.4.1.8.1.1 Air vehicle arrestment performance.

Performance limits for arresting hook systems shall be evaluated by air vehicle test with the specified arrestment system.

VERIFICATION RATIONALE (4.4.1.8.1.1)

Since the performance is basically a function of interface and compatibility with the arrestment system, the most logical demonstration is on the air vehicle with the intended barrier system. Much of the performance is dimensional and dynamic response as a system.

VERIFICATION GUIDANCE (4.4.1.8.1.1)

The design and structural capability should be verified by analysis and laboratory testing. On air vehicle testing should verify overall system performance capability.

VERIFICATION LESSONS LEARNED (4.4.1.8.1.1)

A number of engagements should be performed on the air vehicle during flight testing to ensure there is no damage due to cable dynamics and that the loads are within the design envelopes.

A.3.4.1.8.1.2 Fly-in engagement criteria.

Arresting hook system and attachment shall withstand loads of __(TBS)__ fly-in engagement.

REQUIREMENT RATIONALE (3.4.1.8.1.2)

If the Using Command intends to arrest the air vehicle during emergency by fly-in engagement, this statement should reflect the requirement. If the user does not intend to operate in this manner, the requirement should be deleted. The blank should show the gross weight condition for fly-in engagement.

REQUIREMENT GUIDANCE (3.4.1.8.1.2)

TBS should list the approach speeds expected for this type of engagement and still maintain control of the air vehicle.

Barrier system energy capacity, hook design loads, hook point design, air vehicle configuration, and weight all impact and control meeting this operational need.

This is a new requirement. The loads should be the same as taxi engagement for the same gross weight-velocity engagement. MIL-A-83136 previously excluded fly-in engagements, but this requirement establishes performance for such a maneuver, since the user needs this option in case of emergency.

REQUIREMENT LESSONS LEARNED (3.4.1.8.1.2)

The fly-in engagement loads are significantly higher than those encountered when taxiing into the barrier. Therefore, the weight of air vehicle which can be recovered within the design load envelope is reduced. The impact dynamic loads are high, as well as the loads due to higher energy transmission. It would be anticipated that local damage to the underside of the air vehicle could be expected due to fly-in engagement.

A.4.4.1.8.1.2 Fly-in engagement criteria.

Performance limits for emergency arresting hook systems shall be evaluated by air vehicle flight test with the specified arrestment system.

VERIFICATION RATIONALE (4.4.1.8.1.2)

Since the performance is basically a function of interface and compatibility with the arrestment system, the most logical demonstration is on the air vehicle with the intended barrier system. The dynamic effects play a major part in the ability to arrest the intended air vehicle.

VERIFICATION GUIDANCE (4.4.1.8.1.2)

The fly-in engagement should be verified by air vehicle testing with the required arrestment systems.

VERIFICATION LESSONS LEARNED (4.4.1.8.1.2)

(TBD)

A.3.4.1.8.1.3 Probability of successful engagement.

The probability of successful engagement of the arresting system shall be not less than __(TBS)__ for all air vehicle landing attitudes. The arresting hook system shall provide sufficient hook holddown force and damping to minimize hook bounce and prevent further loss of contact with the runway for all-landing configurations and attitudes.

REQUIREMENT RATIONALE (3.4.1.8.1.3)

This requirement is to establish an acceptable level of reliability of the arresting hook system. It is primarily intended to insure consideration of proper positioning of the hook and prevention of hook bounce.

REQUIREMENT GUIDANCE (3.4.1.8.1.3)

TBS should be filled with an appropriate value based on operational experience with existing systems on air vehicles with similar mission requirements. In some cases it may be desirable to further define the conditions applicable to this success probability. This could include such factors as type of runway surface, type of arrestment system, and maximum lateral or angular misalignment of the air vehicle and arrestment cable.

Runway roughness, damping characteristics, discrete bump characteristics, and hold-down force are parameters influencing the ability to meet this requirement.

Design criteria were previously furnished in legacy documents MIL-A-83136 and AFSC DH 2-1.

REQUIREMENT LESSONS LEARNED (3.4.1.8.1.3)

Prevention of hook bounce prior to arrestment cable engagement is a major factor in the probability of success. Previously it was specified that hook bounce should not exceed $2^1/_4$ inches before arrestment. This has been found to be one way to improve the probability of success and should be strongly considered by the designer. Hook bounce is limited by using a damper.

A hydraulic or mechanical damping device usually provides damping. In most cases the worst case condition is when the nose tire is flat and the nose gear strut is also flat. However, with the viper it is when the nose tire just touches the runway, because the main gears are still extended due to wing lift, essentially 3-point landing with all the gears extended, the hook will sail over the cable. Need to design to successfully engage under this condition also.

A.4.4.1.8.1.3 Probability of successful engagement.

The probability of successful engagement shall be determined by analysis of flight test results.

VERIFICATION RATIONALE (4.4.1.8.1.3)

The requirement should be verified by analysis because the high probability of success would require too much testing to establish a significant sample size. Arrestment failures experienced during flight test should be considered. If the design or procedures that caused the arrestment failure is not corrected, probability of recurrence of the condition should be considered in the analysis.

VERIFICATION GUIDANCE (4.4.1.8.1.3)

Arresting hook dynamics and adequacy of the hold-down force should be determined by computer analysis and should be demonstrated on the air vehicle.

VERIFICATION LESSONS LEARNED (4.4.1.8.1.3)

(TBD)

A.3.4.1.8.1.4 Lateral freedom of hook.

Hook installation shall have lateral freedom for __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.8.1.4)

Frequently, the air vehicle will contact the ground off-center on the runway and in a drift landing attitude, which would make engagement other than straight into the center of the cable span. Therefore, limits on off-center and alignment engagement should be established for operational requirements. In the past, 20 percent (20%) off-center and 20 misalignment have been selected for design purposes.

REQUIREMENT GUIDANCE (3.4.1.8.1.4)

TBS should be filled with: "…20% off-center and 20° misalignment at engagement with respect to the center of the cable span."

Lateral hook loads, centering forces, barrier characteristics, crosswind, direction and velocity are characteristics impacted by this requirement.

This requirement was previously stated in MIL-A-83136. A portion was in the Performance Section and a portion was previously in the Verification or Quality Assurance Section. It is expected that this requirement originally stemmed from the Navy requirement as expressed in MIL-A-18717.

REQUIREMENT LESSONS LEARNED (3.4.1.8.1.4)

Since many of the previous requirements on Air Force arresting hook design stemmed from Navy experience, most of the lessons learned are from this operational regime.

The biggest problems associated with off-center engagement are eccentric loads, control, and air vehicle clearance. If there are any protuberances within the envelope of arresting hook movement, they are in jeopardy of damage due to hook contact. The bottom of the air vehicle should be clear in the envelope of hook movement. A suitable protected fairing is needed for most arresting hook installations.

The attachment of the hook should be designed to take off-center loading to the limit of the design envelope. Cable bounce and dynamics are as important a consideration as the hook movement itself.

Therefore, knowledge of anticipated cable dynamics is an important task of proper design and installation.

Most hook installations have had difficulty in maintaining directional control during barrier runout. This is particularly true for off-center misaligned engagements. On the F-111 and F-5, it was found to be best to maintain control with the use of rudder rather than steering. Rollback after completion of the runout is also a problem. If the brakes are applied too abruptly, air vehicle with aft center of gravity situations will sit back on the tail and suffer structural damage. Each air vehicle should develop the proper technique for the design for steering and handling of rollback. Another problem with rollback is catching the hook point on runway irregularities. This can accentuate the tendency to tip back.

A method should be provided to keep the shank on the air vehicle centerline prior to engagement but permit movement after engagement.

A.4.4.1.8.1.4 Lateral freedom of hook.

Performance limits for arresting hook systems shall be evaluated by air vehicle flight test with the specified arrestment systems. The dynamic and design characteristics shall be evaluated by analysis and inspection.

VERIFICATION RATIONALE (4.4.1.8.1.4)

The air vehicle with the intended system best demonstrates compatibility with the arrestment system. Dynamic response of the system can be predicted to a limited degree, but the final proof is an actual demonstration.

VERIFICATION GUIDANCE (4.4.1.8.1.4)

Appropriate dynamic analysis and laboratory testing may be needed to determine the performance envelope for the arrestment system. The results of the analysis should be supported by on air vehicle tests and demonstrations.

VERIFICATION LESSONS LEARNED (4.4.1.8.1.4)

(TBD)

A.3.4.1.8.1.5 Hook retracted criteria.

The retracted hook shall preclude __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.8.1.5)

The objective of this requirement is to establish a safety requirement for landings where hook engagement is not desired.

REQUIREMENT GUIDANCE (3.4.1.8.1.5)

TBS should be filled with: "…the inadvertent engagement of the arresting system for all air vehicle landing attitudes, including the effects of compressed tires and struts, and rebound of the cable due to the tires running over it."

Rather than define a prescribed ground clearance at maximum tail down attitude, including compressed tires and struts, this requirement is a statement that the stowed hook should not inadvertently engage the barrier or arresting system while in the most critical condition.

Physical details of the hook design, aft fuselage detail design, and high angle of attack flying characteristic impact meeting this design requirement.

This requirement was previously contained in MIL-A-83136.

REQUIREMENT LESSONS LEARNED (3.4.1.8.1.5)

Generally, tail hooks have provided a minimum ground clearance of 14 inches in the stowed position at maximum tail down attitude. This rule of thumb has been to insure ground clearance for the cable that is rebounding from the main tires running over it. It may be conservative, but it represents lessons learned by the Navy after years of experience in arresting hook design and installation.

If such clearance cannot be provided, a fairing can provide suitable protection to preclude inadvertent hook-cable engagement. Considerable damage to the fairing was experienced on the F-111 during category II testing at Edwards AFB. This occurred on routine engagement after the hook picked up the cable and rebounded against the bottom of the air vehicle. Fairing design should be inexpensive or easily replaceable or both.

A.4.4.1.8.1.5 Hook retracted criteria.

The dynamic and design characteristics shall be evaluated by inspection.

VERIFICATION RATIONALE (4.4.1.8.1.5)

No special tests can be conceived to evaluate inadvertent hook engagement on routine landings. This will become readily apparent by observation.

VERIFICATION GUIDANCE (4.4.1.8.1.5)

Inadvertent engagements should be evaluated by analysis and inspection of drawings and the installation.

VERIFICATION LESSONS LEARNED (4.4.1.8.1.5)

(TBD)

A.3.4.1.8.1.6 Position indication.

Current position of the hook shall be __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.8.1.6)

In order for the pilot to maintain control of the air vehicle in emergency or normal operation, it is vital to be able to know whether the hook has been deliberately or inadvertently extended and whether the hook has in fact been extended when such action was initiated. Therefore, indication is deemed necessary to provide this status information to the pilot.

REQUIREMENT GUIDANCE (3.4.1.8.1.6)

TBS should reflect the need for having the current extended/retracted position of the hook be indicated to the crew. Indication should be provided to the crew whenever the hook position is inconsistent with the control position.

Cockpit designs, arresting hook position display, position sensing circuit, redundancy of circuit, power sources, and switch design and location impact the ability to meet this operational need.

This is a new requirement not previously contained in prior documentation.

REQUIREMENT LESSONS LEARNED (3.4.1.8.1.6)

Experience on recent air vehicle indicates that location of the arresting hook release lever is important. On the F-111A and the F-15A, the arresting hook release handle is located in the near proximity to the parking brake control handle. In each case, the handle shapes are similar and there have been incidents with each air vehicle where the wrong handle has been inadvertently actuated. The direct result has been blown tires and a missed barrier. Fortunately, no serious damage resulted in either occurrence.

Therefore, judicious placement of the release handle and some method of position indication are reasonable expectations for new designs.

A.4.4.1.8.1.6 Position indication.

Position indication shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.8.1.6)

Observations from drawings, mock-up, or actual air vehicle confirm the adequacy of the arresting hook controls.

VERIFICATION GUIDANCE (4.4.1.8.1.6)

TBS should be filled with inspection of drawings and on air vehicle demonstrations. The air vehicle demonstrations should check both correct position indications and incorrect position indications.

VERIFICATION LESSONS LEARNED (4.4.1.8.1.6)

(TBD)

A.3.4.1.8.1.7 Maintenance and installation criteria.

For maintenance activity, the hook installation shall __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.8.1.7)

Numerous features are available for arresting hook system designs. Each adds complexity and are cost drivers. If such features are known to be desired by the intended user, this requirement should reflect such choice.

REQUIREMENT GUIDANCE (3.4.1.8.1.7)

TBS should reflect the need to have provisions to secure the hook in the extended and in the retracted positions to prevent inadvertent retraction or extension.

Detail hook design, user's needs, and maintenance procedures are influenced by this requirement. This requirement contains some previous requirements of MIL-A-83136 and has the potential of adding new requirements. The retraction and extension features were previously defined. AFSC DH 1-6 also contained a discussion of this item.

REQUIREMENT LESSONS LEARNED (3.4.1.8.1.7)

If the arresting hook extension is designed to be used only under emergency conditions, no retracting mechanism was required in the past. However, a positive latching device, which prevents inadvertent extension in flight or on the ground, should be provided. If the system is electrically actuated, the controls from the cockpit to the uplock release mechanism should be totally redundant. In the past, extension time has been limited to two seconds or less. With electrically actuated release mechanisms, the ground safety pin should interrupt the electrical power to the release mechanism. This will prevent release mechanism damage if the cockpit switch is actuated with the ground safety pin installed. In the interest of personnel safety, the release mechanism should prevent installation or removal of the ground safety pin with the arresting hook in any position other than fully up and locked.

A.4.4.1.8.1.7 Maintenance and installation criteria.

Maintenance of the hook system shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.8.1.7)

Design features are best reviewed by inspection of drawings and actual air vehicle installations.

VERIFICATION GUIDANCE (4.4.1.8.1.7)

TBS should be filled with inspection and on air vehicle demonstrations.

VERIFICATION LESSONS LEARNED (4.4.1.8.1.7)

(TBD)

A.3.4.1.8.1.8 Hook actuation criteria.

The hook shall be positioned by the following action __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.8.1.8)

This requirement is to establish the design and performance requirements for the arresting hook control.

REQUIREMENT GUIDANCE (3.4.1.8.1.8)

TBS should reflect the hook actuation control method in accordance with the crew station specification. If required the following statement may be added, “The air vehicle shall be able to disengage from the arresting cable without external assistance, and then be able to taxi over the cable without reengagement.”

Factors include location, actuation, and design of the control switch. The following has been specified in the past by MIL-STD-203:

a. (Normal system operation) Single pilot, tandem pilot, operable by pilot. Actuation - Direction of motion should correspond to hook movement. Design - when an indicator light is used, it should be located in the control handle and should be “ON” when the arresting hook is inconsistent with control position.

b. Emergency arresting hook control (ground use only). Single pilot, tandem pilot, side-by-side pilot: Location - Accessible to the pilot’s shaped switch - Down or aft for hook "down". Design - A recessed, guarded push button switch or a guarded hook-shaped, coded toggle switch.

Type of arresting hook (normal of emergency), type of air vehicle, and number of crew influence this requirement.

This requirement was formerly included in MIL-STD-203.

REQUIREMENT LESSONS LEARNED (3.4.1.8.1.8)

(TBD)

A.4.4.1.8.1.8 Hook actuation criteria.

Hook actuations shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.8.1.8)

The characteristics established by this requirement can usually be determined by review of the hardware and engineering drawings. Formal demonstrations or tests may be necessary for some complex control systems such as automatic deployment. Revise the verification requirement to be compatible with the design requirements.

VERIFICATION GUIDANCE (4.4.1.8.1.8)

TBS should be filled with inspection of drawings and demonstration on the air vehicle.

VERIFICATION LESSONS LEARNED (4.4.1.8.1.8)

(TBD)

A.3.4.1.8.2 Drag chutes

A.4.4.1.8.2 Drag chutes

A.3.4.1.8.2.1 Air vehicle drag chute performance.

(TBD)

REQUIREMENT RATIONALE (3.4.1.8.2.1)

(TBD)

REQUIREMENT GUIDANCE (3.4.1.8.2.1)

(TBD)

REQUIREMENT LESSONS LEARNED (3.4.1.8.2.1)

(TBD)

A.4.4.1.8.2.1 Air vehicle drag chute performance.

Drag chute performance requirements shall be __(TBS)__.

VERIFICATION RATIONALE (4.4.1.8.2.1)

Drag chutes should follow standard drag or drogue chute design practices as typically found in JSSG-2010 which provide the performance capability of drag chutes.

VERIFICATION GUIDANCE (4.4.1.8.2.1)

TBS should refer to the latest parachute design guide or specification as needed.

VERIFICATION LESSONS LEARNED (4.4.1.8.2.1)

(TBD)

A.3.4.1.9 Shipboard compatibility.

Landing gear for shipboard compatibility shall include features for __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.9)

(TBD)

REQUIREMENT GUIDANCE (3.4.1.9)

TBS should be filled in with catapulting, arrested landings, deck operations, ski jumps, and parking brakes.

REQUIREMENT LESSONS LEARNED (3.4.1.9)

(TBD)

A.4.4.1.9 Shipboard compatibility.

(TBD)

VERIFICATION RATIONALE (4.4.1.9)

(TBD)

VERIFICATION GUIDANCE (4.4.1.9)

(TBD)

VERIFICATION LESSONS LEARNED (4.4.1.9)

(TBD)

A.3.4.1.9.1 Landing gear catapult compatibility.

Air vehicles with ship-based landing gear shall be compatible with catapult systems by _(TBS)_.

REQUIREMENT RATIONALE (3.4.1.9.1)

Catapult systems provide additional power necessary for an air vehicle to take off from an aircraft carrier.

REQUIREMENT GUIDANCE (3.4.1.9.1)

TBS should be filled in with consideration given to the following:

Provisions for catapulting should be in accordance with MIL-L-22589.

The air vehicle deck clearance should not be less than six inches. This clearance should also be maintained with respect to the composite clearance envelope during all catapulting operations with the air vehicle in all critical off-center positions and rolled to an attitude commensurate with a 25 knot cross wind and the main gear fully compressed and tire flat on the wing-low side.

Landing gears of ship-based air vehicles should include provision to prevent damage due to repeated sudden extension of the landing gear as the wheels pass over the deck edge subsequent to catapulting, a bolter, or a touch and go.

For ship-based air vehicles, tire selection should be based on the dynamic reaction resulting from catapulting whereby tires should not be fully deflected to a bottomed condition.

On ship-based air vehicles, if the shock absorber is of the stored-energy type, the energy stored in the shock absorber during the catapult stroke should be sufficient to provide rotation of the air vehicle to flight attitude at the end of the deck run in the event that one or both nose gear tires have failed during the catapult run. The stored energy should not cause pulsating loads that would jeopardize safe operation of the air vehicle.

When catapulting, means should be provided for automatic retraction of the bumper wheel or skid, if used.

A "park-on" cockpit warning system or an automatic park brake release system should be provided to preclude "brakes-on" during catapulting.

The landing gear retraction time should be compatible with the air vehicle flight performance and should not exceed 10 seconds.

The center of the nose wheel axle of ship-based air vehicle should clear the deck by no less than 6 ½ inches when the tire(s) is flat.

REQUIREMENT LESSONS LEARNED (3.4.1.9.1)

(TBD)

A.4.4.1.9.1 Landing gear catapult compatibility.

Landing gear catapult compatibility shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.9.1)

Verification will ensure that air vehicles can safely and successfully take off from aircraft carriers.

VERIFICATION GUIDANCE (4.4.1.9.1)

(TBD)

VERIFICATION LESSONS LEARNED (4.4.1.9.1)

(TBD)

A.3.4.1.9.2 Arrested landings compatibility.

Landing gear for ship-board conventional takeoff and landing air vehicles shall be capable of arrested landing.

REQUIREMENT RATIONALE (3.4.1.9.2)

Ship-based air vehicles should be capable of landing on ships at high speeds, which requires the use of arresting gear so that the plane does not roll beyond the carrier deck edge.

REQUIREMENT GUIDANCE (3.4.1.9.2)

When designing tires, consideration should be given to dynamic impact loads, especially when traversing a 1-5/8 inch diameter arresting cable.

For ship-based air vehicles, the restraint system should withstand the following ultimate load factors: 20 forward static, 10 lateral static, 7.5 aft static, 20 down static, and 5 up static.

The fuselage aft of landing gear struts of ship-based air vehicles should be designed to prevent or shield external projections that might engage the arresting wires.

Provisions should be made to retain the nose wheel in the centered position until landed, and remain centered during roll back from arrested landings.

The landing gear installation of ship-based air vehicles should not contain features such as sharp projections or edges that would be conducive to failure of the barricade in the event of a barricade engagement.

In any position of the foot, there should not be a tendency for the pilot to apply brake effort unintentionally during the normal use of the rudder pedals or during arrested landings.

Wheel diameter should be selected to prevent the arresting cable from riding over top the wheel when the tires are flat. The recommended dimension of the wheel radius is greater than 6.5 inches.

The tire pressure for ship operating design pressure should not exceed 1.3 times the static pressure at the rated load or 350 psi and 32 percent (32%) deflection.

REQUIREMENT LESSONS LEARNED (3.4.1.9.2)

(TBD)

A.4.4.1.9.2 Arrested landings compatibility.

Arrested landing compatibility shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.9.2)

Verification will ensure that air vehicles can safely and securely land on aircraft carriers.

VERIFICATION GUIDANCE (4.4.1.9.2)

TBS should be filled in with analysis and test to ensure arrested landings can be safely executed.

VERIFICATION LESSONS LEARNED (4.4.1.9.2)

(TBD)

A.3.4.1.9.3 Deck operations.

Deck spotting of ship-based air vehicles shall be provisioned by __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.9.3)

Air vehicles should be able to be operated in a confined area on a carrier. These operations should include but not be limited to taxiing, towing, and spotting.

REQUIREMENT GUIDANCE (3.4.1.9.3)

TBS: The wheel brake hydraulic system should be capable of providing adequate braking for deck handling without engine operation of external power packages and performing at least

10 applications of the normal brake before a hand pump or other means would be utilized to repressurize the brake system. A pressure indicator should be provided in the pilot's cockpit.

A minimum tire section width of six inches should be provided for ship-based air vehicles.

REQUIREMENT LESSONS LEARNED (3.4.1.9.3)

(TBD)

A.4.4.1.9.3 Deck operations.

Deck spotting for carrier air vehicles shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.9.3)

Maneuverability on air vehicles carrier decks is limited. Therefore, it is necessary to ensure air vehicles have the capability to be operated and then stowed to maximize space on the carrier.

VERIFICATION GUIDANCE (4.4.1.9.3)

(TBD)

VERIFICATION LESSONS LEARNED (4.4.1.9.3)

(TBD)

A.3.4.1.9.4 Ski jumps.

Air vehicles with ski jump capability shall have __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.9.4)

The objective of the requirement is to establish performance for the gear for ski jump operations.

REQUIREMENT GUIDANCE (3.4.1.9.4)

(TBD)

REQUIREMENT LESSONS LEARNED (3.4.1.9.4)

(TBD)

A.4.4.1.9.4 Ski jumps.

(TBD)

VERIFICATION RATIONALE (4.4.1.9.4)

(TBD)

VERIFICATION GUIDANCE (4.4.1.9.4)

(TBD)

VERIFICATION LESSONS LEARNED (4.4.1.9.4)

(TBD)

A.3.4.1.9.5 Parking brake.

All shipboard air vehicles shall have a parking brake.

REQUIREMENT RATIONALE (3.4.1.9.5)

Shipboard air vehicles need a parking brake for ready alert status, rough sea conditions, and catapult spotting.

REQUIREMENT GUIDANCE (3.4.1.9.5)

VTOL air vehicles with wheeled-type landing gear should be able to set parking brakes prior to landing.

REQUIREMENT LESSONS LEARNED (3.4.1.9.5)

(TBD)

A.4.4.1.9.5 Parking brake.

(TBD)

VERIFICATION RATIONALE (4.4.1.9.5)

(TBD)

VERIFICATION GUIDANCE (4.4.1.9.5)

(TBD)

VERIFICATION LESSONS LEARNED (4.4.1.9.5)

(TBD)

A.3.4.1.10 Specialized subsystems.

The air vehicle shall have specialized subsystems or landing gear characteristics as follows: (TBS) .

REQUIREMENT RATIONALE (3.4.1.10)

This requirement is to cover those specialized subsystem requirements not normally covered under landing gear subsystem.

The requirement describes landing gear other than nose wheel, main wheel, or tail wheel. Examples could be outrigger or skid-type landing gear. Unique air vehicle design or operational characteristics may drive the need for this gear.

REQUIREMENT GUIDANCE (3.4.1.10)

TBS is filled with the name and requirements of any specialized subsystems to meet mission requirements. Examples of specialized subsystems are: skis, crosswind positioning systems, kneeling systems, and inflator-deflations systems.

Towing and ground handling of air vehicles with skid-type landing gear should be possible with the airplane loaded to maximum gross weight.

REQUIREMENT LESSONS LEARNED (3.4.1.10)

The C-5 have forward and aft kneeling systems, had onboard inflation and deflation systems, and an aft steerable gear to account for cross wind landings.

A.4.4.1.10 Specialized subsystems.

The specialized subsystem shall be verified by (TBS) .

VERIFICATION RATIONALE (4.4.1.10)

Each type of specialized subsystem will have its own particular verification methods and needs.

VERIFICATION GUIDANCE (4.4.1.10)

TBS: Most subsystems should require system analysis, laboratory testing and on air vehicle demonstration and possibility pass and fail criteria.

VERIFICATION LESSONS LEARNED (4.4.1.10)

(TBD)

A.3.4.1.10.1 Floatation gear.

When an air vehicle is equipped with floatation gear, the gear shall facilitate safe takeoff, landing, taxiing, towing, and mooring of the air vehicle on the water's surface.

REQUIREMENT RATIONALE (3.4.1.10.1)

Flotation gear has been used successfully on rotorcraft and other air vehicles, but specialized landing gear setups have unique performance requirements.

REQUIREMENT GUIDANCE (3.4.1.10.1)

Flotation gear is either fixed position or deployable. Deployable flotation gear should be capable of automatic inflation after water contact. Considerations to take into account include, but are not limited to: water buoyancy, drop characteristics, stability and control characteristics at various sea states, stability and control with rotors turning and at rest, weight and balance limitations, effects on aerodynamic performance and aeroelastic qualities, water taxi capabilities, takeoff and landing characteristics with the subsystem installed, validation of adequate clearance for rotors or propellers at various centers of gravity and various sea states. The effects of in-flight deployment should be investigated. Also effects on egress should be investigated.

REQUIREMENT LESSONS LEARNED (3.4.1.10.1)

(TBD)

A.4.4.1.10.1 Floatation gear.

The operational characteristics of the floatation gear shall be verified by analysis and tests.

VERIFICATION RATIONALE (4.4.1.10.1)

Some aspects of the floatation gear's behavior can be verified by analysis (weight and balance limitations, water buoyancy, adequate propeller or rotor clearance) but other aspects should be demonstrated by actual testing (stability and control characteristics, takeoff and landing characteristics)

VERIFICATION GUIDANCE (4.4.1.10.1)

Typical qualification test objectives and measurements are to validate water buoyancy, drop characteristics, stability and control characteristics at various sea states, stability and control with rotors turning and at rest, weight and balance limitations, effects on aerodynamic performance and aeroelastic qualities, water taxi capabilities, takeoff and landing characteristics with the subsystem installed, validation of adequate clearance for rotors or propellers at various centers of gravity and various sea states, maintainability, and electromagnetic compatibility if the flotation gear is squib activated. The effects of in-flight deployment should be investigated. Also effects on egress should be investigated. Typically, strain gages should be used to evaluate structural adequacy of points of attachment. Typical measurements are weight, buoyancy, drag characteristics, clearance, required power, voltage, stress at attachment points, and vibration characteristics.

VERIFICATION LESSONS LEARNED (4.4.1.10.1)

(TBD)

A.3.4.1.10.2 Snow ski gear.

When an air vehicle is equipped with snow skis, the gear shall facilitate safe takeoff, landing, taxiing, towing, and mooring of the air vehicle on snow.

REQUIREMENT RATIONALE (3.4.1.10.2)

Snow ski gear has been used successfully on rotorcraft and other air vehicles, but specialized landing gear setups have unique performance requirements.

REQUIREMENT GUIDANCE (3.4.1.10.2)

Considerations to take into account include, but are not limited to: buoyancy in snow, stability and control characteristics at various wind conditions, visibility in snow with rotors turning, weight and balance limitations, effects of aerodynamic performance, taxi capabilities under various snow conditions, takeoff and landing characteristics with the subsystem installed, validation of adequate clearance for rotors or propellers at various center of gravity positions, and effects on in-flight performance.

REQUIREMENT LESSONS LEARNED (3.4.1.10.2)

(TBD)

A.4.4.1.10.2 Snow ski gear.

The operational characteristics of the snow ski gear shall be verified by analysis and tests.

VERIFICATION RATIONALE (4.4.1.10.2)

Some aspects of the snow ski gear's behavior can be verified by analysis (footprint areas, buoyancy in snow, weight and balance limitations) but other aspects should be demonstrated by actual testing (stability and control characteristics, takeoff and landing characteristics, visibility in snow with rotors turning).

VERIFICATION GUIDANCE (4.4.1.10.2)

Typical qualification test objectives and measurements are to validate footprint areas, buoyancy in snow, stability and control characteristics at various wind conditions, visibility in snow with rotors turning, weight and balance limitations, effects of aerodynamic performance and aeroelastic qualities, taxi capabilities under various snow conditions, takeoff and landing characteristics with the subsystem installed, validation of adequate clearance for rotors or propellers at various center of gravity positions, maintainability, and effects on in-flight performance. Typically, measurements should include weight, footprint area, structural adequacy of attachment points, vibration characteristics, ground and snow clearances, step height, and aerodynamic and aeroelastic characteristics.

VERIFICATION LESSONS LEARNED (4.4.1.10.2)

(TBD)

A.3.4.1.11 COMPONENTS

A.4.4.1.11 COMPONENTS

A.3.4.1.11.1 Tires

A.4.4.1.11.1 Tires

A.3.4.1.11.1.1 Air vehicle tire performance.

The tires shall be capable of performing on the air vehicle for the following: (TBS) .

REQUIREMENT RATIONALE (3.4.1.11.1.1)

The objective is to provide a tire capability compatible with the air vehicle operation and performance for all taxi, turns, takeoff, and landing operations at the critical gross weights and velocities that do not exceed air vehicle structural or operational limits. The blank should be filled with an all inclusive performance requirement such as: conditions of maximum air vehicle takeoff and landing, including all ground maneuvering before and after takeoff and landing. Emergency conditions should also be considered, such as aborted takeoffs and maximum landings. If aerodynamic heating exceeds 160°F during flight, this should be considered.

REQUIREMENT GUIDANCE (3.4.1.11.1.1)

TBS should as a minimum have the following air vehicle performance parameters defined:

a. Tire sizing parameters

1. Air vehicle configuration - This will tend to dictate the gear geometry and possibly the decision for a small number of large diameter tires or a large number of small diameter tires.
2. Flotation - This requirement will tend to dictate tire pressure, gear configuration and may drive the design of the air vehicle fuselage. If flotation does drive the design, tire service life problems will be nil.
3. Tire load - This requirement will be dependent upon 1 and 2, above.
4. Growth allowances - This requirement will tend to dictate tire size, if not established by flotation.
5. Runway considerations - Maximum tire pressure is limited to 300 psi; minimum footprint area is to be equal to or greater than 50 square inches.

b. Tire design parameters

1. Velocity - This requirement will dictate the tread thickness, and therefore, wear life.
2. Taxi distances and turning requirements - These requirements will tend to design the tire carcass, bead step-off area, and the shoulder area due to internal heating from the flexing of the tire.
3. Environmental heating - Aerodynamic heating level, time at high speed, equipment mass and air flow may be significant parameters for the design. This may dictate high temperature compounding.
4. Tire slippage - Wheel and tire interface should be designed to present slippage that could cause loss of air with damage to the tire, tube, valve or wheel.
5. Low temperature - Unless otherwise specified, the low temperature requirement for the tire compounds should be -65°F.
6. Burst pressure - Tires normally are designed to withstand a burst pressure equal to 3.5 times the maximum operating (rated) inflation pressure. A factor of 4.0 is sometimes used for low pressure (Less than 150 psi) tires.

This requirement reflects the concept generated in MIL-PRF-5041, AFSC DH 2-1, and AFSC DH 1-6. This is an Industry accepted practice for military and commercial tire development.

Unless otherwise specified in the detail specification, tires should be tubeless. When specified, inner tubes should be in accordance with SAE AS50141.

The tire land based operating pressure should be equivalent to the rated pressure at a tire static load with a 32 percent (32%) tire deflection.

A tire contour should be selected that provides an aspect ratio above 72 (that is, tire section height to tire section width) unless exception is authorized by the detail specification.

Nosewheel tire size selection should account for maximum dynamic braking loads in addition to the maximum air vehicle static load.

REQUIREMENT LESSONS LEARNED (3.4.1.11.1.1)

Historically, except for the B-52, tires operated at velocities at or above 250 mph and 250 psi have relatively poor service life, less than 25 landings per tire. Tires operated at or less than 225 mph and 200 psi have good service life, over 100 landings per tire. Tires inflated at 250 psi and greater are more susceptible to cuts due to the high stress in the tread compared to a 200 psi tire. Higher inflation pressure also tends to accelerate groove cracking, resulting in tread failure such as chunking or stripping a tread.

As the speed rating increases, the tread thickness decreases which results in less wear life and greater susceptibility to cut removal. The cut depth is much more critical as the velocity increases.

Therefore, when establishing tire operational parameters, strive to limit the adverse effects of high rotational velocities and high pressures. Flotation and growth requirements will aid in a good solution to this problem. This requirement should not dictate design of a high performance air vehicle, such as fighter or interceptor types.

The use of air to inflate main wheel tires, where thermal fuse plugs are used, is not recommended. Release of the fuse plug will result in discharge of the air on to the hot brake increasing the probability of fire. Nitrogen is used to inflate most commercial and some military air vehicle tires.

It is sometimes desirable to mold a ridge in the tire sidewall to deflect water spray or other debris thrown up by the tire. This ridge is known as a “chine” and such tires are usually called “chine tires”. The primary use has been to prevent water spray from entering engine inlets. Chine tires are presently used on F-111 and C-9 air vehicle nose landing gears. Chine tires should be tailored for each application. Flight-testing is necessary to confirm suitability of design.

In the past, the maximum allowable braking dynamic load factor were 1.4 and 1.35 for low-pressure type III tires and for extra high pressure type VII tires, respectively.

A.4.4.1.11.1.1 Air vehicle tire performance.

Takeoff, landing, and taxi performance shall be verified by: __(TBS)__.

VERIFICATION RATIONALE (4.4.1.11.1.1)

The use of a laboratory dynamometer to evaluate the tire performance characteristics permits evaluation to the limits of the tire capability with risk. The design conditions are carefully controlled and are repeatable. The Industry has always utilized this method of evaluation prior to installation on an air vehicle to determine performance limits and to establish safety of flight. It is significantly more economic than any other verification method. The tire will also be observed and evaluated during the routine flight test program.

VERIFICATION GUIDANCE (4.4.1.11.1.1)

TBS should be filled with the air vehicle performance requirements that need to be meet. This should take into account the static and dynamic loads, speeds and time at loads for worst case operational conditions, as well as normal operating conditions.

VERIFICATION LESSONS LEARNED (4.4.1.11.1.1)

(TBD)

A.3.4.1.11.1.2 Service life.

Tires shall have a service life, due to tread wear only, of not less than __(TBS 1)__ landings. This shall apply during operation of the air vehicle as follows: __(TBS 2)__.

REQUIREMENT RATIONALE (3.4.1.11.1.2)

The objective is to provide a satisfactory life. Historically, tires of a conventional design, Types III, VII, and VIII, should provide 50 to 300 cycles (one takeoff and one landing equals one cycle), dependent on diameter and velocity requirements.

REQUIREMENT GUIDANCE (3.4.1.11.1.2)

TBS 1 should be filled with a reference to Tire design load-speed-time figure for the air vehicle application, showing the number of air vehicle cycles required for a given tire diameter and speed rating range.

TBS 2 should describe the operation during which the life requirement is to be applied.

The performance parameters controlling service life are:

a. Tire diameter establishes thickness
b. Velocity rating of tread
c. Tire pressure due to load - stress in tread rubber
d. Installation.

The source of this criteria is MIL-PRF-5041, supplemented by the AFSC-Ogden ALC Life Cycle Cost Program. A similar arrangement is a worthy candidate for future programs.

Tire mold skid depth (tread wear prior to removal) should be compatible with current state of the art for the particular tire size selected.

REQUIREMENT LESSONS LEARNED (3.4.1.11.1.2)

Tire life is frequently affected by the air vehicle installation. If there is excessive camber or yaw abnormal tread wear can be generated. Early F-15 air vehicles are an example of this problem. Obviously, the tire design cannot be held accountable for this performance.

If the landing gear is designed or modified to cause excessive camber or yaw angle, excessive tire wear may result.

The need for venting (drilling of vent holes in the side wall of the tire) high performance tires exists regardless of type of construction to prevent blistering and build up of nitrogen pressure between the cord layers within the tire.

A.4.4.1.11.1.2 Service life.

The service life shall be evaluated on the air vehicle during flight test.

VERIFICATION RATIONALE (4.4.1.11.1.2)

The primary factor in tire service life is tread wear. Laboratory testing does not evaluate this aspect of tire performance. Therefore, the flight test program is the first opportunity to evaluate this aspect of the design. The service life evaluation will be continued into Using Command evaluation to Squadron level. AFMC will further extend this aspect with its wear index tests of the Life Cycle Cost Program.

VERIFICATION GUIDANCE (4.4.1.11.1.2)

The specific operational service spectrum to flown by the air vehicle needs to be agreed to by both the customer and the manufacturer. Otherwise a Life-Cycle-Cost program will have to be established to verify the life of the tire.

VERIFICATION LESSONS LEARNED (4.4.1.11.1.2)

(TBD)

A.3.4.1.11.1.3 Retread and carcass performance.

The tire carcass shall be capable of __(TBS)__ retreads without degradation of tire structure performance.

REQUIREMENT RATIONALE (3.4.1.11.1.3)

The objective is to provide a tire construction that can be retreaded. This has proven to be cost effective in the Air Force and particularly on commercial air vehicle where they have retreaded a single tire as many as nine times.

REQUIREMENT GUIDANCE (3.4.1.11.1.3)

TBS should be filled with a number for repeated retreads that would be compatible with the tire performance and life. If the tire life is relatively long on a large diameter slow speed tire, the aging life of the carcass may limit it to one retread. If the tire is medium in diameter, 34-40 inches and rated in the 225 mph range, it could be retreaded four or five times. A high speed fighter tire of 28-34 inch diameter could also be retreaded five times, providing the carcass could not be subjected to high working stress due to inflation pressure of 250 psi or greater. In this case, only one retread may be cost effective. Performance parameters controlling retreadability include:

a. Tire velocity rating
b. Tire pressure rating
c. Tire construction (special requirements)
    1. Environmental heating
    2. Excessive deflection
    3. Exotic designs
    4. Age limitations
    5. Balancing.

This is a new requirement not currently defined in any general defense specification. It reflects the current state of the art and has been used on all recent systems in the interest of Life Cycle Cost.

REQUIREMENT LESSONS LEARNED (3.4.1.11.1.3)

Reliable retreading is dependent on a sound carcass and sufficient material on the crown of the tire to prepare the surface properly for a new tread. Providing a sound carcass is dependent on testing the initial construction through repeated life test on the dynamometer, stripping the tread and retreading between cycles, and a good inspection of a used carcass prior to retreading.

A.4.4.1.11.1.3 Retread and carcass performance.

Retreading capability shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.11.1.3)

The retread capability of the carcass, can be verified by requiring the tire to complete all the dynamic tests of "Air vehicle tire performance" in this appendix, then buff the tread and repeat the cycle without the heat soak is above 300°F for one hour.

VERIFICATION GUIDANCE (4.4.1.11.1.3)

TBS: The tire should be tested to the operational requirements of the original tire to ensure compatible performance for all air vehicle operational missions.

VERIFICATION LESSONS LEARNED (4.4.1.11.1.3)

(TBD)

A.3.4.1.11.1.4 Growth within tire.

In selecting tire sizes, an allowance shall be made for __(TBS)__ growth in air vehicle maximum design weight within the same size tire.

REQUIREMENT RATIONALE (3.4.1.11.1.4)

The objective is to provide a tire with growth potential within the original clearance envelope. Historically, even in the 1970s era, aircraft continued to grow in gross weight that would overload original tire capabilities. Whereas, by adding plies, the tire can easily be changed to carry the extra load within the same envelope.

REQUIREMENT GUIDANCE (3.4.1.11.1.4)

TBS should be filled with 25 percent (25%) based on past experience.

Performance parameters controlling growth are:

a. Burst pressure
b. Bulk modulus
c. Taxi distances, velocity, and temperature.

This requirement was contained in AFSC DH 1-6 and AFSC DH 2-1. This requirement was originally generated in the mid 1950's based on lessons learned with aircraft growth. Since change in tire size impacts stowage area and airframe sizing, it is considered to be an important concern.

A tire ply rating should be selected that is at least two ply ratings less than the maximum recommended ply rating for any particular tire size.

REQUIREMENT LESSONS LEARNED (3.4.1.11.1.4)

Most aircraft developed in the last 25 years have grown in gross weight from 10 to 40 percent (10 to 40%). In many of these instances the landing gears cannot grow accordingly, and therefore are operated as less than "0" margin. Tires readily lend themselves to easy growth potential within the original designed envelope by increasing the number of plies. This has been a very effective method of providing sufficient tire growth on aircraft developed in the late 1960's and early 1970's.

A.4.4.1.11.1.4 Growth within tire.

An analysis shall be performed to show growth potential in the selected tire sizes.

VERIFICATION RATIONALE (4.4.1.11.1.4)

The requirement for tire growth can be verified by analysis of actual plies to ply rating, to maximum number of plies and maximum ply rating allowed.

VERIFICATION GUIDANCE (4.4.1.11.1.4)

A load analysis should be conducted to show that the tire can handle the specified increase in air vehicle gross weight without having to change tire size, only ply ratings, and load carrying capability.

VERIFICATION LESSONS LEARNED (4.4.1.11.1.4)

(TBD)

A.3.4.1.11.1.5 Multiple tire operation with failures.

For multiple tire gear designs, capacity shall be provided to accommodate __(TBS 1)__ tire failure(s) without additional tire failure, when operating at all gross weights under the following conditions:
__(TBS 2)__.

REQUIREMENT RATIONALE (3.4.1.11.1.5)

The objective is to provide tires with the dynamic load carrying capability to withstand an overload for a short period of time and not cause a catastrophic failure. Should a tire fail during taxi at maximum gross weight, the other tire(s) on that strut should have the capability to support the additional dynamic load while taxiing back to an apron or repair area. On takeoff, the remaining tire(s) should have the capability to support the dynamic load for either aborting or completion of takeoff, followed by a landing at landplane landing gross weight.

REQUIREMENT GUIDANCE (3.4.1.11.1.5)

TBS 1 should be filled with a statement such as; "one" or "fifty percent (50%) of assembly".

TBS 2 should describe the minimum operation with the failed tire(s).

Performance parameters controlling include:

a. Load rating
b. Ply rating
c. Air vehicle gross weight
d. Center of gravity locations
e. Tire construction
f. Operating spectrum.

Criteria for overload capability factors in tire capacity were previously documented in AFSC DH 2-1. The requirement, as expressed, is a new requirement defining the conditions of overload from which the remaining tires are expected to continue to operate. This will allow the airframe manufacturer to properly develop and demonstrated this overload capability.

REQUIREMENT LESSONS LEARNED (3.4.1.11.1.5)

Present specifications do not require testing tires to dynamic loads greater than the rated static load. Nose tires are rated with dynamic load factors ranging from 135 percent (135%) to 150 percent (150%) of the static load rating. The dynamic loads usually are not verified by test.

Development of a tire to withstand a sustained overload, such as excess load due to a mating flat tire, requires a tire test program simulating this condition. For example, if a tire is required to operate safely after a mating tire has failed, at least investigate the following:

a. Failure of a tire during taxi out for takeoff will result in an overload on the mating tire(s). The mating tire should have capability to endure the excess load for taxiing back to a repair area.
b. Tire failure during takeoff run. The mating tire should have the capability to endure the excess load for an aborted stop.

A.4.4.1.11.1.5 Multiple tire operation with failures.

Overload capability shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.11.1.5)

Laboratory dynamometer tests provide the opportunity to conduct a controlled test to the required limits without risk to air vehicle or personnel. It is the most economic approach from a cost and schedule viewpoint.

VERIFICATION GUIDANCE (4.4.1.11.1.5)

TBS should be filled with analysis and tests.

VERIFICATION LESSONS LEARNED (4.4.1.11.1.5)

(TBD)

A.3.4.1.11.2 Wheels

A.4.4.1.11.2 Wheels

A.3.4.1.11.2.1 Air vehicle wheel performance.

The wheel assemblies shall be capable of performing on the air vehicle for the following: (TBS) .

REQUIREMENT RATIONALE (3.4.1.11.2.1)

The purpose of this requirement is to identify the operating conditions that will establish the design envelope for the main, nose, and auxiliary wheel equipment.

REQUIREMENT GUIDANCE (3.4.1.11.2.1)

The conditions should account for maximum gross weight usage (taxi and takeoff), design mission takeoff, landing, and taxi. A spectrum should be generated to simulate the anticipated load distribution to give the required life. If high brake temperatures are typically encountered with main wheels, the design spectrum should include this condition. Eccentric loads induced by installation on the air vehicle or operational usage should be suitably reflected in the requirements. These will not be known until the design of the installation is complete, but provisions for such eventualities should be included in the basic requirements. Examples might be: high frequency pivot, cambered roll, or yawed roll.

TBS should include all ground operation of the air vehicle, in particular worst-case conditions covering both static and dynamic requirements.

Velocity, wheel material and processing, vertical versus side load, fatigue characteristics, sustained stress levels, and tire-wheel-axle interfaces have an impact on the ability of the wheel to meet the required performance requirements. This requirement summarizes the various load discussions previously stated in legacy documents MIL-W-5013, AFSC DH 1-6, and AFSC DH 2-1. This is the very backbone of the wheel design requirements. It establishes the static strength and fatigue requirements for the wheel assemblies.

REQUIREMENT LESSONS LEARNED (3.4.1.11.2.1)

In the past, the static load capability was established by arbitrary criteria, and the design conditions were not necessarily associated with actual operating conditions. An example of problems associated with arbitrary criteria in lieu of rational criteria is the C-141A main wheel. It was designed and tested to maximum-load Military Specification criteria with an arbitrary cambered roll fatigue requirement. On the airplane, with ±80° steering available to the pilot, the landing gear was experiencing numerous full pivots during routine taxi usage. The result was over 75 wheel flange failures in service. The wheel was redesigned to accommodate this specific condition of pivot turn. Since the revised wheel has been put into service (approximately 1970), there have been no further wheel flange failures.

Use of arbitrary criteria does not always drive the designs to structural inadequacy. A recent example has been the use of .5 g turn for yawed roll criteria in design. This particular condition has produced numerous laboratory failures which drove redesign of the wheel hub area. There has never been evidence of field difficulties in this area with the wheels involved. It is suspected that the criteria is quite conservative and is resulting in heavy hub wheels. Research is planned by Flight Dynamics Laboratory to measure stress in various wheels for straight yawed roll versus turn techniques on a dynamometer flywheel to try to resolve this issue.

Another aspect that is some concern is the aspect of corrosion effects in the field as compared with development testing. Corrosion has a significant impact on inventory life, but current criteria do not account for this phenomenon. Recent painting technique improvements will potentially diminish this disparity.

Corrosion effects that occur in the field are not adequately covered during development testing. Thus, design considerations should be given to improve corrosion protection procedures for the wheels. Specifically, ensure the wheel bearing seal will protect the bearings from the environment. (Note that a metal-to-metal interface on the seal is inadequate for this purpose, as discovered on the B-1 wheel.)

Corrosion is one of the main reasons for retiring aluminum wheel halves. Fatigue cracks start from corrosion pits in most of the cases. The tire beads wear off the corrosion protection on the wheel rims.

A.4.4.1.11.2.1 Air vehicle wheel performance.

Laboratory tests shall be conducted to evaluate takeoff, landing, and taxi performance requirements.

VERIFICATION RATIONALE (4.4.1.11.2.1)

Laboratory tests are recommended because of the versatility in evaluating performance and the schedule required for development. The laboratory can explore the load envelope and provide timely answers to the designers and evaluators.

VERIFICATION GUIDANCE (4.4.1.11.2.1)

The wheel should be subject to the operational loading that it will experience on the air vehicle to ensure all mission requirements can be met.

VERIFICATION LESSONS LEARNED (4.4.1.11.2.1)

(TBD)

A.3.4.1.11.2.2 Service life.

The wheel service life shall be __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.11.2.2)

From a logistic consideration, an arbitrary average service life should be established for wheels, consistent with operational needs.

REQUIREMENT GUIDANCE (3.4.1.11.2.2)

In the past, an arbitrary laboratory life of 1500, 2000, or 2500 miles at rated load or 110 percent (110%) of air vehicle design limit load on the wheel was selected for design and the service life achieved was accepted. However, our needs are actually service life, so average field service life should be specified. The number selected is a function of the type of air vehicle on which it will be installed and the overall logistic plan. Some air vehicle places premium on lightweight and the wheel criteria should knowingly reflect this priority. Weight and life are directly related. Ten thousand service miles for a cargo air vehicle are consistent with airline criteria. Two thousand service miles for high performance air vehicle wheels seem to reflect the primary concept of design.

Current airline wheels are designed for 50,000 miles or greater service life.

TBS should reflect a accelerated life performance of 2000 or 2500 mile at 110 percent (110%) of maximum rated load. This allows a reasonable test program and produces a limited life wheel.

Maintenance procedures, air vehicle usage, wheel material; and operating technique are major factors in achieving service life. Wheel fatigue life requirements were contained in MIL-W-5013. Generally, the roll life requirements were straight roll at an arbitrarily established rated load. About 15 years ago, commercial and military development requirements were modified to include typical service abnormalities. This has resulted in improved service performance. In most cases where frequent service failures occur, the cause can be traced to service induced conditions which were not accounted for in the development criteria and evaluation. Therefore, duplication of operating environment in development evaluation is a paramount consideration.

REQUIREMENT LESSONS LEARNED (3.4.1.11.2.2)

Actual wheel service life is difficult to determine. Ogden Life Cycle Management Center (LCMC) is attempting to initiate a system to track wheel forging by serial number. Commercial wheels are traced and tracked. Each major forging is warranted for a given life.

Maintenance has a major role in extending or shortening wheel service life. Bearing and axle nut installation, handling during tire changes, and tire-wheel inflation technique and diligence contribute to wheel life.

Being able to predict a realistic usage spectrum and qualifying to this criteria represents a major factor in achieving long service life. However, if a wheel qualified to the above accelerated life spectrum gives a 10 year life expectance, then only 2-3 shipsets of wheels are needed for the life of the air vehicle, which can be easier and cheaper to maintain than trying to test the wheel to a long and drawn-out test program.

Wheel flanges are the most frequent source of service failure. Extra attention should be placed on this portion of the design.

Air vehicle wheels qualified with one type of tire may not be compatible with other types. This incompatibility may not be limited to radial versus bias construction, but may occur on bias to bias or radial to radial from different vendors. When qualifying different types of tires for the same application (bias versus radial), it is strongly recommended that both a strain survey and a roll test be performed on both types of tires. When an alternate tire supplier is qualifying for the same application a strain survey should be performed to determine if further roll testing is needed.

A-10, F-15, F-16 wheels were qualified with one type of tire, when the other type of tire was later qualified to the same tire requirements, it was found that there was a significant reduction in the wheel fatigue life. Analysis should only be used to design and to obtain confidence that the component will pass the test.

A.4.4.1.11.2.2 Service life.

Service life of wheels shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.11.2.2)

Dynamometer roll test is the most economical and reasonable means of demonstrating service life. The loads and environment are carefully controlled and permit a more formal analysis of results.

VERIFICATION GUIDANCE (4.4.1.11.2.2)

TBS should show verification by analysis and laboratory testing.

VERIFICATION LESSONS LEARNED (4.4.1.11.2.2)

When a second source for tires is qualified the requirement for additional strain and roll testing is not the tire manufacturer responsibility, but belongs to the prime airframer or governments responsibility; the procurement contracts should reflect this.

The latest wheel roll tests include combined load roll tests with the side load inputted by a yawed roll. Cambered roll does not produce a side load and a dynamometer.

Service life can best be determined by a properly structured experimental stress analysis using strain gages. Production tire configurations are an absolute must.

A.3.4.1.11.2.3 Brake overheat capability.

Protection shall be provided to the wheel from brake heat to prevent __(TBS 1)__ after exposure to __(TBS 2)__ energy.

REQUIREMENT RATIONALE (3.4.1.11.2.3)

The purpose of this requirement is to establish performance requirements for heat dissipation.

REQUIREMENT GUIDANCE (3.4.1.11.2.3)

The potential detrimental effects to wheels and tires include wheel or tire explosion due to degradation in strength of either unit, or increase in tire pressure causing overstress. Solutions to these problems include wheel heat shields, and wheel fuse plugs.

TBS 1 should reflect no destructive degradation should occur to the wheel.

TBS 2 should reflect the emergency energy level associated with maximum landing weight landing, which is the highest energy from which you could expect a serviceable assembly.

Peak brake heat sink temperature, thermal conductivity properties of material, effectiveness of heat shields, and fuse plug eutectic are parameters affecting this requirement. Performance requirements similar to this statement on heat dissipation are contained in legacy documents MIL-W-5013, AFSC DH 1-6, and AFSC DH 2-1. Direct requirements for fuse plugs are contained in MIL-W-5013. The requirement reflects design approaches originally developed for commercial air vehicle but currently accepted as standard design practice for the military brake industry. The first fuse plugs were introduced around 1957.

REQUIREMENT LESSONS LEARNED (3.4.1.11.2.3)

Caution should be taken in designing the fuse plug installation to minimize stress risers. If the plug is screwed into the wheel well, extra precautions should be taken with the threads.

The fuse plugs should be located directly within the heat path from the brake to insure an environment similar to that being seen at the tire bead seat. Since this is the area that suffers degradation due to heat, the fuse plug should accurately reflect the environment.

Heat shields can cause structural damage to the wheel forging upon installation by inflicting a scratch. Care should be taken to insure relatively simple installation. Heat shield retention has been a difficult problem to solve on many wheel designs.

All sharp edges should be eliminated from heat shields.

A.4.4.1.11.2.3 Brake overheat capability.

Wheel overheat capability shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.11.2.3)

The laboratory provides the opportunity to explore the total design envelope. Under laboratory conditions, the energy input and other important factors can be controlled and will generally provide a better evaluation than on the air vehicle. Of course, flight test observations will also contribute to the overall assessment of design adequacy for the assembly.

VERIFICATION GUIDANCE (4.4.1.11.2.3)

TBS should be filled with analysis and laboratory testing.

VERIFICATION LESSONS LEARNED (4.4.1.11.2.3)

(TBD)

A.3.4.1.11.2.4 Nonfrangability criteria (flat tire operation).

Each wheel, with a flat tire, shall be __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.11.2.4)

This requirement is to provide a wheel that can roll on its rim without coming apart and damaging the air vehicle. This capability is called non-frangibility.

The roll-on-rim requirement of TSO C26c all but eliminated the flange failure mode on commercial airliners. This area should be carefully investigated in the development stage using strain gage techniques. Flange fatigue lives should be several times that of the area selected as the failure point. Failure point is normally selected for its non-explosive pressure release when a through crack develops.

REQUIREMENT GUIDANCE (3.4.1.11.2.4)

TBS should be filled with: “capable of performing one maximum weight landing touchdown and rollout without failure; reuse of the wheel is not required.”

REQUIREMENT LESSONS LEARNED (3.4.1.11.2.4)

(TBD)

A.4.4.1.11.2.4 Nonfrangability criteria (flat tire operation).

Flat Tire operation shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.11.2.4)

The verification of the non-frangibilty of the wheel is usually demonstrated during laboratory testing and is usually one of the last tests since the wheel is unusable after the test.

VERIFICATION GUIDANCE (4.4.1.11.2.4)

TBS should be filled in with analysis and laboratory testing to the required load-time curves. The wheel is not to come apart, and not to fragment in any way.

VERIFICATION LESSONS LEARNED (4.4.1.11.2.4)

Consider the TSO C26c roll-on-rim test method. This method does not use a tire, for it is believed that a tire will scatter the results over an unacceptable range.

A.3.4.1.11.2.5 Bias and radial tire compatibility.

Wheels shall be compatible with __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.11.2.5)

This requirement is to ensure that wheel life and strength is not lesson or less than what is required for mission operation, when radial or bias tires or when different bearings or brake manufacturers are used.

REQUIREMENT GUIDANCE (3.4.1.11.2.5)

TBS should be filled with: "…bias and radial ply tire designs, brakes, bearings, and axles with respect to life, loads, corrosion, lubrication, sealing, and thermal protection."

REQUIREMENT LESSONS LEARNED (3.4.1.11.2.5)

Wheel that have been qualified with either bias or radial tire designs only have consistently shown shorter service life when the other tire type is used on it. Thus the need to qualify both tire types if the possibility of both type of tires being used on the air vehicle.

A.4.4.1.11.2.5 Bias and radial tire compatibility.

Bias and radial tire compatibility shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.11.2.5)

The life capability of the wheel will be determined by analysis and wheel stress testing and roll testing with all qualified parts intended to be used in air vehicle operations.

VERIFICATION GUIDANCE (4.4.1.11.2.5)

TBS should be filled with: "… analysis and laboratory wheel and tire qualification testing." The testing and analysis should reflect the use of both types of tires if the program intends to allow both types of tires. If different bearings or brakes are to be used the same sets of analysis and testing should be accomplished.

VERIFICATION LESSONS LEARNED (4.4.1.11.2.5)

(TBD)

A.3.4.1.11.2.6 Pressure-release criteria.

Braked wheels shall have __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.11.2.6)

This requirement is to provide protection from wheel and tire explosions due to overpressurization and to over heat protection. The device(s) should release tire pressure before critical failure conditions occur.

REQUIREMENT GUIDANCE (3.4.1.11.2.6)

TBS should be filled with: Protection to prevent wheel or tire explosion due to high pressure or high temperature conditions. Braked wheel should provide a safe method of automatically releasing tire pressure whenever brake energies exceed maximum landing stop conditions. The device should not release at any time during or after a maximum design energy stop as specified for mission operations regardless of brake wear state. The device should not release during any Rejected Takeoff (RTO) stop, but may release after the air vehicle has come to a stop, but should release before the wheel and tire strength is compromised.

REQUIREMENT LESSONS LEARNED (3.4.1.11.2.6)

There has been loss of life from wheel and tire failures where protection was not provided, or malfunctioned.

A.4.4.1.11.2.6 Pressure-release criteria.

The pressure release capability shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.11.2.6)

The verification effort should show that the pressure release devices would release the pressure before any dangerous overpressurization occurs, nor when the strength of the wheel is compromised by over heat due to brake energy inputs.

VERIFICATION GUIDANCE (4.4.1.11.2.6)

TBS should be filled in with: “analysis and laboratory testing.” The analysis should take into account both thermal as well as strength considerations. The analysis should be compatible with the testing accomplished on the wheel, brake and tire assembly.

VERIFICATION LESSONS LEARNED (4.4.1.11.2.6)

Temperature release devices come in only incremental values, thus the location and shielding of the devices are critical to ensure that they will release before the wheel softens enough to fail.

Usually several high energy stops must be performed to determine the suitability of the particular release device and location thereof. Normally several of these devices are need on the wheel since heat rises thus the upper portion of the wheel will be hotter sooner thus one of the devices needs to be in the upper region at all times.

A.3.4.1.11.3 Brakes

A.4.4.1.11.3 Brakes

A.3.4.1.11.3.1 Air vehicle stopping and turn-around performance.

Brake assemblies used to provide any portion of the air vehicle stopping performance shall have the following characteristics: (TBS) .

REQUIREMENT RATIONALE (3.4.1.11.3.1)

This requirement is to define acceptable performance of conventional brake assemblies should the contractor elect to use this approach to provide stopping performance. Requirements should be in the form of success criteria that are unique to the brake assembly and its installation when the brake is used to provide any part of the stopping performance.

REQUIREMENT GUIDANCE (3.4.1.11.3.1)

TBS should be filled in with the expected air vehicle stopping performance need to satisfy the missions.

The requirement will usually be complex in that several aspects of "success" need to be considered. Brake performance criteria may be different for the different stopping conditions specified in air vehicle specification. Requirements to be considered should be selected from the following performance parameters and modified as necessary to clearly indicate the applicable stopping performance.

The following success criteria should be considered in completion of this requirement.

a. There should be no structural failure of the brake assembly during any single stop within the design envelope. This condition does not apply for abuse or usage outside of recommended operating limits.

b. The required stopping performance should be provided at any time during the specified operational life of the brake.

c. After initial installation, it should not be necessary to perform manual adjustment of the brake to permit the stopping performance to be met.

d. Brakes should not squeal, chatter, or cause any vibration during the stop that results in malfunction or reduces the life of any air vehicle component.

e. Brakes should not cause heating of any air vehicle component that causes component malfunction prior to attainment of required life.

f. Brakes should release upon release of the normal brake control during and after the stop.

g. No damage to the air vehicle, including rolling components, except wear of brake friction surfaces and ground-contacting elements should result from stopping.

h. Prevention of structural overload due to braking should not be dependent upon pilot proficiency.

i. Overheating of brake assemblies due to malfunction or abuse should be indicated by

j. The wheel brakes should be adequate for a rapid "turn around" or "park" time of no greater than the time required for refueling operation or no greater than 15 minutes.

Most of the suggested brake criteria were previously stated or implied in MIL-W-5013.

REQUIREMENT LESSONS LEARNED (3.4.1.11.3.1)

A very large percentage of these failures were brake disc failures. Most generally, these failures are not necessarily design failures, but are induced by improper production processing. Another potential cause of brake disc failure is excessive heat input. If dragging or some other operational input abuses a brake, the structural integrity can be compromised. However, design assessment under controlled conditions should give some measure of capability and potentially a measure of tolerable abuse.

Brake chatter is the frictional or mechanical excitation of the landing gear fore and aft vibrational mode. It is generally caused by negative damping from the friction pair and usually has a critical speed range.

Brake chatter should be defined as brake vibration in the 50 to 100 Hz range. Since gear walk is normally in the 5 to 15 Hz range, brake chatter does not cause gear walk. Gear walk is much more complicated than implied by this section. Brake squeal is defined as greater than 100 Hz. Gear walk is a complicated interaction of the airframe structure, brake control system, and dynamic characteristics of all concerned.

Brake housing designs should avoid using a direst part of the housing as a dynamic grease seal rub surface unless it is adequately hardened or protected against wear.

Brake squeal is the induced vibration of the stationary parts of the brake assembly and its mounting. It generally has a natural frequency of several hundred cps as compared to chatter frequency of 6-25 cps.

Brake chatter has been so severe that gear walk was induced on the F-101 and F-105 air vehicles. There are numerous design changes within the brake that can control this compatibility. The most effective change is with the lining rubbing surface materials. The stiffness of some of the structural members controls the response to squeal. Squeal has been so intense on brakes that it has resulted in structural failure. Extensive flight-testing was required on the B-52, KC-135, F-100 and F-101 to evaluate the gear vibration. Recent designs have been "tailored" to the application by establishing response characteristics of the system prior to finalized hardware design. Testing has been modified to evaluate the brake-mounting compatibility prior to installation on the air vehicle.

Peaks in brake torque are generally experienced as a result of various loading conditions. For instance, with steel brakes there is a high probability of brake chatter and peak torque at the low speed end of a normal energy stop. This is particularly true with a brake that is substantially worn. Peak torques are also experienced with very high-energy stops as the lining material reaches a point of maximum heat and wear. Most steel brakes produce very high torque, with maximum pressure applied from 30 to 0 knots. This occurs whether the assembly is cold or hot. It is experienced during taxi-out and taxi-in.

Temperature distribution within the brake and to the surrounding structure is a major factor in the success of a given brake design. Improper balance can produce hot spots in the hydraulic actuation section and contribute to seal deterioration and ultimately to leaks. It can produce excessive disk warpage. It can produce damage to the tire bead through the wheel assembly. Ventilation and elimination of conductive and convective heat is a major concern for assembly design. The problem of distribution is significantly increased with introduction of carbon brake discs. They may be lighter, but they do operate at a significantly higher temperature. Beryllium brake discs operate at significantly lower temperatures than steel or carbon brakes.

Overheating of brake assemblies may be encountered in operational use due to malfunction or abuse. A combination of low energy stops or a dragging brake may result in gradual temperature buildup that will negate normal safety devices or cause fires. Consideration should be given to detection of this condition and design to minimize damage caused by inadvertent overheating of the brake assembly. Several methods of temperature detection have been conceived and tried without overwhelming success. We have tried “TEMP-STICKS”, which are heat sensitive devices that melt at a prescribed value. Maintenance personnel place these units in direct contact with the hot brake to try to ascertain current temperatures. They read fairly reliably, but it is dangerous to place personnel in such close proximity to an overheated brake. The use of “Temp Sticks” on carbon has proven to serve as an oxidation catalyst on the F-16 carbon pressure plated when applied. Temp Sticks should not be used on carbon heat sinks.

Brake temperature sensors and indicators have been used on some air vehicles. Sensors may be mounted either directly in the brake assembly or in the wheel well. Reliability and maintainability problems may be severe due to the severe operating environment. Current use of this system in Air Force air vehicles is limited to the B-1 and C-9A. A system was installed on C-133 air vehicles but removed in operational use due to maintainability problem. Brake temperature monitoring system have been developed and used in several commercial air vehicles.

Life of adjacent components can be severely degraded due to high operating temperatures, or to reduction in material strength due to long term heat exposure. This softening effect has lead to early removal of components from service. The requirements should establish the temperature limits of surrounding components that are not to be exceeded during normal operation of the braking system.

Load deflection characteristics have an impact on design and service performance. If the assembly is too flexible, the torque radius drops and uneven wear and higher operating pressure result. Excessive deflection can also introduce eccentric or non-uniform loading into the brake structural members. The potential results of this can be premature failure in the field.

Often the source of yield failure is warpage and dimensional instability. Slots open-up or close depending on the type service experienced or the temperature-time history of the part. This is why the development cycle should contain as many evaluations of actual service as possible.

Carbon brake discs have a much lower tolerance to abnormal loading. For example, they are incapable of supporting axial loads inadvertently transmitted through wheel deflections. The torsional loads should be properly directed to avoid localized structural failure. Axial deflections of the heat sink should be minimized to prevent degradation since the individual discs have low rigidity in response to loads in that direction.

Performance of some wheel brake systems with anti-skid control is severely degraded as the brake wears. This is because of the increase in volume of brake actuation fluid that must be moved for each skid cycle. Manual adjustment can be used to compensate for brake wear, however, most present day high performance air vehicles use automatic brake adjusters.

Present tires, wheels and brakes are subject to damage when subjected to greater than maximum design landing energy. It is an accepted practice to replace these components after refused takeoffs stop with greater than maximum landing energy. Replacement of other landing gear components after any refused takeoff stop (up to design RTO energy) is unacceptable due to the high cost of components.

Normally the landing gear is designed to withstand a limit drag load resulting from an effective peak brake coefficient of 0.8. In some cases, particularly in growth versions of an air vehicle, this coefficient is reduced. If less than 0.8 is used, a test should be accomplished to verify that peak brake torque does not result in excessive drag load. It may be necessary to limit brake torque to provide a compatible landing gear subsystem. If maximum torque is limited, refused takeoff stopping performance is degraded.

Be careful to associate the maximum wheel static load and the tire static loaded radius at maximum wheel static load if the 0.8 wheel drag force is to be used to calculate peak to peak torque requirement. The 0.8 is not a brake coefficient, but a tire to ground coefficient of friction.

A.4.4.1.11.3.1 Air vehicle stopping and turn-around performance.

Brake durability, operating characteristics and compatibility with interfacing subsystem such as __(TBS 1)__ shall be evaluated by __(TBS 2)__.

VERIFICATION RATIONALE (4.4.1.11.3.1)

Brake evaluation will normally consist of laboratory and flight testing. In so far as possible, verification should be by air vehicle stopping tests. Performance is likely to be highly dependent upon characteristics of the air vehicle and environment that are difficult to simulate simultaneously in the laboratory. Some extreme conditions such as maximum and minimum temperature can be duplicated only in the laboratory. Some extreme operating conditions may also be too hazardous for air vehicle test. The requirement should clearly indicate characteristics to be evaluated by air vehicle test because this can be significant cost and schedule driver.

VERIFICATION GUIDANCE (4.4.1.11.3.1)

TBS 1 should reflect the various subsystems that are to be tested together to verify the stopping performance of the air vehicle.

TBS 2 should be filled with; "analysis, laboratory, and air vehicle testing." The laboratory testing is to evaluate maximum performance envelops. The flight testing is to verify that the analysis and laboratory test accurately demonstrated the stopping performance of the air vehicle is as published in the flight handbooks.

VERIFICATION LESSONS LEARNED (4.4.1.11.3.1)

Brake failure modes experienced in the laboratory may have little correlation with failure modes on the air vehicle because of poor simulation of air vehicle operation. Modification of the brake to eliminate laboratory failure modes may induce additional failure modes on the air vehicle. An example is that large drive key clearances may result in severe battering damage to brake disc keyways. Reduction of the clearance to eliminate the problem can lead to severe dragging brake problems on the air vehicle. This is primarily due to the fact that the actual loading cycle on the air vehicle is quite different than the accelerated life test usually used in the laboratory. Verification requirements should be structured to insure that performance on the air vehicle is the final success criterion. Laboratory test failures should not be ignored; however, laboratory successes are of no value to the operational Air Force.

Consideration can be given to allow structural failure or gross deformation of the brake assembly during a RTO if the stopping performance is satisfied.

A.3.4.1.11.3.2 Wear indicator and servicing criteria.

Means shall be provided to determine current status of brake wear without disassembly or the use of special tools.

REQUIREMENT RATIONALE (3.4.1.11.3.2)

This is an expression of an operational need to be able to determine status of brake wear during a pre-flight inspection or after any given flight. Rather than dictate wear pins for measurement, the designer is free to develop any means which will provide this inspection capability, consistent with his overall maintainability plan.

REQUIREMENT GUIDANCE (3.4.1.11.3.2)

Mechanical design of the brake, friction wear characteristics of the discs or lining material, and maximum permissible wear have marked influence on the ability to accurately display current wear status of the brake assembly.

This item was previously expressed in MIL-W-5013, calling specifically for "brake lining wear indicators". This requirement has been established from operational lessons learned, and generally expresses the desires of most Using Commands.

REQUIREMENT LESSONS LEARNED (3.4.1.11.3.2)

The details of attachment of wear indicators generally control the adequacy of the design. The problems encountered include improper use of frictional mechanical devices, which do not "pull through" to give an accurate assessment of brake disk wear. Other mechanical designs have encountered eccentric loadings and resulted in broken parts. There have been designs that utilize the mechanism of the automatic brake loadings. Frequently, design reliability is low due to exposure to this hostile environment.

Wear indicators should be readily observed and generally simple in design to provide a reliable indication of wear. Little or no interpretation should be required to assess the state of disk wear. Some degree of protection should be provided if the indicator extends beyond a reading surface to prevent damage due to foreign object impact.

A.4.4.1.11.3.2 Wear indicator and servicing criteria.

Brake wear indications and servicing suitability shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.11.3.2)

Brake evaluation will normally consist of laboratory and flight testing. In so far as possible, verification should be by air vehicle stopping tests. Performance is likely to be highly dependent upon characteristics of the air vehicle and environment that are difficult to simulate simultaneously in the laboratory. Some extreme conditions such as maximum and minimum temperature can be duplicated only in the laboratory. Some extreme operating conditions may also be too hazardous for air vehicle test. The requirement should clearly indicate characteristics to be evaluated by air vehicle test because this can be a significant cost and schedule driver.

VERIFICATION GUIDANCE (4.4.1.11.3.2)

TBS should be filled with: "laboratory testing and on air vehicle demonstration."

VERIFICATION LESSONS LEARNED (4.4.1.11.3.2)

Brake failure modes experienced in the laboratory may have little correlation with failure modes on the air vehicle because of poor simulation of air vehicle operation. Modification of the brake to eliminate laboratory failure modes may induce additional failure modes on the air vehicle. An example is that large drive key clearances may result in severe battering damage to brake disc keyways. Reduction of the clearance to eliminate the problem can lead to severe dragging brake problems on the air vehicle. This is primarily due to the fact that the actual loading cycle on the air vehicle is quite different than the accelerated life test usually used in the laboratory. Verification requirements should be structured to insure that performance on the air vehicle is the final success criterion. Laboratory test failures should not be ignored; however, laboratory successes are of no value to the operational Air Force.

A.3.4.1.11.3.3 Structural failure criteria.

Structural failure of the brake during normal, emergency or parking operation shall not result in __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.11.3.3)

The intention of the requirement is to define the unacceptable modes of failure for the brake assembly. If the design can tolerate minor discrepancies, strict adherence to no crack philosophy may be an unnecessary cost driver. It is our intention to define unacceptable results.

REQUIREMENT GUIDANCE (3.4.1.11.3.3)

TBS should reflect unacceptable consequences of failure, such as locking, piston over-extension, pieces of disc inducing locked wheel or structural failure of the wheel, deformation of the piston, bushing, or housing due to high operating pressures when the brakes are hot.

Maximum surface and heat sink temperature, heat sink materials, lug loadings, peak torques, and running clearances provide technical influence in meeting this requirement.

MIL-W-5013 contains a very superficial discussion of brake disc failure in section 4, which is inadequate to evaluate performance in the field. Therefore, this requirement is basically a new requirement to reflect all the lessons learned in maintenance and safety.

REQUIREMENT LESSONS LEARNED (3.4.1.11.3.3)

Brake disintegration can be the cause of serious accidents and potential fires.

A design approach, which has been used successfully to prevent fires as a result of brake disc failure, is to use actuation piston stops. The stops prevent the pistons from being pushed from the housing and subsequent flooding of the brake with hydraulic fluid from the open ports.

Carbon disk brakes are more susceptible to disk disintegration than steel discs due to the lack of strength when loaded axially. Extra precaution should be taken with this type of design to insure piston retention and fire prevention. Carbon brake discs generally are operated at higher temperatures than its steel brake counterparts.

The wheel to brake interface (wheel keys and brake clips) is critical, a number of carbon disc have been broken or cracked because of interference or brake dynamics in this area. Insure sufficient clearance is maintained at all loadings and the interface design is a proven concept.

A.4.4.1.11.3.3 Structural failure criteria.

Structural capacity of brake components shall be evaluated by test and analysis and the wheel lock-up range at various speeds on different surfaces shall be evaluated by analysis.

VERIFICATION RATIONALE (4.4.1.11.3.3)

Theoretical response to numerous modes of failure can be considerably more comprehensive than that which could be evaluated by test. Limited testing can be used to evaluate and validate the failure mode analysis.

VERIFICATION GUIDANCE (4.4.1.11.3.3)

The analysis should look at all possible brake failure modes and ensure the air vehicle is not compromised, and will not produce a catastrophic failure. The testing accomplished on the braking system should verify the safety design features are working as expected, and where relief devices are used they release as designed. Piston retention features should be demonstrated.

VERIFICATION LESSONS LEARNED (4.4.1.11.3.3)

Numerous brake fires have been experienced due to expansion and deformation of brake components such as bushings, pistons, and housings from the high temperatures of the brakes. The result is leaking hydraulic fluid on the hot brake stack. Therefore, the verification should demonstrate that the brake assemblies are protected from the heat, or the components should operate normally without failure within the heat environment experienced throughout the air vehicle operating range.

A.3.4.1.11.3.4 Secondary braking capability (fail-safe).

__(TBS)__ failure of the brake control system shall not result in a total loss of air vehicle braking capability.

REQUIREMENT RATIONALE (3.4.1.11.3.4)

Objective is to define whether single or dual failures will be permitted before loss of control. If the redundancy of dual failure concepts is significant cost drivers, the program management will have to determine what level of risk they are willing to take. The user should commit their feelings on this matter. The blank should indicate “single” or “dual”.

REQUIREMENT GUIDANCE (3.4.1.11.3.4)

TBS should list the number of failures that can occur and still not lose air vehicle braking and should indicate whether or not 100 percent (100%) braking capability of alternate braking systems is available.

Brake system design, redundancy, and reliability are key words in arriving at a decision for this requirement.

This requirement was previously contained in AFSC DH 2-1 and the intent is to clarify what is or is not acceptable performance for the brake system. It establishes the degree of redundancy, which is required. There is an obvious price to pay for double redundancy, but if the Using Command desires such features, the airframe manufacturer should be notified in advance so that the requirement is clear to all competitors during Source Selection.

The AFSC DH 2-1 contains a requirement just for single failure, but this "tailorable" requirement presents an option to increase the redundancy if the system needs the capability. Under no circumstances should a single failure in a hydraulic, electrical, or mechanical component of the normal braking system cause degradation of the emergency system capabilities.

REQUIREMENT LESSONS LEARNED (3.4.1.11.3.4)

The sources of failure that impact the ability of the system to maintain control are numerous. Failures may occur in the actuation system (hydraulic, pneumatic, or mechanical), the brake assembly, the pedal linkage, or the tire.

In one case, an electrical connector became disconnected and caused both the normal and emergency system to become inoperable. Do not route normal and emergency systems through the same connectors.

A.4.4.1.11.3.4 Secondary braking capability (fail-safe).

The effect of component malfunctions shall be evaluated by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.11.3.4)

Options available for this verification include simulator demonstrations, flight test, or analysis. Depending on the complexity of the system, the availability of the simulator, and experience level of the proposed contractors, the blank should be completed. It is also a function of economics, since each approach has associated costs. Technically, the simulator in conjunction with an analysis is most desirable because the interfaces can be evaluated and the conditions can be controlled.

VERIFICATION GUIDANCE (4.4.1.11.3.4)

TBS should reflect analysis and laboratory simulations and brake control system testing.

VERIFICATION LESSONS LEARNED (4.4.1.11.3.4)

(TBD)

A.3.4.1.11.3.5 Fire prevention criteria.

Setting the parking or holding brake immediately after __(TBS 1)__ stop conditions shall not cause damage to the brake, landing gear, or other air vehicle equipment. Brake fluid temperatures shall not exceed __(TBS)__°F at any time after any design-landing stop, or up to fuse plug release conditions.

REQUIREMENT RATIONALE (3.4.1.11.3.5)

Due to the high temperatures that can occur within the brake, the rest of the brake, seals and fluid needs to be protected from over temperatures that would degrade the seals, or cause fluid to escape on to the hot brake surfaces resulting in fire.

REQUIREMENT GUIDANCE (3.4.1.11.3.5)

TBS 1 should reflect the number of high-energy stop conditions that the brake system can experience in service. The maximum landing or stopping conditions.

TBS 2 is the maximum operation temperatures for the hydraulic fluid and seals used in the system. Typically, the values is 275°F. However, a number of fighters have raised the temperature limits up to 350°F and higher as long as test prove that the brake assembly can successfully operate at these elevated temperatures without any system equipment degradations.

REQUIREMENT LESSONS LEARNED (3.4.1.11.3.5)

F-16 brake system experienced a number of brake fires after the parking brake was set at the end of operational missions. Found that their was a direct heat flow path to the brake seals, which cause them to deteriorate allowing fluid to escape on the brake resulting in a self-feeding fire. Solved the problem by providing insulators between the piston and the brake stack.

A.4.4.1.11.3.5 Fire prevention criteria.

Fire prevention shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.11.3.5)

The brake system design should take into account the heat generated in the heat sink and determine the heat flow and provide protection from over heat to those components not able to withstand the high heat.

VERIFICATION GUIDANCE (4.4.1.11.3.5)

TBS should be filled in with: "...analysis and laboratory demonstration of the brake system at the design energies."

VERIFICATION LESSONS LEARNED (4.4.1.11.3.5)

(TBD)

A.3.4.1.11.3.6 Refurbishment criteria.

Provisions for brake friction members to be refurbished or the use of spacers after initial stack wearout shall be incorporated to provide cost effective wear life extension. The refurbished brakes shall be capable of all requirements herein.

REQUIREMENT RATIONALE (3.4.1.11.3.6)

Some heat sink material is quite expensive, yet structurally sound even though the stack has used its initial service life. It has been shown that the worn stack can be rebuilt either mechanically of by reprocessing to have nearly the initial life capability and meet all the performance requirements of the air vehicle for fraction of the cost of a new brake heat stack.

REQUIREMENT GUIDANCE (3.4.1.11.3.6)

Cost effectiveness of using refurbished brakes or use of a spacer disc in the heat stack to extend brake wear life needs to stated, so the initial design can take this requirement into account. The cost of refurbishment or of a additional spacer has to be balanced against the expect air vehicle life and the number of landing and stopping cycles.

REQUIREMENT LESSONS LEARNED (3.4.1.11.3.6)

There are a number of air vehicles that are using spacers or having their brake heat sinks refurbished at a great savings over buying new heat stacks.

The use of spacers and refurbished heat sinks should be carefully investigated for their effect on the new and worn brake RTO capability. Thermal constraints defined using the original equipment heat sink may not be appropriate for spacers or refurbished configurations.

A.4.4.1.11.3.6 Refurbishment criteria.

The use of refurbishment shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.11.3.6)

The spacer and or refurbished brake stack needs to be tested to the initial design requirements to ensure that there is not compromise to air vehicle performance.

VERIFICATION GUIDANCE (4.4.1.11.3.6)

TBS should reflect all the testing that qualifies the airworthiness of the refurbished equipment to the original equipment testing.

VERIFICATION LESSONS LEARNED (4.4.1.11.3.6)

(TBD)

A.3.4.1.11.3.7 Temperature interface criteria.

Temperature interface between the brake heat sink and surrounding equipment shall be __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.11.3.7)

Typically the material used in the equipment around carbon heat sinks have temperature-operating limits much lower than the capability of the heat sinks. Need to ensure that none of the surrounding equipment is degraded due to high heat and heat soak.

REQUIREMENT GUIDANCE (3.4.1.11.3.7)

TBS should be filled in with the temperature limits of each material temperature limits.

REQUIREMENT LESSONS LEARNED (3.4.1.11.3.7)

The tires, wheels, and brake housing, plus axles and wheel bearings should be able to operate without degradation for all normal brake operation up to RTO operations.

A.4.4.1.11.3.7 Temperature interface criteria.

The temperature interface limits shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.11.3.7)

The brake qualification testing at all energy levels should record equipment temperatures for all the test conditions. The temperature levels are not to exceed the capability of each item to continue to operate as designed, apart from the RTO energy level.

VERIFICATION GUIDANCE (4.4.1.11.3.7)

TBS should be filled in with laboratory testing at al the brake design energy levels.

VERIFICATION LESSONS LEARNED (4.4.1.11.3.7)

(TBD)

A.3.4.1.11.3.8 Service life and replacement criteria.

Service life of the arresting hook shall be __(TBS 1)__ without replacement of components except
__(TBS 2)__.

REQUIREMENT RATIONALE (3.4.1.11.3.8)

This requirement is to establish the minimum service life of the arresting hook system. The requirement should recognize that the hook point or shoe is subject to severe wear and may need to be replaced at some interval less than the life of the system.

REQUIREMENT GUIDANCE (3.4.1.11.3.8)

TBS 1: Service life should be determined by analysis of the air vehicle mission and arrestment concepts. If no study results are available, it is suggested that a service life of 1000 landing engagements without replacement of components.

TBS 2: Ground-contacting elements may be replaced after each 15 landing engagements be used.

Hook point wear characteristics, attachment fatigue characteristics, shank design and load levels, and hook materials, are parameters influencing the ability to meet this requirement.

This is a new requirement. MIL-A-83136 required a replaceable hook point.

REQUIREMENT LESSONS LEARNED (3.4.1.11.3.8)

“Weak link” theory should be considered in design of an arresting hook system. Inadvertent overload is frequently a possibility due to the hostile environment in which the hook is loaded. Frequently, the most severe loads are dynamically applied, and these are the most difficult to calculate. Therefore, attachment structure is extremely critical for capacity and life. Attachment is usually integral with the structure or bulkhead of the fuselage.

Obviously, the hook life will be very low if the hook shank and hook point are integral. If life over 15 landings is desired, the hook point should be separate from the shank to minimize replacement cost.

The F-111/FB-111 hook shank and point were integral. During category II testing, the average life for FB-111 hook was 6 or 7 landings. The F-111A average life was 10-12 landings. These are considered to be economically high. The replacement hook cost was $3,200.00 in 1966.

A.4.4.1.11.3.8 Service life and replacement criteria.

Service life of the hook shall be evaluated by laboratory tests for fatigue life and air vehicle tests for durability.

VERIFICATION RATIONALE (4.4.1.11.3.8)

The environment, load level, and load orientation can best be controlled in a laboratory. Therefore, lab tests with airplane certified loads produces the best combination for accurate verification. The cost of a laboratory test is significantly lower than airplane tests.

VERIFICATION GUIDANCE (4.4.1.11.3.8)

Service life of the hook system should be accomplished by analysis and laboratory testing.

VERIFICATION LESSONS LEARNED (4.4.1.11.3.8)

(TBD)

A.3.4.1.11.3.9 Drag chute service life.

Deceleration drag chutes shall __(TBS)__.

REQUIREMENT RATIONALE (3.4.1.11.3.9)

The life of the drag chute should be depended on the number of expected operations, and how often it should be replaced.

REQUIREMENT GUIDANCE (3.4.1.11.3.9)

TBS should reflect the life requirements for deceleration operations and environmental conditions.

REQUIREMENT LESSONS LEARNED (3.4.1.11.3.9)

(TBD)

A.4.4.1.11.3.9 Drag chute service life.

Drag chute service life shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.1.11.3.9)

Life capability should be demonstrated and proven to last the require number of deployments.

VERIFICATION GUIDANCE (4.4.1.11.3.9)

TBS should specify the analysis, demonstrations and air vehicle testing.

VERIFICATION LESSONS LEARNED (4.4.1.11.3.9)

(TBD)

A.5 PACKAGING

A.5.1 Packaging

For acquisition purposes, the packaging requirements shall be as specified in the contract or order (see 6.2). When packaging of materiel is to be performed by DoD or in-house contractor personnel, these personnel need to contact the responsible packaging activity to ascertain packaging requirements. Packaging requirements are maintained by the Inventory Control Point's packaging activities within the Military Service or Defense Agency, or within the military service's system commands. Packaging data retrieval is available from the managing Military Department's or Defense Agency's automated packaging files, CD-ROM products, or by contacting the responsible packaging activity.

A.6 NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

A.6.1 Intended use.

The landing subsystem descriptions in this appendix are intended for use in air vehicle systems developed to perform combat and combat-support missions in environments unique to military weapon systems.

A.6.2 Acquisition requirements.

Acquisition documents should specify the following:

b. Title, number, and date of the specification.

A.6.3 Acronyms.

The following list contains the acronyms/abbreviations contained within this appendix.

AGE Aerospace Ground Equipment

AMST Advanced Medium Short Take Off and Landing Transport

CAD/CAM Computer Aided Design / Computer Aided Manufacturing

CBR California Bearing Ratio

GVT Ground Vibration Test

HIAD Handbook of Information for Aircraft Designers

LCN Load Classification Number

MLG Main Landing Gear

RRR	Rapid Runway Repair
RTO	Rejected Takeoff
VTOL	Vertical Takeoff and Landing
WOW	Weight On Wheels

A.6.4 Subject term (key word) listing.

Actuation

Arresting hook

Brake

Drag chute

Fire prevention

Flotation gear

Nose wheel

Restraint

Ski jump

Skid

Steering

Tires

Wheel

A.6.5 International standardization agreement implementation.

This specification implements NATO STANDARD AASSEP-1, Aircraft Jacking; STANAG 3098, Aircraft Jacking; and STANAG 3278, Aircraft Towing Attachments and Devices. When amendment, revision, or cancellation of this specification is proposed, the preparing activity must coordinate the action with the U.S. National Point of Contact for the international standardization agreements, as identified in the ASSIST database at https://assist.dla.mil.

A.6.6 Responsible engineering office.

The office responsible for the development and technical maintenance of this appendix is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL. Requests for additional information on this appendix can be obtained from AFLCMC/ENRS, BLDG 28 RM 118, 2145 MONAHAN WAY, WPAFB OH 45433-7017 USA; DSN 674-5476; COMMERCIAL (937) 904-5476; ENGINEERING.STANDARDS@US.AF.MIL.

A.6.7 Amendment notations.

The margins of this specification are marked with vertical lines to indicate modifications generated by this amendment. This was done as a convenience only and the Government assumes no liability whatsoever for any inaccuracies in these notations. Bidders and contractors are cautioned to evaluate the requirements of this document based on the entire content irrespective of the marginal notations.

APPENDIX B

AIR VEHICLE HYDRAULIC POWER SUBSYSTEM

REQUIREMENTS AND GUIDANCE

B.1 SCOPE

B.1.1 Scope.

This appendix provides the requirements, verifications, tailoring guidance, and background information for the Hydraulic Power Subsystem provided for in Part 1 of this specification. The appendix has been developed and coordinated by technical personnel from the Air Force, Navy, and Army and has been approved as an official guide for use by Government personnel for assistance in tailoring the air vehicle subsystems specification for acquisition and model specifications. This appendix is a mandatory part of the specification. The information contained herein is intended for compliance.

B.1.2 Structure.

The appendix structure replicates the structure of the Air Vehicle Subsystems Specification except it places each corresponding section 3 requirement and section 4 verification together.

B.1.3 Appendix.

This appendix provides tailoring guidance and background information for individual paragraphs of the Air Vehicle Subsystems Specification. Guidance gives recommendations on how to tailor the specification paragraph. Where ___(TBS)___ appears, the guidance paragraph provides recommended values or text that the using service may use to insert in the __(TBS)__. When contractors are expected to complete the __(TBS)__, the Guidance paragraph will so state. The Using Service makes the final decision on whom completes the __(TBS)__ in the specification. Finally, Lessons Learned are provided to give insight to past events that could impact the tailoring of the specification.

B.1.4 Deviations.

Projected designs for given applications which will result in improvement of the system performance, reduced life cycle cost, or reduced developmental cost through deviations from this guidance, or where requirements of the specification results in compromise in operational capability, should be brought to the attention of the using service.

B.1.5 Environmental impact.

Air Vehicle Subsystems will be designed such that their operation, maintenance, and repair may be accomplished without violating the most stringent environmental regulations applicable to locations where subsystems are used or supported. Compliance with environmental regulations will not prevent subsystems from achieving and sustaining mission performance capability. Materials, processes, and environmental control equipment necessary to meet these environmental requirements must currently be available in the Using Service's maintenance and supply system. The design will not use environmentally unsuitable materials such as ozone depleting fluorocarbons, chlorofluorocarbons, and halons, or highly volatile organic compounds in solvents and coatings during development, production, operation, maintenance, or repair. The Environmental Protection Agency maintains an online list of toxic chemicals and hazardous substances on its Ozone Layer Depletion Website at http://www.epa.gov/ozone/snap/ that should be consulted. The Significant New Alternatives Policy (SNAP) Program available thereon identifies substitutes for ozone depleting chemicals.

The contractor will conduct an environmental analysis of air vehicle subsystems.

B.1.6 Responsible engineering office.

The responsible engineering office (REO) for this appendix is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL.

B.2 APPLICABLE DOCUMENTS

B.2.1 General.

The documents listed in this section are specified in sections 3 and 4 of this handbook. This section does not include documents cited in other sections of this guide specification or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3 and 4 of this handbook, whether or not they are listed.

B.2.2 Government documents

B.2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this appendix to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

DEPARTMENT OF DEFENSE SPECIFICATIONS

MIL-DTL-5498	Accumulators, Hydraulic, Cylindrical, 3000 PSI, Aircraft
MIL-PRF-6083	Hydraulic Fluid, Petroleum Base, for Preservation and Operation

MIL-F-8815	Filter and Filter Elements, Fluid Pressure, Hydraulic Line, 15 Micron Absolute and 5 Micron Absolute, Type II Systems; General Specification
MIL-PRF-46170	Hydraulic Fluid, Ruse Inhibited, Fire Resistant, Synthetic Hydrocarbon Base, NATO Code No. H-544
MIL-PRF-83282	Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Metric, NATO Code Number H-537
MIL-PRF-87257	Hydraulic Fluid, Fire Resistant; Low Temperature, Synthetic Hydrocarbon Base, Aircraft and Missile

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-5522	Test Procedure for Aircraft Hydraulic and Pneumatic Systems, General

(Copies of these documents are available online at http://quicksearch.dla.mil or from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia PA 19111-5094 USA.)

B.2.3 Non-Government publications.

The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

SAE INTERNATIONAL

SAE AIR 1243	Anti Blow-By Design Practice for Cap-Strip Seals
SAE AS5440	Hydraulic Systems, Aircraft, Types I and II, Design and Installation Requirements for
SAE AS8775	Hydraulic System Components, Aircraft and Missiles, General Specification for
SAE AMS-P-83461	Packing, Preformed, Petroleum Hydraulic Fluid Resistant, Improved Performance at 275˚F (135˚C)

(Copies of these documents are available from www.sae.org; SAE International, 400 Commonwealth Drive, Warrendale PA 15096-0001 USA; and www.ihs.com to qualified users.)

B.2.4 Order of precedence.

Unless otherwise noted herein or in the contract, in the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

B.2.5 Streamlining.

The Air Vehicle Subsystems Specification has been streamlined. The documents listed in this appendix which are required for acquisition have the same status as those referenced directly in section 2 (first tier). All other documents referenced through tiering, may be used for guidance and information only.

B.3 REQUIREMENTS

B.4 VERIFICATIONS

B.3.1 Definition

B.4.1 Definition

B.3.2 Characteristics

B.4.2 Characteristics

B.3.3 Design and construction

B.4.3 Design and construction

B.3.4 Subsystem characteristics

B.4.4 Subsystem characteristics

B.3.4.1 Landing subsystem

B.4.4.1 Landing subsystem

B.3.4.2 Hydraulic power subsystem.

The hydraulic power subsystem shall accept power from an energy source internal or external to the air vehicle and thus generate, condition, and distribute hydraulic fluid power to the control and actuation devices of the air vehicle utilizing systems which are dependent upon hydraulic power for normal, alternate, or emergency operation. The hydraulic power subsystems may include components in the other systems dependent upon hydraulic power, such as landing gear or flight controls. The hydraulic power subsystem(s) shall be sized and configured to supply hydraulic power, as required, to the using systems and utility functions in all modes of ground and flight operation.

REQUIREMENT RATIONALE (3.4.2)

The function of the hydraulic power subsystem is to deliver fluid at sufficient flow rates and pressure to the actuating devices in all modes of flight or ground operation. The speed of actuation is a function of fluid flow-rate whereas the actuating force is a function of pressure. Hydraulic fluid power has been found to be the lightest and most efficient method to transmit high horsepower in air vehicles.

REQUIREMENT GUIDANCE (3.4.2)

Important aspects of hydraulic power subsystem operation are fluid quality (absence of dirt, moisture, and air), control of fluid leakage and extreme temperature performance (especially at temperatures lower than -20°F or temperatures higher than +225°F). Sufficient fluid power should be available for all known conditions. Conditions should include:

a. Ground operations
b. Taxi, takeoff, and landing
c. All flight attitudes within structural limitations
d. Zero gravity or negative gravity
e. All altitudes within the flight envelope
f. Structural deflection
g. Loss of all engine propulsive power
h. Emergency and alternate hydraulic power subsystem operation.

Many of the requirements for hydraulic power subsystem design, installation, and general use may be found in the applicable documents in Section 2 (these documents may also be used as a reference source to prepare specific requirements which are appropriate for particular hydraulic power subsystem(s); other inappropriate requirements may be discarded or modified to achieve a "tailored" document).

The hydraulic power subsystem(s) is often oversized to meet a short duration function. For example, the landing gear and brake system on the C-5A, and the gun drive system on the A-10. The hydraulic power subsystem should be divided into a finite number of separate, independent hydraulic power subsystems to meet redundancy requirements for mission performance or emergency use. The separate system(s) may transmit power from one system to another, but should not transmit fluid from one system to another. Experience has shown that one contaminated fluid system can contaminate another.

Standard practice is to use engine-driven pumps (direct or remote gearbox drive) for primary power. The required pump flow (proportional to engine gearbox speed) is often greatest when air vehicle airspeed is lowest, as in the landing phase. Multiple engine air vehicle hydraulic power subsystems using engine-driven pumps should have pumps driven by at least two engines.

Potential growth in flow requirements for hydraulic services should be considered in establishing the pump sizes. Eight-thousand-psi pressure systems are being considered to save space and weight.

Whenever hydraulic power is required for primary flight controls, it is desired that one system is primarily used to power the flight controls. This hydraulic power subsystem should not be used to supply any other system or component in the air vehicle. This hydraulic power subsystem should be as simple as practicable and should contain a minimum number of components.

REQUIREMENT LESSONS LEARNED (3.4.2)

(TBD)

B.4.4.2 Hydraulic power subsystem.

The verifications (inspections, analyses, demonstrations, and tests) specified shall verify the ability of the hydraulic power subsystems to meet the requirements of section 3 herein. Verification shall encompass planning, procedure preparation, and reporting and shall be accomplished by inspection, analysis, demonstration, or test, or a combination of these methods.

VERIFICATION RATIONALE (4.4.2)

The design and operating characteristics to fulfill the needs of the weapon system should be known before full-scale development.

VERIFICATION GUIDANCE (4.4.2)

The hydraulic power subsystem should be verified incrementally by one or more of the following:

a. Analysis.
    1. A hydraulic power subsystem description and analysis report.
    2. Computer program analysis of steady state and dynamic performance. This is a data item, when required.
b. Laboratory tests.
    1. Qualification tests to verify specific component and system design and performance requirements including durability and environmental requirements.
    2. Full-scale functional hydraulic power subsystem mockup and simulators.
c. Ground and flight tests.
    1. Contractor tests
    2. Procuring activity tests
d. Inspection.
    1. Conformance to drawing(s)
    2. Identification verification
e. Demonstration.

Guidance for qualification tests is contained in component documents listed in primary documents such as SAE AS5440 and SAE AS8775, and legacy documents MIL-H-5440 and MIL-H-8775. Guidance for ground and flight tests is also included in MIL-STD-5522.

VERIFICATION LESSONS LEARNED (4.4.2)

Hydraulic power subsystem design verification is normally the contractor's responsibility. The government on occasion desires to witness or conduct verifications. So for contractual reasons, a statement such as the following is added: "All verifications shall be the responsibility of the contractor but the government reserves the right to witness or conduct any verification."

B.3.4.2.1 Hydraulic power subsystem general requirements

B.4.4.2.1 Hydraulic power subsystem general requirements

B.3.4.2.1.1 Fluid selection.

The hydraulic power subsystem(s) fluid shall be __(TBS)__.

REQUIREMENT RATIONALE (3.4.2.1.1)

Fluid selection is critical to the performance of the hydraulic power subsystem. It affects the operation of every component in the system and should be the same as the fluid used in ground support equipment.

REQUIREMENT GUIDANCE (3.4.2.1.1)

TBS should be filled in with a hydraulic fluid based on the hydraulic power subsystem's requirements for various hydraulic fluid properties, such as, thermal and chemical stability, viscosity, oxidation-corrosion inhibition, lubricity, fire resistance, seal and system material compatibility, cost, and logistics. The procuring activity should specify the fluid, unless there are unique performance requirements, which would require a trade study.

REQUIREMENT LESSONS LEARNED (3.4.2.1.1)

The Navy successfully converted all its air vehicles to MIL-PRF-83282 for increased fire resistance. The initial conversion caused problems with initial increased filter replacement due to the better detergent action of MIL-PRF-83282. After a period of time, filter replacement returned to normal. Similar behavior was observed by the Air Force during its conversion of air vehicles to MIL-PRF-83282. Self-contained units, such as dampers and landing gear shock absorbers, were also converted to MIL-PRF-83282. Due to the high viscosity at low temperatures, hydraulic power subsystem temperature is restricted to -40^{o}F. For lower temperature, the air vehicles should be converted to MIL-PRF-5606. The Army similarly requires change of their air vehicle hydraulic fluid from MIL-PRF-83282 to MIL-PRF-5606 at temperatures below -40^{o}F. In the Air Force, those air vehicles, which had extreme low temperature operational requirements, were not converted to MIL-PRF-83282 but are now in the process of converting to MIL-PRF-87257.

Performance Specification MIL-PRF-5606 (formerly MIL-H-5606) petroleum base fluid has been widely used in military air vehicles for about 35 years. It operates in a temperature range of -65^{o}F to +275^{o}F and is generally satisfactory. It is non-Newtonian which means its viscosity will change with high rates of fluid shear, as when pumping, and, most importantly, it is also flammable. Because of its flammability, alternate fluids have been developed and are in common usage. These fluids are less flammable. As a result of the increased fire resistance of the alternate fluids, MIL-PRF-5606 is no longer used as a design fluid in new air vehicles.

Performance Specification MIL-PRF-83282 is a polyalphaolefin-based synthetic hydrocarbon fluid with an operating temperature range of -40°F to +400°F. It is more fire resistant (200° higher flash and fire points) than MIL-PRF-5606 and has a lower flame propagation rate and greater gunfire ignition resistance. However, it is capable of ignition under certain conditions, such as hot manifold ignition. MIL-PRF-5606 and MIL-PRF-83282 are chemically compatible and physically miscible but do not have the same low temperature fluid characteristics. The viscosity of MIL-PRF-83282 at -40°F is equivalent to that of MIL-PRF-5606 fluid at -65°F. Therefore, fluid system warm-up procedures with MIL-PRF-83282 fluid may be required at cold temperatures. MIL-PRF-83282, unlike MIL-PRF-5606, is shear stable. Thus, MIL-PRF-83282 can be pumped at 8000 PSI without loss of fluid viscosity.

Phosphate ester hydraulic fluids are used in commercial air vehicles as well as military derivatives, such as the C-9 (DC-9), TA3 (737), E-4 (747), KC-10 (DC-10) and the presidential air vehicle. Phosphate ester fluids are also fire resistant, but are not chemically compatible with many military air vehicle materials, such as hydrocarbon base fluids, MIL-PRF-5606 and MIL-PRF-83282 fluids, elastomeric seals, wire insulation, and paint. The physical properties, such as bulk modulus, also are incompatible with military hydraulic power subsystems. However, the commercial airlines and suppliers have developed materials compatible with phosphate ester fluids, which meet the demanding needs of commercial air vehicle operations. Military air vehicles using phosphate ester hydraulic power subsystems have contract maintenance programs. The fluid is more fire resistant than petroleum base fluids but should be restricted to less than 250°F for long term operation because of thermal decomposition. Phosphate ester fluid systems should be checked periodically for viscosity change and acid number: an Air Force air vehicle had to have a change of hydraulic tubing because of fluid decomposition and subsequent system corrosion.

Department of Defense Specification MIL-PRF-46170 is the rust-inhibitor version of MIL-PRF-83282 and was used as a preservative fluid. Defense Specification MIL-PRF-6083 is the rust-inhibitor version of MIL-PRF-5606 and likewise used as a preservative fluid. Neither MIL-PRF-6083 nor MIL-PRF-46170 should be used as a working fluid in air vehicle systems because the sulfonate inhibitor is marginally stable above 250˚F, and has been found to precipitate out of solution and form a film on internal surfaces. This precipitate film can cause close-fitting components to jam and lead to component failure.

The newest hydrocarbon hydraulic fluid is MIL-PRF-87257, which is similar to MIL-PRF-83282. This newer fluid has full performance characteristics from -65˚F to 350˚F. It was developed in direct response to the low temperature limits of MIL-PRF-83282 and is completely interchangeable with both MIL-PRF-5606 and MIL-PRF-83282. This fluid has good viscosity to the limit of -65˚F and no replacement is needed for cold weather operation. The fire resistance of MIL-PRF-87257 is between MIL-PRF-5606 and MIL-PRF-83282 but is more like MIL-PRF-83282 than MIL-PRF-5606. It should be used where fire resistance is important and where extreme cold or high temperature operation is critical.

B.4.4.2.1.1 Fluid selection.

Suitability of the hydraulic fluid selected shall first be verified by analysis and then by hydraulic simulator test, as required. The analysis may include a trade study between different fluids.

VERIFICATION RATIONALE (4.4.2.1.1)

The fluid selected affects every component in the hydraulic system and it should be suitable over the entire air vehicle environment. Analysis and test should show this compatibility.

VERIFICATION GUIDANCE (4.4.2.1.1)

Initial fluid selection should be based on analysis, considering all operational and environmental factors. Final fluid verification should be accomplished with system-level test using flight worthy components. Care should be taken to include all normal as well as abnormal environments. Internal and external corrosion of components by the fluid may cause some fluids to be unsuitable. Fluids with good environmental properties may be toxic to humans and therefore should be unsuitable except in the most extreme conditions. Fluid lubricity is another operational property that is extremely important. It affects the wear and overall life of components. An early test program may be required to establish fluid properties for a unique application. Air vehicle operational environmental may also affect the fluid selection process. Some fluids may be suitable for air vehicle operation but not satisfactory for shipboard use, as in Navy operations, or for desert maintenance operations.

VERIFICATION LESSONS LEARNED (4.4.2.1.1)

Careful testing should precede any fluid change, even if a minor change, for the fluid affects each component in the system. Three development bomber air vehicles used M2V hydraulic fluid, which is similar to the silicate-ester fluid used in the B-58 and B-70 air vehicles. The rotating equipment, hydraulic pumps, and motors in the bomber were designed and qualified to use M2V. However, to reduce costs, the fourth development bomber was designed for use with MIL-H-5606 fluid. Because of the extensive and successful linear actuator testing with MIL-H-5606 fluid, it was decided to conduct a 100-hour test on existing pump and motor designs instead of the 750-hour qualification test.

The pumps showed very high wear rates and had to have some material and geometry (increased clearance) changes to pass a 100-hour test. Hydraulic pumps and motors should be fully requalified when a significant fluid change is to be made. High-speed rotating equipment is especially sensitive to hydraulic fluid characteristics.

Property differences in qualified fluid sources can also affect the fluid performance. A performance-type specification can result in fluid property variations among qualified sources. Hydraulic packing and fluid manufacturers met in the 1950s to establish reference materials to insure control and compatibility of fluids and packings when brought together. For example, elastomer volume change varied about 4 percent (4%) when tested in different qualified fluids. This difficulty was repeated when the Navy changed from MIL-H-5606 to MIL-H-83282 (now MIL-PRF-5606 and MIL-PRF-83282). Different fluid sources for the MIL-H-83282 used different percentages of an ester component. This ester component affected the swell of elastomeric

O-rings. As a result of seal performance variations with the different qualified sources, the ester component was more tightly restricted to ensure the same seal performance.

B.3.4.2.1.2 System fluid capacity.

The total fluid volume, including reserves, shall be optimized to accommodate all operating modes of the air vehicle including emergency and normal operation.

REQUIREMENT RATIONALE (3.4.2.1.2)

The total system volume needs sufficient volume to operate all normal and emergency functions. Total fluid volume should provide for system fluid exchanges, compressibility, thermal effects, and leakage. Hydraulic fluid should be available in the reservoir in sufficient quantity to supply the hydraulic pumps under all operational conditions and air vehicle attitudes.

REQUIREMENT GUIDANCE (3.4.2.1.2)

Hydraulic power subsystem operation requires a variable system volume, and the reservoir accommodates these changes in volume to provide more or less fluid as needed. Fluid thermal expansion and contraction, variations in component volumes during operation, and emergency operations cause system volume changes. Guidance for the reservoir volume is given in MIL-DTL-5498 for closed reservoirs. Reservoir volume includes volume exchange for actuators due to unbalanced areas, accumulator charging and discharging, thermal expansion, emergency reserve, and leakage reserve. If not sized properly, changes in the volume can cause fluid to be spilled overboard or the pump to cavitate due to insufficient fluid.

The reservoir should be located so that the following conditions will be obtained:

a. A static head of fluid should be supplied to the hand pump and the power-driven pump or pumps in all normal flight attitudes of the air vehicle.

b. The length of suction line to the pump is a minimum.

c. Protection from combat damage

d. If practicable, suction lines should be so routed as to prevent breaking of the fluid column caused by gravity after engine shutdown and during the parking period. Where such routing is not possible, or where the reservoir cannot be located above the pump, suitable provisions should be installed to maintain the fluid column to the pump after engine shutdown. A swing type check valve in the suction port of the reservoir should normally maintain the fluid column to the pump.

e. If routing of the pump bypass cannot be accomplished so that breaking of the fluid column by gravity after engine shutdown is prevented, check valves should be incorporated in the lines.

If a vent is provided in the reservoir, it should be arranged so that loss of fluid will not occur through the vent during flight maneuvers or ground operations of the air vehicle. A filter should be incorporated into the vent line if the temperature requirement is suitable. If a filler cap is used, the act of removing the filler cap should automatically vent the reservoir in such manner that the energy contained in the pressurizing air is not dissipated by imparting kinetic energy to either the filler cap or the fluid contained in the reservoir or elsewhere in the system.

REQUIREMENT LESSONS LEARNED (3.4.2.1.2)

Reservoir volume includes volume exchange for actuators due to unbalanced areas, accumulator charging and discharging, thermal expansion, emergency reserve, and leakage reserve. If not sized properly, changes in the volume can cause fluid to be spilled overboard or the pump to cavitate due to insufficient fluid.

B.4.4.2.1.2 System fluid capacity.

System fluid capacity shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.2.1.2)

System fluid capacity factors are based on analytical data, expected operating sequence, as well as experience.

VERIFICATION GUIDANCE (4.4.2.1.2)

TBS: Analysis, inspections, ground and flight tests, and demonstration programs should verify the hydraulic fluid capacity requirements. A hydraulic simulator capable of performing all normal and emergency functions will demonstrate an adequate system fluid capacity. Loss of fluid from the system overboard relief valves should also be checked with the simulator.

Actual operational conditions of the air vehicle should be used for the test verifications. Start up, take off, flight, weapons delivery, return to base, and landing conditions should be included.

VERIFICATION LESSONS LEARNED (4.4.2.1.2)

The UH-1 helicopter incorporated an overboard relief valve in the reservoir to prevent rupture due to overfill. During routine shut down, pressure surges caused fluid to be squirted overboard onto the ground. Routine reservoir servicing was required. The problem was not discovered during tests because all modes of operation were not evaluated. The problem could have been easily corrected during design and manufacture with higher relief valve settings or check valves to prevent pressure surges from reaching the valves.

B.3.4.2.1.3 System fluid monitoring.

A means shall be provided to monitor hydraulic system fluid quantity.

REQUIREMENT RATIONALE (3.4.2.1.3)

Fluid quantity indication provides a means to detect impending system failure due to fluid loss, and is needed to properly fill and service the system.

REQUIREMENT GUIDANCE (3.4.2.1.3)

A means to indicate hydraulic fluid level should be located on or near the hydraulic reservoir.

REQUIREMENT LESSONS LEARNED (3.4.2.1.3)

Reservoir sight gauge - Transparent reservoir level sight gauges can easily be damaged unless they are encased in a protective metal jacket.

B.4.4.2.1.3 System fluid monitoring.

The means for monitoring system fluid quantity shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.2.1.3)

System fluid quantities should be verified for flight operation and servicing.

VERIFICATION GUIDANCE (4.4.2.1.3)

TBS: The hydraulic fluid quantity monitoring system should be verified by inspection and air vehicle ground and flight tests.

VERIFICATION LESSONS LEARNED (4.4.2.1.3)

(TBD)

B.3.4.2.1.4 System pressure.

The system pressure shall be __(TBS)__ psi.

REQUIREMENT RATIONALE (3.4.2.1.4)

The operating pressure of the hydraulic power subsystem(s) establishes test and design requirements for hydraulic power subsystem components. This requirement is needed for proof and burst pressure tests and for designing components such as hydraulic pumps and motors, relief valves, pressure switches, accumulators, crew station, and flight test instrumentation parameters.

REQUIREMENT GUIDANCE (3.4.2.1.4)

TBS: Pressure selection should be based on air vehicle hydraulic power subsystem weight, reliability, design loads, cost, safety and state-of-the-art. Selection of pressure levels with available components that reduce development, procurement, test, and system support costs should be considered. The availability and development cycle for ground support equipment is also factors.

REQUIREMENT LESSONS LEARNED (3.4.2.1.4)

(TBD)

B.4.4.2.1.4 System pressure.

System pressure shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.2.1.4)

Analyses should support the pressure selection. Tests should supplement the selected operating pressure level(s).

VERIFICATION GUIDANCE (4.4.2.1.4)

TBS: System pressure should be verified by analysis of the contractor design report and drawings, laboratory tests of components, and system tests.

VERIFICATION LESSONS LEARNED (4.4.2.1.4)

(TBD)

B.3.4.2.1.4.1 Pump inlet pressure.

Pressure at the hydraulic pump(s) inlet shall be __(TBS)__.

REQUIREMENT RATIONALE (3.4.2.1.4.1)

Sufficient pressure should be available at the hydraulic pump inlet port to prevent pump cavitation and degradation in performance at maximum steady-state or transient flow demands. Extreme cold temperatures and high altitude pump startup should be considered.

REQUIREMENT GUIDANCE (3.4.2.1.4.1)

TBS should be filled in with the pump inlet pressure derived for the system.

The airframe contractor and hydraulic pump manufacturers should define values for pump inlet pressures.

Inlet pressure should be provided during system startup, if necessary, to compensate for lack of bleed air pressurization during engine start or lack of bootstrap pressurization during hydraulic power subsystem starts. Also consider the effect of firewall shutoff valve closure on a windmilling engine-driven hydraulic pump without inlet fluid flow.

REQUIREMENT LESSONS LEARNED (3.4.2.1.4.1)

The use of a portable cart to gas pressurize the reservoir during auxiliary pump startup has been generally unacceptable. Either the ground equipment is not available or it is a maintenance nuisance. The result has been pump cavitation damage. One cargo air vehicle pump suction line is about 100 feet long. When there was sudden flow demand, sufficient fluid flow could not be accelerated to the pump inlet to prevent pump cavitation. A corrective action was to reduce the response time of the pump. Pumps are also unloaded during engine start to reduce drag torque on the engine gearbox.

B.4.4.2.1.4.1 Pump inlet pressure.

Inlet pressure(s) to the pump(s) shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.2.1.4.1)

Pump durability and pump flow characteristics are dependent on pump inlet pressure and flow.

VERIFICATION GUIDANCE (4.4.2.1.4.1)

TBS: The hydraulic pump inlet pressure should be measured and evaluated during the air vehicle ground and flight test program and during the pump qualification tests. Inlet pressure should be provided during system startup, if necessary, to compensate for lack of bleed air pressurization during engine start or lack of bootstrap pressurization during hydraulic system starts. Also consider the effect of firewall shutoff valve closure on a windmilling engine-driven hydraulic pump without inlet fluid flow.

VERIFICATION LESSONS LEARNED (4.4.2.1.4.1)

High-speed pumps - In general, high-speed piston-type hydraulic pumps require higher inlet pressures as compared to lower speed piston-type hydraulic pumps.

B.3.4.2.1.4.2 System start pressurization.

Sufficient system pressurization, if required, shall be maintained for normal pump operation in the event the normal system start up pressurization source (reservoir bootstrap pressure or other pressurization source) is not available.

REQUIREMENT RATIONALE (3.4.2.1.4.2)

Sufficient pressure should be available at the pump inlet port during startup to prime the pump when the normal system start pressurization source is not available.

REQUIREMENT GUIDANCE (3.4.2.1.4.2)

One method to pressurize the pump inlet, during the transition to normal pressurization, is to use an accumulator.

REQUIREMENT LESSONS LEARNED (3.4.2.1.4.2)

(TBD)

B.4.4.2.1.4.2 System start pressurization.

System start pressurization shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.2.1.4.2)

System start pressurization should be verified. Sufficient pressure should be available at the pump inlet port during startup.

VERIFICATION GUIDANCE (4.4.2.1.4.2)

TBS: Analysis, inspection, and system tests are used to verify this requirement.

VERIFICATION LESSONS LEARNED (4.4.2.1.4.2)

(TBD)

B.3.4.2.1.4.3 System pressure indication.

Means shall be provided to sense and transmit hydraulic pressure indications in each hydraulic power subsystem.

REQUIREMENT RATIONALE (3.4.2.1.4.3)

Flight crew personnel should know the operating status of the air vehicle hydraulic power subsystems.

REQUIREMENT GUIDANCE (3.4.2.1.4.3)

The system pressure indicating device should be installed in the air vehicle in a location easily observable to the pilot or other flight personnel.

REQUIREMENT LESSONS LEARNED (3.4.2.1.4.3)

Pressure indicators - Flight station space allotted to hydraulic power subsystem pressure indicators often allows only the use of small size indicators. This makes the indicator hard to read accurately.

B.4.4.2.1.4.3 System pressure indication.

Availability and measurement of system pressure shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.2.1.4.3)

The usefulness of pressure determination(s) should be established.

VERIFICATION GUIDANCE (4.4.2.1.4.3)

TBS: The pressure indicating system should be verified by inspection and test.

The visibility and accuracy of the gage readout should be verified during the air vehicle ground and flight test program.

VERIFICATION LESSONS LEARNED (4.4.2.1.4.3)

(TBD)

B.3.4.2.1.4.4 System low-pressure warning.

Means shall be provided to indicate low system pressure(s) as follows: __(TBS)__.

REQUIREMENT RATIONALE (3.4.2.1.4.4)

In order to maintain flight safety when a hydraulic power subsystem is lost, air vehicle designs incorporate redundant hydraulic power subsystems. Therefore, essential hydraulic powered flight control is still available when one of the redundant systems has failed. The flight crew should be alerted by a low pressure warning device (which denotes a failed hydraulic power subsystem if it comes "on") that the air vehicle may no longer have hydraulic power subsystem redundancy, and that appropriate action should be taken.

REQUIREMENT GUIDANCE (3.4.2.1.4.4)

TBS: The low-pressure warning device should be installed in the air vehicle in addition to the pressure indicating system. It should be installed in a location easily observable to the pilot or other flight personnel.

REQUIREMENT LESSONS LEARNED (3.4.2.1.4.4)

An indicator light that only senses a low needle position on the oil pressure gage can result in erroneous warnings if the gage system fails.

B.4.4.2.1.4.4 System low-pressure warning.

The low-pressure warning shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.2.1.4.4)

The utility of low-pressure indication should be established.

VERIFICATION GUIDANCE (4.4.2.1.4.4)

TBS: The low-pressure warning device should be verified by conducting tests in accordance with appropriate specification(s) and it should be evaluated during the air vehicle ground and flight test program.

VERIFICATION LESSONS LEARNED (4.4.2.1.4.4)

False warnings - Low-pressure warning devices have come "on" due to anomalies in the air vehicle electrical system. Design provisions should be included in the warning device to minimize false warning occurrences due to electrical system anomalies.

B.3.4.2.1.5 Pressure control.

Overpressure protection shall be provided.

REQUIREMENT RATIONALE (3.4.2.1.5)

Limiting system pressures are needed to prevent malfunctioning of hydraulic components or prevent component structural failures.

REQUIREMENT GUIDANCE (3.4.2.1.5)

Variable-displacement hydraulic pumps incorporate a pressure-sensing device, which controls the pump flow rate into the system as a function of the system pressure. Fixed-displacement hydraulic pumps often use a pressure regulator (unloading valve). System pressure relief valves and thermal relief valves are also used in hydraulic power subsystems to prevent excessive pressures, which could cause component structural failures. For pumps not designed to withstand reverse rotation, the system should be designed so that no single failure will permit reverse rotation.

REQUIREMENT LESSONS LEARNED (3.4.2.1.5)

(TBD)

B.4.4.2.1.5 Pressure control.

Control of hydraulic pressures shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.2.1.5)

Pressure control is necessary as a proof of system safety.

VERIFICATION GUIDANCE (4.4.2.1.5)

TBS: The performance of the hydraulic power subsystem pressure control devices should be verified by analyses, inspections, laboratory tests, and ground tests.

VERIFICATION LESSONS LEARNED (4.4.2.1.5)

(TBD)

B.3.4.2.1.5.1 Peak pressure.

Peak pressure resulting from any phase of system operation shall not exceed __(TBS)__.

REQUIREMENT RATIONALE (3.4.2.1.5.1)

Peak pressure limits are needed to prevent damage to hydraulic components.

REQUIREMENT GUIDANCE (3.4.2.1.5.1)

TBS: The maximum peak surge pressure during any phase of system operation should not exceed 135 percent (135%) of the system operating pressure unless the system is designed to accommodate higher peak pressures. Peak pressures less than 135 percent (135%) may be required for some hydraulic power subsystems.

REQUIREMENT LESSONS LEARNED (3.4.2.1.5.1)

The use of constant-displacement pumps with unloading valves generates excessive peak pressures in some air vehicles. Free air trapped in a hydraulic fluid system also contributes to excessive peak pressures.

B.4.4.2.1.5.1 Peak pressure.

Peak pressure characteristics shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.2.1.5.1)

Transient peak pressures are a major factor in causing fatigue failures in hydraulic components.

VERIFICATION GUIDANCE (4.4.2.1.5.1)

TBS: Peak pressures can be predicted by computer analysis. Component, mockup, and air vehicle tests should be used to verify the transient pressure characteristics.

VERIFICATION LESSONS LEARNED (4.4.2.1.5.1)

(TBD)

B.3.4.2.1.5.2 Pressure ripple.

Pressure ripple shall not exceed __(TBS)__.

REQUIREMENT RATIONALE (3.4.2.1.5.2)

Pressure ripple amplitude and frequency generated by high-speed rotating fluid equipment should be identified and attenuated to prevent hydraulic power subsystem instabilities.

REQUIREMENT GUIDANCE (3.4.2.1.5.2)

TBS: Pressure ripple amplitude limits should be expressed as a percentage of nominal system pressure. The military pump specification permits ripple amplitude of ±10 percent (±10%) of system output pressure. The blank should be filled in to limit pressure amplitude to a lesser value and, further, to prevent destructive resonance in the hydraulic distribution system at the range of operating pump speeds.

REQUIREMENT LESSONS LEARNED (3.4.2.1.5.2)

The pressure ripple in the flow output of a piston-type hydraulic pump is transmitted throughout the supply side of the hydraulic power subsystem. The dynamic resistance (impedance) of the hydraulic fluid column creates pressure pulsations throughout the hydraulic supply system.

When the frequency (speed) of the acoustic source (pump) is equal to the natural frequency of the hydraulic fluid column, a resonance condition occurs. Pressure ripple at resonance may be very high; +1000 psi in a 3000 psi system. These resonant conditions are potentially very destructive to the system hardware. In extreme cases, the pressure vessel (lines or components) may reach fatigue failure limits in a few minutes. Hydraulic flow and pressure ripples excite high frequency mechanical motion in lines and components. Excessive motion causes stresses that may result in failure of lines, components, or mounting hardware.

Pump discharge lines are generally the most vulnerable since they are in the area of maximum acoustic energy close to the pump. Dead-end lines to service ports and pressure transmitters are also vulnerable to pulsation induced damage.

Pressure ripples also occur in the pump inlet and return system. Normally, the inlet system is not a problem because of the low pressure at which it operates. However, thin wall tubing, high installation stresses, and an adverse resonance condition could produce inlet system failures.

The coupling of hydraulic to mechanical resonances is a complex phenomenon, and is a function of line size, configuration (routing), and installation constraints. Total stresses in lines are a combination of hoop stress from internal pressure and bending stress due to installation and induced vibration. Large pump discharge and inlet lines (one inch and above) are particularly vulnerable to high installation stress. Total combined line stress should be low enough to provide infinite fatigue life.

An acceptable level of pressure ripple in one system may not be acceptable in another system due to differences in mechanical response. High frequency line motion induced by pressure ripple cannot be controlled by normal line support techniques (clamps). Clamps should be designed to withstand the line vibration without wearing out the cushion and chafing through the line. Table B-I relates central system pulsation level with potential problems.

TABLE B-I. Pump pressure ripple, peak to peak.

MAXIMUM PULSATIONS	POTENTIAL PROBLEMS
>600 PSI	Rapid failure of pump discharge line due to pressure and vibration stresses. Possible failures of mounting structure and internal functions of central components.
300 – 600 psi	Line clamp cushion wearout, line failure due to clamp chaffing, poor clamp life, frequent inspections required, discharge line check valve wearout.
<150 psi	Trouble free, long-life service.

The first category (>600 psi) is a potential safety of flight situation. The second category is one of nuisance level problems that probably surface only after a considerable amount of operational flight experience. The best approach is to verify acceptable line stresses on the iron bird and the first flight air vehicle to preclude failures of the first category. Pump to filter line lengths or other simple plumbing changes may be identified to relocate resonances away from continuous operating speeds. If stress levels are not acceptable, wideband attenuators or hoses for mechanical decoupling should be considered. Beyond the central system (that is, away from the high acoustic energy of the pumps, gearboxes, and engines), the vibration environments are relatively benign. Good line support and adequate clearances between lines and lines and structure precludes significant vibration related problems.

B.4.4.2.1.5.2 Pressure ripple.

The required pressure ripple limits shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.2.1.5.2)

Pump ripple characteristics should be determined by appropriate high response electronic instrumentation.

VERIFICATION GUIDANCE (4.4.2.1.5.2)

TBS should be filled in by “analysis and test.” A computer program can predict the system dynamics once the hydraulic power subsystem configuration has been modeled. The Defense Specifications for pumps include a test procedure to determine ripple characteristics in a specific test circuit. However, this test circuit may not have the same configuration or impedance as the system being developed. Changing the hydraulic power subsystem impedance could appreciably increase the amplitude of the hydraulic pump pressure ripple. Consequently, if any major changes are made to hydraulic power subsystems such as rerouting hydraulic lines or adding components, tests should be rerun to determine the effects on the pump outlet pressure characteristics.

Pump ripple pressures and peak pressure transients (water hammer) are attenuated at the system pressure filter. Therefore, emphasis should be placed on evaluating system dynamics between the pump outlet and system pressure filter. Pressure-attenuating devices such as Helmholtz resonators, accumulators, and system architecture can reduce pressure amplitudes. Some air vehicles use pumps that incorporate Helmholtz resonators to attenuate output pressures.

VERIFICATION LESSONS LEARNED (4.4.2.1.5.2)

There have been several air vehicles that have experienced tube and tube clamp failures because of resonance. Most failures occur in the engine nacelle area and could have been prevented or corrected if system evaluation tests had been conducted.

Pump pressure ripples in a distribution circuit are damped at the pressure line filter. Therefore, transducer pickups should be placed close to the pump pressure outlet.

B.3.4.2.1.5.3 Back pressure.

Proper functioning of any unit shall not be affected by back pressure in the system.

REQUIREMENT RATIONALE (3.4.2.1.5.3)

The hydraulic power subsystem back pressure limits should be controlled to preclude degradation and malfunctions from occurring.

REQUIREMENT GUIDANCE (3.4.2.1.5.3)

Legacy Military Specifications MIL-H-5440 and MIL-H-8891, and SAE AS5440 could be used as guides. Factors to consider include reservoir pressurization and hydraulic line loss as a function of fluid viscosity.

The system or systems should also be so designed that malfunctioning of any unit in the system will not render any other subsystem, emergency system, or alternate system inoperative because of back pressure.

Back pressure resulting from the operation of any unit while the air vehicle is on the ground should create no greater back pressure at the brake valve return port than 90 percent (90%) of that pressure which will cause contact of braking surfaces. In addition, supply pressure to the brake system should not drop below the maximum brake-operating pressure during the operation of any other subsystem in the air vehicle during taxiing, landing, or takeoff.

REQUIREMENT LESSONS LEARNED (3.4.2.1.5.3)

Brake system return fluid should go directly to the reservoir instead of another return line. Clogged filter(s) can cause serious back pressure problems. A clogged brakeline filter contributed to a bomber mishap after landing.

B.4.4.2.1.5.3 Back pressure.

Operating effects from back pressure shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.2.1.5.3)

System back pressure characteristics should be identified during development to avoid redesign after full-scale development.

VERIFICATION GUIDANCE (4.4.2.1.5.3)

TBS: The verification of the hydraulic power subsystem back pressure should be by analysis, laboratory tests, and air vehicle ground and flight tests.

VERIFICATION LESSONS LEARNED (4.4.2.1.5.3)

(TBD)

B.3.4.2.1.6 System level contamination prevention.

There shall be means to remove solid particulate contaminants from hydraulic power subsystem fluid during flight, ground, and filling operations.

REQUIREMENT RATIONALE (3.4.2.1.6)

It is important that particulate contaminants be removed from hydraulic fluid to reduce component wear and prevent contaminant-induced component malfunctions, such as servo valve stiction.

REQUIREMENT GUIDANCE (3.4.2.1.6)

If filters are used, the following should be considered. The filter rating(s) issue for hydraulic power subsystems can be controversial. Most of the controversy is focused on 5- versus 15-micron absolute filtration. A desirable goal is to establish a contamination level that is practical to maintain and still ensure reliable hydraulic power subsystems. The trend has been to go to 5-micron absolute filters in new designs.

REQUIREMENT LESSONS LEARNED (3.4.2.1.6)

Levels of needed filtration have been a controversial subject for years. In the 1950s, the filter element was a 10-micron nominal rating which did not define the maximum particle size removed by the filter.

In the 1960s absolute ratings were specified. The MIL-F-8815 filter has a 15-micron absolute rating that essentially means that the largest spherical particle removed is 15 microns, whereas the largest particle removed was undefined in older filter specifications.

On the basis of early experience with 5-micron absolute filters in improving the pump life on an air vehicle, U.S. Navy personnel recommended the immediate adoption of 5-micron filtration in all systems.

About 1961, the use of 3-micron absolute filters on ground service equipment (GSE) successfully “cleaned” contaminated hydraulic power subsystems on a bomber air vehicle. Thus, the 3- to 5-micron absolute filter became a “standard” for GSE. The contamination in the systems was actually from pumps and reservoirs that were not clean.

Naval Air Development Center laboratory tests for pump wear data indicates decreased pump internal surface damage with the use of finer filters. Five-micron absolute filters were reported to produce 71 percent (71%) less wear than 15-micron absolute filters. The reason is that the finer filter removed more of the smaller abrasive wear particles from the lubricating film thickness separating component operating surfaces.

The use of hydraulic-powered flight controls and servo valves do, generally, require finer filtration.

The changeover from 25-micron absolute filters to 5-micron absolute filters improved the performance of silt-prone servo valves in a cargo air vehicle.

The use of a 5-micron absolute filter in place of a 10-micron absolute filter improved the performance of the Maverick missile hydraulic power subsystem that uses single stage servo valves.

A large degree of success depends on the system designer and the degree of effort that the user is willing and able to put into the maintenance and filtration control program. A clear fluid is not necessarily a clean fluid. The unaided eye cannot see particles smaller than 40 microns. Education and re-education is critical at all working levels to keep clean hydraulic power subsystems clean.

At one time, reusable (cleanable) wire mesh filter elements were used. However, the cleaning procedure, including ultrasonic bath, did not sufficiently restore the full effectiveness of the metal elements. Experience has shown that the disposable (noncleanable) elements are more efficient and are more cost effective than “cleanable” wire mesh elements.

Experience has shown that filter media migration can occur from sintered bronze filters; that is, bronze particles separate from the filter itself.

Separate pump case drain filters are recommended instead of piping case drain flow upstream of system return line filters. Return lines filter pressure drop and return line system pressure surges can adversely affect case drain line pump seal integrity. Also, a pump failure causes debris in the case drain line.

B.4.4.2.1.6 System level contamination prevention.

The means to remove solid particulate contamination shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.2.1.6)

Filter characteristics are usually proven by qualification tests on the filter element and filter assembly.

VERIFICATION GUIDANCE (4.4.2.1.6)

TBS: This requirement should be verified by inspection of drawings, and laboratory test data.

VERIFICATION LESSONS LEARNED (4.4.2.1.6)

There is a difference between laboratory tested dirt capacity and actual system filter life. Dirt capacity of a filter element as measured in the laboratory is designed to produce repeatable, relative data demonstrating a filter's ability to remove artificial test contaminant under specific test conditions. System contamination is not the same as the contaminant used in the laboratory. Actual filter life would have to be established by test in the air vehicle system. An experimental test method used to rate a filter is known as Beta X, where X is a particle size, for example X = 10 microns. The filtration ratio for X micron size is determined by obtaining particulate measurement data while recirculating flow with predetermined weight of contaminant added continuously to the test system (also called multipass testing). The dimensionless ratio for Beta X micron particles is equal to the number of particles upstream of the filter greater than X microns, divided by the number of particles downstream greater than X microns. This test is not called out in military filter specifications.

The ability of a finer filter to remove more fine particles than a coarser filter does not necessarily mean that the finer filter will have a shorter life in the system because of dirt holding limitations. The finer filter should remove more of the abrasive smaller particles which contribute to higher wear rates. This should result in less component surface wear which should reduce the overall amount of system generated contamination. The question becomes "How fine a filter is necessary for a given system."

Pump performance tests at the Franklin Institute resulted in the following:

a. 10-micron size and larger particles were detrimental.

b. Hardness of the particle(s) is a dominant factor in wear.

B.3.4.2.1.6.1 Contamination control maintainability.

Contamination control assemblies shall be readily accessible and shall be replaceable with no fluid loss other than the fluid in the assembly.

REQUIREMENT RATIONALE (3.4.2.1.6.1)

This is a maintenance-driven requirement. Contamination controls assemblies need to be located where they are easily accessible and prevent fluid loss during maintenance actions.

REQUIREMENT GUIDANCE (3.4.2.1.6.1)

The contamination control assemblies should be located so that maintenance personnel can easily see the contamination control assembly indicator, readily replace contamination control assemblies as needed; and have sufficient working envelope space to allow wrenching and space to remove and replace a contamination control assembly element. During contamination control assembly replacement, fluid should be retained in the hydraulic power subsystem and not be permitted to spill. The function of an automatic shut-off is to prevent fluid from draining out of the system upstream and downstream of the system contamination control assembly during element removal.

REQUIREMENT LESSONS LEARNED (3.4.2.1.6.1)

The following addresses filter assemblies that have historically been used for contamination control.

The location of the filter assemblies also involves environment considerations. A filter on a fighter was located in the aft fuselage near the engine area and was exposed to heat soak. There were leakage problems with the static seal at the filter bowl interface. An air-to-air missile, which used special low viscosity fluid experienced static seal leakage problems, caused by extreme low temperatures during qualification tests; the Buna N O-ring was replaced with a fluorosilicone O-ring.

A special filter for use in a manifold was procured by an air vehicle prime. This resulted in a non-competitive situation that was costly and added to the logistics burden.

When changing a dirty filter element, clean fluid should be placed in the filter bowl with a clean filter element to minimize particle and air contamination ingestion into the hydraulic system during this maintenance action.

B.4.4.2.1.6.1 Contamination control maintainability.

Accessibility of installed contamination control assemblies for ease of element replacement shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.2.1.6.1)

There should be sufficient envelope to remove and replace contamination control assembly elements.

VERIFICATION GUIDANCE (4.4.2.1.6.1)

TBS: A review of contamination control assembly drawings can show the envelope dimensions needed to remove and replace the element. A demonstration on the mock-up and air vehicle is the best way to verify ease of contamination control assembly removal and replacement.

VERIFICATION LESSONS LEARNED (4.4.2.1.6.1)

The following addresses filter assemblies that have historically been used for contamination control.

Some filter differential pressure indicators have given false indications of clogged filter elements on some air vehicles.

These false indications occurred so often that some maintenance personnel chose to ignore the button indicator. Consequently, filter element replacement time was based on air vehicle operating hours in lieu of the indicator for some air vehicles.

B.3.4.2.1.6.2 Cleanliness level of delivered systems.

Hydraulic particulate contamination shall not exceed __(TBS)__ when the air vehicle is delivered to the procuring activity. Fluid sampling capability shall be available.

REQUIREMENT RATIONALE (3.4.2.1.6.2)

A desired goal is to establish a contamination level that is practical to maintain and still ensure hydraulic power subsystem reliability.

REQUIREMENT GUIDANCE (3.4.2.1.6.2)

TBS: A generally accepted contamination level for delivered air vehicles is NAS 1638, Class 6 or Class 7, depending on the complexity of the hydraulic power subsystem.

REQUIREMENT LESSONS LEARNED (3.4.2.1.6.2)

(TBD)

B.4.4.2.1.6.2 Cleanliness level of delivered systems.

Hydraulic particulate contamination of delivered air vehicles shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.2.1.6.2)

The initial cleanliness level should be measured.

VERIFICATION GUIDANCE (4.4.2.1.6.2)

TBS: Contamination level is determined by analysis of representative fluid samples taken from the air vehicle hydraulic power subsystems. It is recommended that a sampling valve be located upstream of the return line contamination control assembly. Other sampling points, if desired, should be selected by mutual agreement.

VERIFICATION LESSONS LEARNED (4.4.2.1.6.2)

Samples should be taken from a moving fluid stream. A sample of fluid from a static location is of little value. Contamination level of new and cleaned air vehicles may be acceptable, but can build to an unacceptable level within 100 flying hours. Peak contamination levels appear to coincide with component replacement, pump defects, and servicing activities.

Contamination can arise from internal or external sources.

Ground service equipment fluid, which is not clean, contributes to air vehicle system contamination. Ground service equipment should be monitored for fluid cleanliness levels.

Hydraulic pumps generate considerable contamination, especially during wear-in periods, and during a primary failure. Much of the wear-in debris is less than 5 microns. Hydraulic pumps should be procured that have already completed a run-in test.

Consider contamination control assemblies in proportion to the number of components in the system rather than for only maximum pump flow.

Unless conflicting engineering data is available for particular hydraulic power subsystems, it is recommended the following contamination levels in table B-II be considered as a maximum limit:

TABLE B-II. Contamination levels.

NEW FLUID	SEE THE APPLICABLE FLUID SPECIFICATION.
Ground Service Equipment	Class 6, NAS 1638
Delivered Air Vehicles	Class 6 or 7, NAS 1638
In-Service Air Vehicles	Class 8, NAS 1638

B.3.4.2.1.7 System air removal.

The system shall be designed and configured such that entrained air shall not cause sustained loss of system pressure or degradation of system operational performance during all conditions of intended air vehicle operation. There shall be provisions for bleeding air from the hydraulic fluid at critical points for maintenance purposes.

REQUIREMENT RATIONALE (3.4.2.1.7)

Air in hydraulic power subsystems can cause problems with sluggish response due to lower effective fluid bulk modulus, pump cavitation, or in some cases, the complete loss of hydraulic power due to air lock of the hydraulic pump(s) (free air in the pump inlet line).

There have been cases where fighter air vehicles have lost hydraulic power in one or two hydraulic power subsystems for periods of a few seconds to several minutes or more. Several cases of pump air lock occurred during a flight maneuver and negative "g" mode.

REQUIREMENT GUIDANCE (3.4.2.1.7)

The use of unvented hydraulic power subsystems (that is, the reservoir does not vent to atmosphere) makes it more difficult to remove air from hydraulic fluid. Bleed fittings should be provided in the brake lines. Bleed fittings should be considered at strategic high points in the hydraulic power subsystem.

REQUIREMENT LESSONS LEARNED (3.4.2.1.7)

a. Air vehicle system design. Some examples of designs, which could reduce the air in hydraulic power subsystems, are:

   1. Some system accumulators can be eliminated by providing high-response pumps, backed up by high-response relief valves. This reduces the frequent maintenance associated with accumulator piston seal leakage of gas into the hydraulic fluid.

   2. Using quick-disconnect couplings having low air inclusion on components that require periodic maintenance, and using quick-disconnect fittings at service ports. This results in negligible fluid loss and air entrainment.

b. Ground service equipment. The use of closed hydraulic power subsystems with "bootstrap" type reservoirs has made air bleeding more difficult. Reservoirs of the open or vented design make air bleeding simpler.

   Effective removal of air from air vehicle hydraulic power subsystems is important and can be accomplished with a conventional hydraulic ground cart if it has open loop capability. The cart reservoir should be kept open to the atmosphere to separate air from the air vehicle oil. The actual bleed time depends on the initial air content of the oil, volume of the circuit being cycled, the cart flow rate and the air settling capability of the cart reservoir. Further, if there are multi-hydraulic power subsystems in the air vehicle, the ground cart should have simultaneous multi-hydraulic power subsystem capability with a separate open loop reservoir for each system.

   Never service the air vehicle using a pneumatically pressurized cart reservoir. The oil in the cart reservoir dissolves large amounts of the pressurizing gas that finds its way into the air vehicle system during servicing. Keeping the cart reservoir vented to atmosphere allows the air to come out of solution and separate from the air vehicle oil during open loop bleeding.

c. Reservoir bleed valve. Bleeding of the air vehicle reservoir via the reservoir overboard bleed valve removes a free bubble from the top of an air vehicle reservoir. Momentary reservoir bleeding is a good practice after each long down period and also as a preflight activity. However, it is not practical to remove air in this manner from the entire system. Closed loop air removal via a reservoir bleed cannot wash out the air. Detection of free air in a bootstrap type reservoir system can be roughly indicated by reservoir piston sink (the change in reservoir piston position indicator before and after hydraulic power subsystem pressurization).

d. Laboratory tests. Air separation and collection in the reservoir is most effective when oil-flow rate through the reservoir and the reservoir pressure are both low. However, high oil-flow rates are necessary to flush air from remote system locations. Air was adsorbed by oil at normal return pressure (50 psi) and system flows. Bootstrap pressure, combined with high flows necessary to sweep air through the system, actually helps the hydraulic fluid to adsorb the system air. Shutdown of the system causes the air to come out of solution without collecting at the reservoir. Another phenomenon noted was that the pump seemed to homogenize the air within the oil, aiding in air adsorption at high flow conditions.

e. Laboratory and iron bird system tests. Laboratory and iron bird system tests demonstrated system modifications to clear pump air lock independent of temporary system pressure loss. The main objective was the capability to restore pressure to an air locked system in less than four seconds for ingested air volumes of up to 66 cubic inches of free air. The modification consisted of adding a bypass valve, and a check and one way restrictor relief valve. The bypass valve, which closes when system pressure increases to 600 psi, allows sufficient flow through the reservoir and pump suction line to sweep out the air. It was found necessary to increase the bypass valve orifice flow capacity from the 3-5 gallons per minute (gpm) design goal at a differential pressure of 3000 psi to obtain a satisfactory recovery time. The larger orifice was needed to move the oil in the pump pressure hose at the low differential pressure (about 50 psi) available during the air locked condition, while the pump is acting as an air compressor. The in-line relief valve aids in “trapping” bootstrap reservoir pressure and allows free flow into the reservoir.

   A potential drawback to a bypass valve in this application is the heat that could be generated if the valve were to fail in continuous bypass. However, a thermal switch could be incorporated if operational analysis showed that thermal protection was mandatory.

f. Deaeration devices. A fighter nose gear system incorporates a deaeration device that eliminates nose wheel steering shimmy caused by air in the hydraulic power subsystem. The device can handle the amount of air in this application because nose steering is not a continuous function. An operational test of a deaerator in the main system of a fighter air vehicle showed that saturation occurred because of the system oil flow rates.

g. Air tolerance. Dissolved air measured in a fighter air vehicle was in a range of 14 to 26 percent (26%) by volume. Dissolved air is air in solution in a fluid. Free air is air entrapped in a system but not totally in contact with a fluid. Entrained air is air suspended in a fluid and normally exists in the form of bubbles. MIL-PRF-5606 hydraulic fluid contains about 10 percent (10%) dissolved air by volume at 15 psi. Saturated air volume in solution is proportional to pressure and is inversely proportional to temperature. There is no universal acceptable minimum value for air in a system, but good bleeding and maintenance procedures should reduce the air content. Open loop bleeding can reduce the air vehicle system air content to 14 percent (14%) or less.

h. Deaerated hydraulic fluid. Some missiles are charged with deaerated hydraulic fluid using a vacuum technique.

B.4.4.2.1.7 System air removal.

Entrained air effects and provisions for air removal shall be verified by (TBS) .

VERIFICATION RATIONALE (4.4.2.1.7)

It may be necessary to introduce known quantities of free air into a laboratory system (subsystem) to evaluate performance.

VERIFICATION GUIDANCE (4.4.2.1.7)

TBS: Entrained air phenomena can be evaluated in functional test rigs (iron bird). The provisions for air removal should be verified by inspection, demonstration, and tests.

VERIFICATION LESSONS LEARNED (4.4.2.1.7)

(TBD)

B.3.4.2.1.8 Moisture exclusion.

The hydraulic power subsystem shall be designed to restrict the ingestion and collection of moisture.

REQUIREMENT RATIONALE (3.4.2.1.8)

Moisture in a hydraulic power subsystem can cause malfunctions from corrosion, shorts in electrical devices, and freezing.

REQUIREMENT GUIDANCE (3.4.2.1.8)

Specific water concentration will vary with the fluid system. The limit in new MIL-PRF-5606 fluid is 100 ppm (parts per million) and is 500 ppm in new MIL-PRF-6083 fluid, the preservative version of MIL-PRF-5606 fluid. Consider moisture ingression from moist bleed air reservoir pressurization (if used), from air vehicle washing, and from operating in the rain or snow. Solenoid valves in a low spot can accumulate water and freeze.

REQUIREMENT LESSONS LEARNED (3.4.2.1.8)

Water in conjunction with chlorinated solvents in a hydrocarbon fluid system can cause sticking of slide valves and promote a form of corrosion on low-chromium steels. Experience has shown that chlorine concentration of 200 ppm and 100 ppm of moisture can promote corrosion phenomena. This has occurred on several different air vehicles.

Water running down the landing gear strut wiring entered a “black box” and caused a short. Locate electrical devices related to the hydraulic power subsystem to preclude water ingestion or hermetically seal from moisture.

There is no universal specified maximum limit for moisture content in a hydraulic fluid system. Although it would be desirable to be below 150 ppm, a 300-ppm moisture limit has been considered for one specific hydraulic power subsystem with MIL-PRF-83282 hydraulic fluid.

There have been many cases of adding drilled vent holes in valves after water problems occurred. Also, valves with drilled vent holes should be oriented to drain moisture instead of collecting moisture.

B.4.4.2.1.8 Moisture exclusion.

Means to restrict ingestion and collection of moisture shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.2.1.8)

Operations analysis and systems layout are factors to identify potential moisture problems.

VERIFICATION GUIDANCE (4.4.2.1.8)

TBS: Verification can be by system design analysis, inspection, first article (air vehicle) inspection, and ground and flight test experience.

VERIFICATION LESSONS LEARNED (4.4.2.1.8)

Analyzing air vehicle system fluid samples for water content is not normally done, unless a water-related problem occurs or is suspected. Occasionally, water in GSE hydraulic fluid is transmitted to an air vehicle.

B.3.4.2.1.9 Leakage control.

Acceptable leakage limits shall be defined for components and systems.

REQUIREMENT RATIONALE (3.4.2.1.9)

External leakage should be minimized to reduce maintenance problems and potential fire hazards. Leakage, even within allowable limits, is a general nuisance.

REQUIREMENT GUIDANCE (3.4.2.1.9)

Static seals should not leak at all. Dynamic seals usually have finite amounts of leakage. Allowable leakage values are normally specified for individual components in contractor-prepared specifications or in Defense Specifications. Leakage values should be evaluated for "reasonableness," and overall performance expectations. O-ring seals are most commonly used, although other specialty seals are often used successfully.

REQUIREMENT LESSONS LEARNED (3.4.2.1.9)

A common cause of leakage is inadequate design squeeze. Use of the largest standard cross section O-ring possible is highly recommended. It is difficult to seal with a "string."

The O-ring seal is affected by changes in physical shape combined with loss of mechanical and physical properties. These are time-dependent functions after the seal is installed. In type I hydraulic power subsystems, the seal is expected to last the life of the air vehicle. However, there is a loss of seal life at fluid temperatures greater than 225°F for Buna N seals in either MIL-PRF-5606 or MIL-PRF-83282 fluid. This was learned in a fighter air vehicle and could be predicted by O-ring specification fluid aging tests for type I (7 days at 160°F) versus 70 hours at 275°F for type II O-ring material. It is recommended that heat exchangers be used to keep hydraulic power subsystem fluid below 225°F if practical and below 250°F if possible, to achieve reasonable seal life. This is reflected in SAE AS5440. Aerospace Material Specification SAE AMS-P-83461 Buna N O-rings should be used in MIL-PRF-5606 and MIL-PRF-83282 hydraulic fluid systems.

O-ring spiral failures occur when there is differential twisting of the O-ring, which results in a spiral cutting failure. The failures have been attributed to several factors, but marginal seal lubrication with rapid stroking duplicated the failure in the laboratory. Side loading a shock strut and completely drying the strut before stroking induced the laboratory failures. Spiral failures have been corrected by using a seal shape that resists rolling in the seal groove.

An in-service leakage problem results when a low squeeze design is used to reduce seal friction, even though the design passed qualification tests. If such a design is contemplated, the absolute worst design conditions should be tested. Experience has shown that a low squeeze design results in unacceptable leakage in service.

Using the O-ring elastomer as a spring to maintain contact between the tetrafluoroethylene (TFE, Teflon®) and the metal rod has used cap strips of TFE to reduce friction or cylinder bore. In certain piston applications a blow-by phenomena has occurred where a pressure reversal separates the TFE cap and cylinder bore interface, allowing a massive pressure drop across the piston. Corrective action was to make notches on the sides of the TFE cap. Blow-by caused the crash of an experimental air vehicle. The failure mode was duplicated in the laboratory. A failure to extend a fighter landing gear was attributed to blow-by of a rod type cap seal, although this could not be duplicated in the laboratory. Additional information on blow-by is found in SAE AIR 1243.

The use of dual rod seals can reduce external leakage. The dual rod seals are usually vented to return. Unvented rod seals have been used in the United Kingdom with great success and also in several United States air vehicles. The dual unvented seals are usually “specialty” seals that permit some seepage, and furthermore, are not operating in high temperature environments where thermal expansion of trapped fluid can generate extreme high local pressure. Dual unvented seals should not be used when a pressure trap force or friction force between seals is greater than the actuating force, such as spring-loaded devices or free fall actuators.

The fitting boss seal installation has been a problem because separate manufacturers usually make the mating flat metal surfaces. In addition, the axis of the threads should be perpendicular to the fitting hex surface. The absence of a fitting “hex” flat to the mating surface can permit extrusion of the boss fitting O-ring, especially in larger port sizes. Several air vehicles are using the Rosán® boss fitting to prevent the potential service difficulties with the older boss type fitting installation.

B.4.4.2.1.9 Leakage control.

Acceptable leakage rates shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.2.1.9)

Allowable leakage should consider the effects of in-service use as well as leakage from "new" seals.

VERIFICATION GUIDANCE (4.4.2.1.9)

TBS: Use individual component qualification and acceptance requirements, laboratory evaluation(s), air vehicle extreme-temperature tests, and air vehicle flight and service experience

Duplicate the operating conditions as much as practical and consider adverse seal design tolerances.

VERIFICATION LESSONS LEARNED (4.4.2.1.9)

(TBD)

B.3.4.2.1.10 Emergency operation.

Normal and emergency systems and their controls shall be designed so that the desired function is attained when either is initiated first or when both systems are operated at the same time.

REQUIREMENT RATIONALE (3.4.2.1.10)

The desired function should be accomplished after selection of either a normal mode or an emergency mode of operation.

REQUIREMENT GUIDANCE (3.4.2.1.10)

Operational capability should be considered to avoid any adverse interaction between normal and emergency modes of operation.

Two or more subsystems pressurized by a common pressure source, one of which is essential to flight operation and the other not essential, should be so isolated that the system essential to flight operation will not be affected by any damage to the nonessential system.

Hydraulic pumps required to provide emergency power for direct application to flight controls or other essential hydraulic flight requirements should not be used for any other function.

REQUIREMENT LESSONS LEARNED (3.4.2.1.10)

(TBD)

B.4.4.2.1.10 Emergency operation.

Intended functional performance with normal and emergency operation shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.2.1.10)

The function should not be lost because of an adverse interaction between normal and emergency modes of operation.

VERIFICATION GUIDANCE (4.4.2.1.10)

TBS: Verification should be done by design review(s), subsystem tests, ground demonstration, and flight tests.

VERIFICATION LESSONS LEARNED (4.4.2.1.10)

(TBD)

B.3.4.2.1.11 Proof pressure.

No component shall fail, take any permanent set, or be damaged in any manner, when subjected to applicable proof pressure of __(TBS 1)__. Systems and components shall satisfy this requirement when subjected to a proof pressure of __(TBS 2)__.

REQUIREMENT RATIONALE (3.4.2.1.11)

The intent of this requirement is to assure that all systems and components are adequately designed and tested for functional and structural integrity.

REQUIREMENT GUIDANCE (3.4.2.1.11)

TBS 1: The system and its components should be designed to withstand the proof pressure requirements without permanent deformation and should be fully functional following the test.

TBS 2: When proof tests are conducted at temperatures other than design temperatures, account for the degradation of material properties at design temperatures in determining the proof pressure. The proof load should be of sufficient magnitude to ensure that the service life requirements are met.

REQUIREMENT LESSONS LEARNED (3.4.2.1.11)

(TBD)

B.4.4.2.1.11 Proof pressure.

Proof pressure compliance shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.2.1.11)

A material factor of safety should be established.

VERIFICATION GUIDANCE (4.4.2.1.11)

TBS: This requirement can only be demonstrated by actual tests on the system and components.

a. System. Proof pressure is applied to the system to prove the integrity of connections at each component.

b. Component. Proof pressure is applied to the component to prove the integrity of the component.

VERIFICATION LESSONS LEARNED (4.4.2.1.11)

(TBD)

B.3.4.2.1.12 Burst pressure.

No component shall rupture when subjected to an applicable burst pressure of __(TBS)__.

REQUIREMENT RATIONALE (3.4.2.1.12)

The intent of this paragraph is to ensure all components are adequately designed and tested for structural integrity.

REQUIREMENT GUIDANCE (3.4.2.1.12)

TBS: The components should be designed to withstand burst pressure requirements without rupture. Deformation resulting from the test is acceptable and the component need not be functional after the test. When burst tests are conducted at temperatures other than design temperatures, account for the degradation of material properties at design temperature in determining the burst pressure.

REQUIREMENT LESSONS LEARNED (3.4.2.1.12)

(TBD)

B.4.4.2.1.12 Burst pressure.

Burst pressure compliance shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.2.1.12)

The intent is to ensure that all components are adequately designed and tested for structural integrity.

VERIFICATION GUIDANCE (4.4.2.1.12)

TBS: Burst pressure compliance should be verified by tests. Burst pressure is applied to the component to prove the integrity of the component. SAE AS8775 and the legacy document MIL-H-8775 may be used as guides for the test procedure and pressure level.

VERIFICATION LESSONS LEARNED (4.4.2.1.12)

(TBD)

B.3.4.2.1.13 Low-temperature operation.

The hydraulic power subsystem shall operate at low temperature conditions as follows: __(TBS).

REQUIREMENT RATIONALE (3.4.2.1.13)

The low temperature operating conditions should be defined.

REQUIREMENT GUIDANCE (3.4.2.1.13)

TBS: The low temperature operating temperature is normally defined in the weapon system procurement document.

REQUIREMENT LESSONS LEARNED (3.4.2.1.13)

At one time, O-ring seals were aged for 72 hours at -65°F to test for O-ring material crystallization phenomena. Current low temperature tests are performed after stabilizing the component at the desired low temperature plus a 4- to 8-hour low temperature soak, depending on the mass and size of the component.

The O-ring seal properties that enhance low temperature sealing can be in opposition to good seal performance at higher temperatures. For example, high tolerance O-ring cross section, low tolerance O-ring glands, higher volume change material, and use of "high volume swell" fluid can improve low temperature sealing.

A valuable laboratory test known as temperature retraction (TR) was developed in the 1950s. TR 50-10 denotes the temperature to return an elastomer specimen 10 percent (10%) after the specimen had been stretched 50 percent (50%) and "frozen" in a cold bath. It was determined that an O-ring should pass a -65°F performance test if an oil aged test specimen had a TR 50-10 of -49°F or colder.

Laboratory component tests at -65°F should be conducted with a tolerance of -5°F, +0°F.

B.4.4.2.1.13 Low-temperature operation.

Low-temperature performance shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.2.1.13)

The suitability of low-temperature performance should be verified and information, as required, included in the pilot's handbook and maintenance cold weather operating procedures.

VERIFICATION GUIDANCE (4.4.2.1.13)

TBS should be filled in with analyses and tests. Low temperature tests are performed at the component level and are performed at a system level in the Climatic Hangar at Eglin AFB FL. Low temperature ground and flight tests are performed during operation and test evaluations.

VERIFICATION LESSONS LEARNED (4.4.2.1.13)

A component should be capable of functioning when assembled with adverse tolerance parts without binding at low temperatures. The effect of different materials should be considered in the design stage. The manufacturer can verify this by analysis. In critical applications, a test might be preferred.

B.3.4.2.1.14 High-temperature operation.

The maximum hydraulic bulk fluid temperature shall be __(TBS)__.

REQUIREMENT RATIONALE (3.4.2.1.14)

The high temperature operating conditions should be defined to ascertain possible fluid cooling needs and general operation.

REQUIREMENT GUIDANCE (3.4.2.1.14)

TBS: The high temperature-operating limit is usually a function of seal life rather than a function of fluid life. Consideration should also be given to heat soak-back after engine shutdown.

REQUIREMENT LESSONS LEARNED (3.4.2.1.14)

A fighter has a thermal switch that diverts hydraulic fluid to the heat exchanger when the fluid temperature exceeds 225°F.

A helicopter had heat degradation of fluid and seals after cumulative ground test operation using the onboard auxiliary power unit (APU). Corrective action was to include an air-fluid heat exchanger.

B.4.4.2.1.14 High-temperature operation.

High temperature operation shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.2.1.14)

The suitability of high temperature performance should be verified.

VERIFICATION GUIDANCE (4.4.2.1.14)

TBS should be filled in with analyses and tests. High temperature tests are performed at the component level. System high temperature performance tests are performed during operation and test evaluations.

VERIFICATION LESSONS LEARNED (4.4.2.1.14)

High temperature component aging should be carefully controlled in an oven (or fluid bath) having uniform temperature throughout. The system maximum fluid temperature is usually in the pump case drain.

B.3.4.2.1.14.1 Thermal relief.

Pressure relief for hydraulic fluid thermal expansion shall be provided for all components in hot locations and closed plumbing segments.

REQUIREMENT RATIONALE (3.2.1.14.1)

Temperature and pressure conditions, if not controlled, could cause over pressurization component failures.

REQUIREMENT GUIDANCE (3.2.1.14.1)

Particular emphasis should be placed on the following:

a. Pressure and temperature control

b. Avoiding component location in proximity to hot compartments heats sources and hot surface.

REQUIREMENT LESSONS LEARNED (3.2.1.14.1)

(TBD)

B.4.4.2.1.14.1 Thermal relief.

Pressure relief for hydraulic fluid thermal expansion shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.2.1.14.1)

The pressure relief function should be verified.

VERIFICATION GUIDANCE (4.4.2.1.14.1)

Analysis and inspection of drawings should show protection features. Tests may be required in some instances.

VERIFICATION LESSONS LEARNED (4.4.2.1.14.1)

(TBD)

B.3.4.2.1.15 Fire and explosion hazard proofing.

Integration of the hydraulic power subsystem in the vehicle shall be in accordance with _(TBS)_.

REQUIREMENT RATIONALE (3.4.2.1.15)

Temperature and pressure conditions, if not controlled, could present a potential fire hazard.

REQUIREMENT GUIDANCE (3.4.2.1.15)

TBS: Particular emphasis should be placed on the following:

a. Pressure and temperature control

b. Keeping combustibles to a minimum

c. Avoiding proximity to ignition sources, hot surfaces, and electrical wiring.

REQUIREMENT LESSONS LEARNED (3.4.2.1.15)

(TBD)

B.4.4.2.1.15 Fire and explosion hazard proofing.

Fire and explosion resistance shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.2.1.15)

Fire and explosion resistance should be verified because it is a critical safety-of-flight issue.

VERIFICATION GUIDANCE (4.4.2.1.15)

Analysis and inspection of drawings should show protection features. Tests may be required in some instances.

TBS: MIL-F-87168 should be used for guidance.

VERIFICATION LESSONS LEARNED (4.4.2.1.15)

(TBD)

B.3.4.2.1.16 Survivability-Vulnerability (S-V).

The hydraulic power subsystems shall be configured to accept ___(TBS)___ by the threat(s) specified in the system or air vehicle specification without loss of flight and mission-essential functions.

REQUIREMENT RATIONALE (3.4.2.1.16)

Air vehicle performance limitations after hydraulic power subsystem(s) damage should be defined.

REQUIREMENT GUIDANCE (3.4.2.1.16)

TBS: Capability should be defined for loss of systems as well as impact by specific threat(s). Refer to the mission completion in a combat environment specification for guidance.

A single failure in the hydraulic power subsystem component or any other subsystem supplying power to the hydraulic power subsystem should not prevent the completion of the air vehicle's primary mission.

The hydraulic system(s) should be configured such that any two fluid system failures due to combat or other damage, which cause loss of fluid or pressure, will not result in complete loss of flight control. For rotary-wing air vehicles, the surviving system(s) should provide sufficient control for return to the intended landing area. Where duplicate hydraulic power subsystems are provided, these systems should be separated as far as possible to obtain the maximum advantage of the dual system with regard to vulnerability from gunfire or engine fires. Where practicable, dual systems should be on opposite sides of the fuselage, the wing spar, or similarly separated.

REQUIREMENT LESSONS LEARNED (3.4.2.1.16)

(TBD)

B.4.4.2.1.16 Survivability-Vulnerability (S-V).

S-V of the hydraulic power subsystems shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.2.1.16)

Performance limitations after hydraulic power subsystem(s) damage should be defined.

VERIFICATION GUIDANCE (4.4.2.1.16)

TBS: Survivability-vulnerability characteristics should be verified by analysis.

VERIFICATION LESSONS LEARNED (4.4.2.1.16)

(TBD)

B.3.4.2.1.16.1 Resistance to gunfire.

Hydraulic power subsystem pressure vessels shall not fragment from a single impact by (TBS)__.

REQUIREMENT RATIONALE (3.4.2.1.16.1)

Gunfire damage to a pressure vessel should not result in fragmentation that can injure personnel or cause serious damage to the airframe.

REQUIREMENT GUIDANCE (3.4.2.1.16.1)

TBS: High-pressure vessels have been required to take a single Armor Piercing Incendiary (API) .50-caliber projectile without fragmenting.

Low-pressure vessels may require resistance to a single .30-caliber API projectile.

REQUIREMENT LESSONS LEARNED (3.4.2.1.16.1)

Experience has shown that American Iron and Steel Institute (AISI) Code 4130 steel and comparable steels should not be heat treated above 160,000 psi to preclude fragmentation.

B.4.4.2.1.16.1 Resistance to gunfire.

Pressure vessel resistance to fragmentation shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.2.1.16.1)

Gunfire damage to a pressure vessel should not result in fragmentation that can injure personnel or cause damage to the air vehicle.

VERIFICATION GUIDANCE (3.4.2.1.16.1)

TBS: Resistance to fragmentation should be evaluated by test. Past practice (reference MIL-DTL-5498) has been: For accumulators three inches or less in diameter, the ammunition should be .30-caliber M-2 armor piercing. For all other sizes, the ammunition should be .50-caliber M-2 armor piercing. Muzzle velocity should be 2800 feet per second (fps). The accumulator should be positioned with its longitudinal axis 45° from normal away from the gun position. The projectile should be tumbled so that the .30-caliber shell produces an "in" hole at least $^{1}/_{4}$ inch wide by $^{5}/_{8}$ inch long and the .50-caliber shell should produce an "in" hole at least $^{1}/_{2}$ inch wide by $1^{1}/_{2}$ inches long. The projectile velocity after tumbling should be monitored during the last 10 feet prior to impact. Minimum velocity should be 2300 fps. The accumulator should remain in one piece, and the material of the cylinder should not tear excessively in any one direction.

VERIFICATION LESSONS LEARNED (3.4.2.1.16.1)

(TBD)

B.3.4.2.1.17 Clearance.

Clearance shall be maintained between moving system components and structure or other components to ensure that no possible combinations of temperature effects, airloads, wear, or structural deflections can cause binding, rubbing, or jamming. There shall also be adequate clearance for component installation, removal, and maintenance.

REQUIREMENT RATIONALE (3.4.2.1.17)

The intent of this requirement is to prevent binding, chafing, or jamming of components in static or operating modes. In addition, there are minimum clearances necessary to accommodate removal and installation of components.

REQUIREMENT GUIDANCE (3.4.2.1.17)

Component installation should have separation clearances that are maintained under all air vehicle-operating modes. There should be clearance for hand tools required removing and installing components. There should be sufficient space to remove and install components. This may require additional access panels and doors.

REQUIREMENT LESSONS LEARNED (3.4.2.1.17)

(TBD)

B.4.4.2.1.17 Clearance.

Compliance with clearance requirements shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.2.1.17)

The best way to determine clearance is by close examination of installation mock-up(s) and by examination of the air vehicle before and after flight tests. Tests may be required to demonstrate maintenance of adequate clearances during dynamic operation; such as landing gear, etc., and structural deflections caused by air loads, landing loads, etc.

VERIFICATION GUIDANCE (4.4.2.1.17)

TBS: Separation clearance under all static or operating modes should be verified by analysis, inspection, and test.

VERIFICATION LESSONS LEARNED (4.4.2.1.17)

(TBD)

B.3.4.2.2 Interface requirements.

Hydraulic power subsystem and component interfaces shall be identified and controlled to ensure form, fit, and functional compatibility.

REQUIREMENT RATIONALE (3.4.2.2)

Interface baseline design data should be established in the air vehicle development phase to minimize the need for extensive design changes that emerge during air vehicle assembly and test.

REQUIREMENT GUIDANCE (3.4.2.2)

Hydraulic power subsystem interfaces should be identified in hydraulic power subsystem design reports and appropriate contractual documents.

REQUIREMENT LESSONS LEARNED (3.4.2.2)

(TBD)

B.4.4.2.2 Interface requirements.

Hydraulic power subsystem interface(s) with other air vehicle systems shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.2.2)

Interface control data is necessary to ensure physical and functional compatibility.

VERIFICATION GUIDANCE (4.4.2.2)

Verification may be accomplished by analysis, demonstration, inspection and tests.

VERIFICATION LESSONS LEARNED (4.4.2.2)

(TBD)

B.3.4.2.2.1 Electrical power system interface.

All electrical components shall operate with electrical power defined by __(TBS)__.

REQUIREMENT RATIONALE (3.4.2.2.1)

The quality and quantity of available power should be matched to the required needs of the system and component operation(s).

REQUIREMENT GUIDANCE (3.4.2.2.1)

TBS: The electrical power available should be defined at the system and component level. The number of different electrical connectors should be identified and limited to reduce life-cycle costs.

REQUIREMENT LESSONS LEARNED (3.4.2.2.1)

There have been cases where D.C. solenoids would not overcome component forces at minimum voltage.

B.4.4.2.2.1 Electrical power system interface.

Electrical power system interfaces shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.2.2.1)

Physical and functional compatibility with electrical system(s) is paramount for hydraulic power subsystem(s) performance.

VERIFICATION GUIDANCE (4.4.2.2.1)

TBS: Operation of hydraulic power subsystem components at specified power should be verified by system and component tests. Required performance should be demonstrated for all variations permitted by the specification.

VERIFICATION LESSONS LEARNED (4.4.2.2.1)

(TBD)

B.3.4.2.2.2 Support equipment (SE) interface.

Means shall be provided to mate with the following ground test and service equipment: __(TBS)
.

REQUIREMENT RATIONALE (3.4.2.2.2)

All SE which is in operation and is expected to be compatible with new air vehicle systems should be identified to ensure interface compatibility.

REQUIREMENT GUIDANCE (3.4.2.2.2)

TBS: Identify SE such as hydraulic power carts and fluid filling equipment. Ground service connections for hydraulic power subsystem checkout should be accessible at ground level for maintenance personnel and be so specified. Further identify peculiar fittings to mate with the SE.

System ground test provisions should be so designed that pressurization of any hydraulic power subsystem in the air vehicle is not necessary in order to test another hydraulic power subsystem.

REQUIREMENT LESSONS LEARNED (3.4.2.2.2)

(TBD)

B.4.4.2.2.2 Support equipment (SE) interface.

The interface of the hydraulic power subsystem with specified SE shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.2.2.2)

Physical and functional interface of support equipment is essential for timely checkout and maintenance.

VERIFICATION GUIDANCE (4.4.2.2.2)

Compatibility of SE should be verified by ground demonstration, analysis, and inspection.

VERIFICATION LESSONS LEARNED (4.4.2.2.2)

(TBD)

B.3.4.2.2.3 Instrumentation interface(s).

Instrumentation interface(s) shall be identified.

REQUIREMENT RATIONALE (3.4.2.2.3)

The type and quantity of instrumentation needed for a subsystem is dependent upon the desires of the operator and the complexity and flexibility of the subsystem.

REQUIREMENT GUIDANCE (3.4.2.2.3)

As a minimum, the following instrumentation should be provided:

a. Hydraulic power system pressure (each system)
b. Low pressure indicator (each system).

A simple system requires limited instrumentation.

REQUIREMENT LESSONS LEARNED (3.4.2.2.3)

(TBD)

B.4.4.2.2.3 Instrumentation interface(s).

The presence of required instrumentation shall be verified by _(TBS 1)_. The accuracy and range of the instrumentation shall be verified by _(TBS 2)_.

VERIFICATION RATIONALE (4.4.2.2.3)

The physical and functional interface of instrumentation system(s) is essential to measure the health of the hydraulic power subsystem(s).

VERIFICATION GUIDANCE (4.4.2.2.3)

TBS 1: The presence of the required instrumentation should be verified by inspection and tests.

TBS 2: The accuracy and range of the instrumentation should be verified by component testing and system calibration.

VERIFICATION LESSONS LEARNED (4.4.2.2.3)

(TBD)

B.5 PACKAGING

B.5.1 Packaging.

For acquisition purposes, the packaging requirements shall be as specified in the contract or order (see 6.2). When packaging of materiel is to be performed by DoD or in-house contractor personnel, these personnel need to contact the responsible packaging activity to ascertain packaging requirements. Packaging requirements are maintained by the Inventory Control Point's packaging activities within the Military Service or Defense Agency, or within the military service's system commands. Packaging data retrieval is available from the managing Military Department's or Defense Agency's automated packaging files, CD-ROM products, or by contacting the responsible packaging activity.

B.6 NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

B.6.1 Intended use.

The hydraulic subsystem descriptions in this appendix are intended for use in air vehicle systems developed to perform combat and combat-support missions in environments unique to military weapon systems.

B.6.2 Acquisition requirements.

Acquisition documents should specify the following:

a. Title, number, and date of the specification.

B.6.3 Definitions.

Inspection: Inspection is defined as visual verification that the system, including system documentation, conforms to the specification requirements. Visual verification can be in the form of inspection of the physical installation, or inspection of drawings showing physical relationships, or review of documents reflecting qualification status with respect to specification requirements.

Analysis: Analysis is defined as verification that specification requirements have been achieved by evaluation of equations, charts, and reduced data, and by comparisons of analytical predictions with available test data, etc. Verification analysis, however, does not include the normal analysis of data generated during ground or flight-testing.

Demonstration: Demonstration is defined as an uninstrumented test where success is determined by observation only, such as fit and function checks and tests that require simple quantitative measurements.

Test: Test is defined as verification of the specification requirements through the application of established test procedures within specified environmental conditions and subsequent compliance confirmation through analysis of the data generated.

Verification by similarity: When verification by similarity is proposed, it should be accomplished by using verification data from previously developed and qualified items. The verification data from the earlier verification should be submitted with design data to substantiate that:

a. The equipment is to perform a similar function in the new application as it did in its earlier verification.

b. The environment and operating limits should be no more demanding or degrading than in the earlier operation.

c. The new item does not incorporate differences that would invalidate the criteria of "Inspection" or "Analysis," above.

d. The equipment meets requirements of its earlier application(s) as indicated by its Mean Time Between Failures (MTBF) and other field failure data.

Considerable effort is expended when similarity claims are made late in a program and rejected by the procuring activity or additional testing is required. Similarity claims should be established early in a program.

B.6.4 Acronyms.

The following list contains the acronyms/abbreviations contained within this document.

API	Armor Piercing Incendiary
GSE	Ground Service Equipment
SE	Support Equipment
S-V	Survivability-Vulnerability
TFE	Tetrafluoroethylene
TR	Temperature Retraction

B.6.5 Subject term (key word) listing.

Burst pressure

Contamination

Fluid

Leakage

Moisture

Peak pressure

Pressure

Proof pressure

Pump

B.6.6 Responsible engineering office.

The office responsible for the development and technical maintenance of this appendix is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL. Requests for additional information on this appendix can be obtained from AFLCMC/ENRS, 2145 MONAHAN WAY, BLDG 28 RM 118, WRIGHT-PATTERSON AFB OH 45433-7017 USA; DSN 674-5476; COMMERCIAL (937) 904-5476; ENGINEERING.STANDARDS@US.AF.MIL.

B.6.7 Amendment notations.

The margins of this specification are marked with vertical lines to indicate modifications generated by this amendment. This was done as a convenience only and the Government assumes no liability whatsoever for any inaccuracies in these notations. Bidders and contractors are cautioned to evaluate the requirements of this document based on the entire content irrespective of the marginal notations.

APPENDIX C

AIR VEHICLE AUXILIARY POWER SUBSYSTEM

REQUIREMENTS AND GUIDANCE

C.1 SCOPE

C.1.1 Scope.

This appendix provides the requirements, verifications, tailoring guidance, and background information for the Auxiliary Power Subsystem provided for in Part 1 of this specification. The appendix has been developed and coordinated by technical personnel from the Air Force, Navy, and Army and has been approved as an official guide for use by Government personnel for assistance in tailoring the air vehicle subsystems specification for acquisition and model specifications. This appendix is a mandatory part of the specification. The information contained herein is intended for compliance.

C.1.2 Structure.

The appendix structure replicates the structure of the Air Vehicle Subsystems Specification except it places each corresponding section 3 requirement and section 4 verification together.

C.1.3 Appendix.

This appendix provides tailoring guidance and background information for individual paragraphs of the Air Vehicle Subsystems Specification. Guidance gives recommendations on how to tailor the specification paragraph. Where __(TBS)__ appears, the guidance paragraph provides recommended values or text that the using service may use to insert in the __(TBS)__. When contractors are expected to complete the __(TBS)__, the Guidance paragraph will so state. The Using Service makes the final decision on whom completes the __(TBS)__ in the specification. Finally, Lessons Learned are provided to give insight to past events that could impact the tailoring of the specification.

C.1.4 Deviations.

Projected designs for given applications which will result in improvement of the system performance, reduced life cycle cost, or reduced developmental cost through deviations from this guidance, or where requirements of the specification results in compromise in operational capability, should be brought to the attention of the using service.

C.1.5 Environmental impact.

Air Vehicle Subsystems will be designed such that their operation, maintenance, and repair may be accomplished without violating the most stringent environmental regulations applicable to locations where subsystems are used or supported. Compliance with environmental regulations will not prevent subsystems from achieving and sustaining mission performance capability. Materials, processes, and environmental control equipment necessary to meet these environmental requirements must currently be available in the Using Service's maintenance and supply system. The design will not use environmentally unsuitable materials such as ozone depleting fluorocarbons, chlorofluorocarbons, and halons, or highly volatile organic compounds in solvents and coatings during development, production, operation, maintenance, or repair. The Environmental Protection Agency maintains an online list of toxic chemicals and hazardous substances on its Ozone Layer Depletion Website at http://www.epa.gov/ozone/snap/ that should be consulted. The Significant New Alternatives Policy (SNAP) Program available thereon identifies substitutes for ozone depleting chemicals.

The contractor will conduct an environmental analysis of air vehicle subsystems.

C.1.6 Responsible engineering office.

The responsible engineering office (REO) for this appendix is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL.

C.2 APPLICABLE DOCUMENTS

C. 2.1 General.

The documents listed in this section are specified in sections 3 and 4 of this handbook. This section does not include documents cited in other sections of this guide specification or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3 and 4 of this handbook, whether or not they are listed.

C.2.2 Government documents

C.2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this appendix to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

INTERNATIONAL STANDARDIZATION AGREEMENTS

NORTH ATLANTIC TREATY ORGANIZATION

STANAG 3372	Low Pressure Air and Associated Electrical Connections for Aircraft Engine Starting

(Copies of this document are available at http://nso.nato.int and www.ihs.com to qualified users.)

DEPARTMENT OF DEFENSE SPECIFICATIONS

JSSG-2001	Air Vehicle Joint Service Specification Guide
JSSG-2007	Engines Joint Service Specification Guide
MIL-PRF-7808	Lubricating Oil, Aircraft Turbine Engine, Synthetic Base
MIL-PRF-23699	Lubricating Oil, Aircraft Turbine Engine, Synthetic Base, NATO Code Number O-156

(Copies of these documents are available online at http://quicksearch.dla.mil or from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia PA 19111-5094 USA.)

C.2.3 Non-Government publications.

The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

SAE INTERNATIONAL

SAE AIR713	Guide for Determining, Presenting, and Substantiating Turbine Engine Starting and Motoring Characteristics
SAE AIR781	Guide for Determining Engine Starter Drive Torque Requirements
SAE AS943	Starter, Pneumatic, Aircraft Engine
SAE ARP949	Turbine Engine Starting System Design Requirements
SAE AIR1087	Aircraft Accessory Drag Torque during Engine Starts
SAE AIR1160	Aircraft Engine and Accessory Drives and Flange Standards
SAE AIR1174	Index of Starting System Specifications and Standards
SAE AIR1467	Gas Energy Limited Starting Systems
SAE AIR1639	Safety Criteria for Pneumatic Starting Systems

(Copies of these documents are available from www.sae.org; SAE International, 400 Commonwealth Drive, Warrendale PA 15096-0001 USA; and www.ihs.com to qualified users.)

AMERICAN SOCIETY OF MECHANICAL ENGINEERS

ASME Paper 79-GT-95 Journal of Turbomachinery

(Copies of this document are available from https://www.asme.org/shop/journals on the ASME Website at https://www.asme.org; ASME, Three Park Avenue, New York NY 10016-5990 USA.)

C.2.4 Order of precedence.

Unless otherwise noted herein or in the contract, in the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

C.2.5 Streamlining.

The Air Vehicle Subsystems Specification has been streamlined. The documents listed in this appendix which are required for acquisition have the same status as those referenced directly in section 2 (first tier). All other documents referenced through tiering may be used for guidance and information only.

C.3 REQUIREMENTS

C.4 VERIFICATIONS

C.3.1 Definition

C.4.1 Definition

C.3.2 Characteristics

C.4.2 Characteristics

C.3.3 Design and construction

C.4.3 Design and construction

C.3.4 Subsystem characteristics

C.4.4 Subsystem characteristics

C.3.4.1 Landing subsystem

C.4.4.1 Landing subsystem

C.3.4.2 Hydraulic subsystem

C.4.4.2 Hydraulic subsystem

C.3.4.3 Auxiliary power subsystem.

The auxiliary power subsystem (APS), in its performance of the functional requirements specified in ___(TBS)___, shall provide on-board auxiliary power generation, conversion and transmission required by the air vehicle in the types, quantities, and duration of power required by the interfacing subsystems for all applicable phases of vehicle operation and specific performance requirements specified herein.

REQUIREMENT RATIONALE (3.4.3)

Auxiliary power subsystems are used to generate, convert, and transmit power for various subsystems of the air vehicle.

REQUIREMENT GUIDANCE (3.4.3)

TBS should reference the applicable section of the Air Vehicle Specification (section 3.5 of JSSG-2001) that establishes the subsystems and their required functions.

In the context of this document, the term “auxiliary power subsystem” refers to those subsystems that generate, convert and or transmit power on the air vehicle other than the main propulsion system(s) and which are provided to interfacing subsystems, such as electrical and hydraulic, for further conversion and distribution. The APS may include subsystems and components such as Auxiliary Power Units, Emergency Power Units, Airframe Mounted Accessory Drives, Power Take-Off Shafts, Ram Air Turbines, and Engine starting systems (Air Turbine Starters, Jet Fuel Starters, and such). Given the current trend in the integration of subsystem functions, the term APS does not have to be used to reflect the proposed peculiar system solution containing these functions nor must these functions be grouped within this category. However, all relevant requirements of this section should be addressed in the applicable sections (however re-categorized) of the proposed solution.

Most manned air vehicle systems may require an on-board auxiliary power subsystem and should use this and subsequent paragraphs as the requirements. For those systems that may not require a separate on-board system, such as a missile, this requirement and possibly all subsequent sub-requirements should be deleted.

Power requirements for all air vehicle subsystems during specified missions, ground maintenance, and emergency conditions should be obtained and consolidated for proper system selection and sizing. Some parameters that should be considered in determining performance requirements are as follow:

a. Mission profiles

b. Power requirements or profiles of pneumatic hydraulic and electrical including number of units; minimum and maximum rotational speeds; torque and speed; bleed pressure, temperature, and flow-rate characteristics and efficiencies

c. Engine starting characteristics, including accessory drag during starting

d. Changes in drag characteristics due to ambient temperature variations

e. Emergency power response time and duration

f. Ground maintenance and hanger-deck maintenance requirements

REQUIREMENT LESSONS LEARNED (3.4.3)

(TBD)

C.4.4.3 Auxiliary power subsystem.

Analysis and tests shall be conducted on the APS to validate the system's capability to provide the types and quantities of power which are required for operation of the air vehicle for all the flight and ground conditions specified. Verification shall be accomplished incrementally and shall consist of __(TBS)__.

VERIFICATION RATIONALE (4.4.3)

Verification is necessary to assure that performance, interface, and functional requirements are met.

VERIFICATION GUIDANCE (4.4.3)

TBS: The capability of the auxiliary power subsystem to provide the types and quantities of power for the specified mission profiles should be evaluated during full scale engineering development. The capabilities of the onboard equipment to deliver the required shaft power and bleed air, at the temperature and altitude extremes typical of system requirements, should be verified during qualification laboratory tests and during air vehicle ground and flight tests.

VERIFICATION LESSONS LEARNED (4.4.3)

(TBD)

C.3.4.3.1 Secondary air vehicle power

C.4.4.3.1 Secondary air vehicle power

C.3.4.3.1.1 Mechanical power transmission.

When applicable, the APS shall transmit mechanical power from the engine(s) to the __(TBS)__ power conversion accessories at the appropriate torque and speed for the environments, loads, attitudes, and misalignments resulting from the possible air vehicle ground and flight operations.

REQUIREMENT RATIONALE (3.4.3.1.1)

This requirement establishes the needed capability of the accessory drive system, to include airframe-mounted gearboxes and power takeoff shafts.

REQUIREMENT GUIDANCE (3.4.3.1.1)

When airframe mounted accessory drive gearboxes are used in the proposed system, this requirement should apply as written with the exception of the wording, "When applicable". Power transmission by means other than mechanical such as electrical, hydraulic, or pneumatic, should be governed by the respective specification sections (see this specification guide's appendix B for hydraulic, appendix H for electrical, and appendix M for pneumatic).

TBS: Specify the power conversion accessories being driven. These may typically include primary flight and utility system hydraulic pumps and electrical generators. Specialty devices such as fuel and lubrication pumps, blowers or other equipment should also be included.

The environments, loads, attitudes, and misalignments are derived based on the equipment location, mounting structure and flexibility, manufacturing tolerances, accessory demands, flight capabilities and other factors. The specific derived values should be specified in the next lower tier component specification.

REQUIREMENT LESSONS LEARNED (3.4.3.1.1)

(TBD)

C.4.4.3.1.1 Mechanical power transmission.

The power transmission capability of the APS shall be verified by analysis, bench tests, air vehicle ground and flight tests, and demonstrations.

VERIFICATION RATIONALE (4.4.3.1.1)

Verification is required to provide an acceptable degree of confidence in gearbox capability prior to use on the air vehicle.

VERIFICATION GUIDANCE (4.4.3.1.1)

Verification should be accomplished by:

a. Analysis of power requirements, duty cycles, and installed system interface limitations
b. Analysis of predicted component and installed system performance and endurance
c. Component and system bench tests validating functionality, endurance capabilities, and mechanical limits at maximum permissible misalignments

d. Simulated environmental tests, analysis, or combinations of tests and analysis that extend the test results to all specified environmental conditions

e. Air vehicle ground and flight tests and demonstrations that validate performance and demonstrate integrated system functionality and capability

Proven gearbox endurance should precede usage time-cycles during the flight test program.

VERIFICATION LESSONS LEARNED (4.4.3.1.1)

(TBD)

C.3.4.3.1.2 Power generation.

When applicable, the APS shall provide __(TBS 1)__ power generation in accordance with the requirements of __(TBS 2)__ for all phases of vehicle operation.

REQUIREMENT RATIONALE (3.4.3.1.2)

This requirement establishes a key functional capability for the APS system and identifies supporting requirements.

REQUIREMENT GUIDANCE (3.4.3.1.2)

This requirement is applicable when the APS is required to provide direct primary electrical, pneumatic, hydraulic power generation, or combinations thereof for the air vehicle.

TBS 1 should specify the type of non-propulsive power to be provided such as primary air vehicle electrical, pneumatic, hydraulic. A distinction as to the nature of the power usage, such as primary, back-up, emergency, utility, should be included in the description.

TBS 2 should specify the air vehicle subsystem section that specifies the requirements for that type of power (appendix B for hydraulic, appendix H for electrical, and appendix M for pneumatic).

REQUIREMENT LESSONS LEARNED (3.4.3.1.2)

(TBD)

C.4.4.3.1.2 Power generation.

The power generation capability of the APS shall be verified by analysis, bench tests, air vehicle ground and flight tests, and demonstrations.

VERIFICATION RATIONALE (4.4.3.1.2)

Verification will insure that the APS will properly provide the required primary flight system power.

VERIFICATION GUIDANCE (4.4.3.1.2)

Verification should be accomplished by:

a. Analysis of power requirements, duty cycles, and installed system interface limitations
b. Analysis of predicted component and installed system performance
c. Component and system bench tests validating functionality, performance and endurance capabilities
d. Simulated environmental tests or analyses (or both) that extend the test results to all specified environmental conditions
e. Air vehicle ground and flight tests and demonstrations that validate performance and demonstrate integrated system functionality and capability.

VERIFICATION LESSONS LEARNED (4.4.3.1.2)

(TBD)

C.3.4.3.2 APS starting.

The on-board auxiliary power generation equipment shall start, without exceeding any APS operating limits, in the time required to support (TBS 1) requirements as specified in (TBS 2). The system shall start and operate on the ground throughout the air vehicle temperature and pressure altitude ranges as specified in (TBS 3). In-flight, the APS shall start and operate throughout the air vehicle temperature and pressure altitude range defined in (TBS 4). Preconditioning of the subsystem components shall not be required, except as follows: (TBS 5).

REQUIREMENT RATIONALE (3.4.3.2)

The ability of the APS to start in a timely manner is critical to achieving higher air vehicle level readiness, launch or emergency functional support requirements. The remaining portion of this requirement is needed to define the temperature and altitude starting capability of the onboard auxiliary power subsystem and preconditioning necessary to make a successful start at the specified ambient environments.

REQUIREMENT GUIDANCE (3.4.3.2)

Air System, Air Vehicle and other interfacing subsystem level requirements should be evaluated as to the need for a start time requirement.

TBS 1 should be filled in with the type of requirement to be supported. These would include air vehicle readiness, rapid reaction launch, emergency power response, or a combination of these. Maintainer requirements and needs should also be considered.

TBS 2 should be filled in with the appropriate document or specification number and paragraph associated with the requirement(s) to be supported. In some situations where the requirement is a derived value, such as may be the case with emergency response power, no higher level document or paragraph will be available to be referenced in TBS 2. Hence the "as specified in TBS 2" portion of the requirement should be deleted and consideration be given to specifying the actual time requirement in its place. Actual time allocation of the total "system" requirement to the various APS equipment generally should be specified at the next lower tier specification. In the absence of any higher level or derived requirements, starting performance experienced with similar commercial and military systems should be utilized (typically no greater than 30 seconds).

TBS 3 should reference the air vehicle ground operational envelope from the Air Vehicle Specification.

The capability to start and operate the system in-flight may be required to supplement air vehicle power demands under certain flight modes, mission scenarios or in-flight emergencies by providing extra power capacity or by unloading the main engine(s) of bleed and or mechanical power extraction loads. Generally, this is a capability that is inherent in most systems and can enhance air vehicle survivability with little system penalty, depending upon the desired operational envelope. A multi-position door may be required for improved performance.

TBS 4 should define a flight envelope if in-flight starting is required.

A tradeoff should define the optimum compromise between start system sizing, insulation, location, and preconditioning impact on logistics and operation. Limiting preconditioning reduces special actions required prior to air vehicle launch, reduces burdens on maintenance personnel, and may limit special ground support equipment. Generally, with the exception of batteries (which are sometimes used for auxiliary power unit (APU) starting and emergency power), no special external thermal conditioning should be required for APS equipment.

TBS 5 should define any preconditioning requirements.

Industry documents (SAE AIR1467, SAE AIR1639, and ASME Paper 79-GT-95) contain additional information.

REQUIREMENT LESSONS LEARNED (3.4.3.2)

(TBD)

C.4.4.3.2 APS starting.

APS starting shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.3.2)

Verification is needed to assure adequacy of APS starting and the APS starting system.

VERIFICATION GUIDANCE (4.4.3.2)

TBS: A review of trade studies should be accomplished verifying that an optimum solution of start system sizing, insulation, location, and preconditioning impact on logistics and operation has been achieved.

Verification should be by a combination of analysis, bench tests of components and subsystem including temperature and altitude extremes, APS test stand tests, air vehicle ground and flight tests and analysis that extends the test results to all specified conditions.

To verify the low and high temperature starting capability, the equipment, including the starting system, should be soaked to the condition that it would encounter when installed in an air vehicle exposed to the specified extreme temperatures.

VERIFICATION LESSONS LEARNED (4.4.3.2)

(TBD)

C.3.4.3.2.1 APS start system capacity.

The APS starting subsystem shall provide the capacity for __(TBS 1)__ ground start(s) at temperatures __(TBS 2)__. In flight, when required to meet emergency requirements of “Emergency power” and the airstart requirements of “APS starting” in this appendix, the starting subsystem shall provide sufficient capability to achieve successful start throughout the APS temperature and pressure-altitude envelope in the first start attempt.

REQUIREMENT RATIONALE (3.4.3.2.1)

APS start systems generally use stored energy from an on-board, limited capacity source. Once depleted without a successful start, re-servicing with ground support equipment may be required to recharge the system that may impact the mission. This requirement establishes the necessary start system capability in support of mission and air vehicle survivability requirements.

REQUIREMENT GUIDANCE (3.4.3.2.1)

TBS 1 should be filled in with the number of ground starts desired. The anticipated starting reliability and design of the APS equipment should dictate the number of ground starts to be required. First starts of the day or first starts after maintenance could be problematic due to air in the fuel lines, moisture or other factors effecting ignition thereby necessitating a two-start capability. However, providing such capability under very low temperature conditions, could result in an excessively large system that may not be in the best interest of the total weapon system. Hence, only a single attempt is usually specified for low temperatures. Typically a temperature value in the range from -20° to 0°F is selected, below which, only single start attempt capability is required.

TBS 2 should specify the applicable temperature conditions.

REQUIREMENT LESSONS LEARNED (3.4.3.2.1)

(TBD)

C.4.4.3.2.1 APS start system capacity.

The capacity of the start system shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.3.2.1)

Verification is needed to assure adequate capacity of the APS starting system.

VERIFICATION GUIDANCE (4.4.3.2.1)

TBS: Verification should be by a combination of analysis, bench tests of components and subsystem including temperature and altitude extremes, APS test stand tests, air vehicle ground and flight tests and analysis that extends the test results to all specified conditions.

VERIFICATION LESSONS LEARNED (4.4.3.2.1)

(TBD)

C.3.4.3.2.2 APS start system charging.

The APS starting subsystem shall be replenished or recharged automatically by onboard equipment during operation of the APS or main engine(s) and have ground accessible provisions and capability for replenishment by ground support equipment.

REQUIREMENT RATIONALE (3.4.3.2.2)

This requirement establishes methods for replenishing the APS start system that impacts mission readiness and maintainability. Automatic recharge eliminates the need for equipment and manpower intensive ground service after each use.

REQUIREMENT GUIDANCE (3.4.3.2.2)

Depending upon mission readiness and maintainability requirements, the requirement should be applied directly. For systems that may have a single use duty cycle, such as may be required for a cruise missile, only ground servicing provisions should be specified.

REQUIREMENT LESSONS LEARNED (3.4.3.2.2)

(TBD)

C.4.4.3.2.2 APS start system charging.

The capability of the APS to be recharged by on-board equipment shall be verified by _(TBS)__. The capability of the system to be charged from ground support equipment shall be verified by air vehicle ground tests.

VERIFICATION RATIONALE (4.4.3.2.2)

Verification is needed to assure the APS starting system has the capability of being recharged by the appropriate equipment.

VERIFICATION GUIDANCE (4.4.3.2.2)

TBS: Verification should be by a combination of bench testing of components, APS test stand tests, air vehicle ground and flight tests and analysis that extends the test results to all specified conditions.

VERIFICATION LESSONS LEARNED (4.4.3.2.2)

(TBD)

C.3.4.3.2.3 APS start system recycle.

The time required to replenish or recharge the APS start system to a fully functionally capable status shall be consistent with air vehicle readiness and emergency power requirements.

REQUIREMENT RATIONALE (3.4.3.2.3)

This requirement is needed to define mission-critical performance. Air vehicle on "ALERT" status must be mission ready continuously.

REQUIREMENT GUIDANCE (3.4.3.2.3)

Depending upon the air vehicle readiness, safety and other APS functional requirements, a recharge time should be allocated to the APS start system and specified in the next lower tier equipment specification. The capability to return immediately to mission-ready status following training alerts, false alerts, or aborted alerts should not be degraded by start system recycling requirements. If the start system is an integral part of the emergency power function, it should be ready before the air vehicle can take flight.

REQUIREMENT LESSONS LEARNED (3.4.3.2.3)

(TBD)

C.4.4.3.2.3 APS start system recycle.

The proper allocation of time to recharge shall be verified by analysis of simulated usage and mission scenarios. APS return to readiness status shall be verified.

VERIFICATION RATIONALE (4.4.3.2.3)

Verification is necessary to insure that the starting system does not require more than the appropriately allocated amount of time to return to ready status following shutdown.

VERIFICATION GUIDANCE (4.4.3.2.3)

Verification should be by a combination of bench testing of components, APS test stand tests, air vehicle ground tests and analysis that extends the test results to all specified conditions.

VERIFICATION LESSONS LEARNED (4.4.3.2.3)

(TBD)

C.3.4.3.3 Main engine starting.

The APS shall provide power to start the main engine(s) throughout the air vehicle ground temperature and pressure altitude ranges within the time allocated to support the air vehicle readiness, rapid launch and propulsion system requirements, while simultaneously providing power for air vehicle subsystem loads required during engine starting without exceeding any engine and APS starting or operating limitations.

REQUIREMENT RATIONALE (3.4.3.3)

This requirement is needed to establish the constraints on a key functional requirement of main engine starting which can have significant impact on APS system design and sizing.

REQUIREMENT GUIDANCE (3.4.3.3)

The APS should provide adequate power for starting the main engine(s) in the time required to meet air vehicle rapid launch requirements, general readiness and any propulsion system requirements. Engine start times as derived from alert response requirements should dictate APS torque or power levels required. If no air vehicle requirements are specified, then typical start times as experienced throughout the aerospace industry (approximately 45 seconds standard day at sea level conditions, per engine and 60 seconds on a hot or cold day sea level conditions) should be used. Engine characteristics can be obtained from the applicable engine specification or the Engine Airframe Interface Control Document (ICD). APS and engine operating limitations that should be observed include but are not limited to:

a. Acceleration rates

b. Torque limits

c. Maximum exhaust gas temperatures (EGT)

d. Time in start window.

Power source redundancy may be necessary to provide flexibility and meet mission requirements. Starting by ground support equipment and air vehicle self-sufficiency (such as onboard starting equipment) may be required. For additional guidance, refer to C.3.4.3.3.1, as well as Industry standards (SAE AIR944 (NONCURRENT), SAE AIR1174, and SAE ARP949) for additional information.

Design consideration for sizing the starter should include the torsional spring constant of the entire drivetrain, the drivetrain total backlash, the speed ratio between the starter pad and driven rotor system and the effective mass moment of inertia and drag of all rotating parts. The drivetrain should be designed to accept impact loads and other dynamic loads that can occur during startup.

REQUIREMENT LESSONS LEARNED (3.4.3.3)

(TBD)

C.4.4.3.3 Main engine starting.

The capability of starting main engines within required times and without exceeding any engine or APS operating limitations with simultaneous air vehicle subsystem loads shall be verified by (TBS) .

VERIFICATION RATIONALE (4.4.3.3)

This verification is to assure required main engine start capability with simultaneous air vehicle demands on the APS. For air systems with alert or mission readiness requirements (or both), it is essential to accurately verify engine start times to determine if air vehicle response time can be met.

VERIFICATION GUIDANCE (4.4.3.3)

TBS: Verification should consist of bench tests, air vehicle ground tests and analysis of engine design data and test data. For new complex APS, verification on an integrated test stand may also be required.

The capability of the starting methods to provide the specified power should be verified by laboratory testing. Ground and in-flight air vehicle tests should be conducted to verify that the engine can be satisfactorily started by the methods specified.

Bench verification testing adequately demonstrates equipment power producing capability. Accurate analysis of the impact of installation losses on starting performance (such as pressure loss, flow loss, duct leakage, current loss, or mechanical losses) can be verified only by air vehicle testing.

Ground and flight start tests should be conducted. Starting performance curves should be generated. (SAE AIR713 contains additional information.)

Utilizing the defined power sources, figures showing the main engine starting characteristics versus starter output torque-speed characteristics at the normal and worst case environmental conditions should be presented. Ground and in-flight capability should be shown (refer to SAE AIR781 and AIR1087 for additional information).

With the air vehicle established in a simulated alert status, the APS should be started and main engine starting should follow immediately. Environmental conditions for the test should be defined. The total elapsed time from initiation of the start cycle to final engine idle speed should be within the allocated time. Verification of start times for the most critical conditions should be provided.

The air vehicle should be exposed to the required extreme environmental conditions and the main engines started using the required power sources. The started main engine should attain idle revolutions per minute (RPM) when employing the required power sources.

VERIFICATION LESSONS LEARNED (4.4.3.3)

Experience has shown that engine start characteristics vary greatly from design predictions. Testing has provided one of the best methods to assess system performance and indicate where modifications may be required.

C.3.4.3.3.1 Alternative power sources.

A means of utilizing alternative sources of starting power such as cross bleed power or ground power sources shall be provided to meet air vehicle mission requirements.

REQUIREMENT RATIONALE (3.4.3.3.1)

When the calculated reliability of the primary starting mechanism or power source will not meet mission specified requirements, the capability of utilizing alternative sources of power for the main engine starter should be provided.

REQUIREMENT GUIDANCE (3.4.3.3.1)

The need for utilization of alternative power sources should depend on the expected main starting system reliability, the mission criticality of the air vehicle and survivability considerations. Alternate power sources should include other main engines and ground cart for pneumatic or electrical power. Use of pneumatic ground carts should require that connections be compatible with requirements of NATO STANAG 3372. Start time is not critical when using an alternative power source.

Generally, on-board pneumatic power start systems should have the capability to use a ground cart or, as the available facilities may dictate, pneumatic supply from another air vehicle.

REQUIREMENT LESSONS LEARNED (3.4.3.3.1)

One Air Force bomber system had two APUs, each coupled to two remote gearboxes, all of which had to operate properly to start the engines. Failure of any one of these devices could have resulted in non-flyable status. To provide starting power to any engine not capable of receiving power by the normal means, a pneumatic probe starter was developed to connect directly into the engine-mounted gearbox. Pneumatic power could be directed from another operating engine through an externally connected hose.

Two modern day USAF fighter air vehicles do not have the capability to use alternative power sources and cannot be launched until failed equipment is repaired. However, another modern day USAF fighter has its emergency power function integral to the engine starting function, hence if the APS cannot start the engines, having the capability to start from an alternative power source provided no advantage since the “safety critical” emergency power function would not be available for the mission.

C.4.4.3.3.1 Alternative power sources.

Verify by analysis and air vehicle test that the APS provides a means of utilizing alternative power sources for main engine starts.

VERIFICATION RATIONALE (4.4.3.3.1)

Capability must be proven by air vehicle test since other verification methods cannot assure adequacy of design.

VERIFICATION GUIDANCE (4.4.3.3.1)

Testing should be conducted during air vehicle ground testing. Capability at environmental extremes should be verified.

VERIFICATION LESSONS LEARNED (4.4.3.3.1)

(TBD)

C.3.4.3.3.2 Starting conditions.

The starting system shall be capable of performing main engine start(s) under all airframe operational and maintenance configurations that may require engine operation and under the environmental conditions stated in JSSG-2001, "Environment". Ground start capability shall be provided for ambient conditions __(TBS)__.

REQUIREMENT RATIONALE (3.4.3.3.2)

This requirement defines and limits restrictions to starting the main engines.

REQUIREMENT GUIDANCE (3.4.3.3.2)

Airframe effects, such as movable wings, cargo doors, or unique configurations in addition to the starting power generator (such as auxiliary power unit and jet fuel starter) and its physical interfaces; inlet and exhaust door locations, should be evaluated.

TBS should be filled in with the allowable extremes of temperature, pressure, wind direction and velocity, and other relevant ambient conditions, from the applicable air vehicle specification paragraph that specifies ground operating conditions.

REQUIREMENT LESSONS LEARNED (3.4.3.3.2)

(TBD)

C.4.4.3.3.2 Starting conditions.

Verification that the APS is capable of performing main engine start(s) under the required airframe configurations and environments specified shall be by __(TBS)__.

VERIFICATION RATIONALE (4.4.3.3.2)

Verification is needed to insure the capability of the engines to start within the limits specified.

VERIFICATION GUIDANCE (4.4.3.3.2)

TBS: Verification should be accomplished by a combination of APS test stand tests, air vehicle ground and flight tests and analysis of interfacing airframe designs and test data.

Testing should be conducted over the entire air vehicle operating envelope. Simulations of defined conditions may be required.

VERIFICATION LESSONS LEARNED (4.4.3.3.2)

(TBD)

C.3.4.3.3.3 In-flight starting assist.

The APS shall assist in-flight main engine starting by motoring the engine core rotor within the envelope defined in the air vehicle - engine ICD __(TBS)__, while simultaneously providing any required secondary power as specified in “Secondary air vehicle power” and emergency power as specified in “Emergency power” in this appendix, as applicable.

REQUIREMENT RATIONALE (3.4.3.3.3)

This requirement defines the required in-flight starting assist capability based on air vehicle survivability requirements and anticipated operable engine flameout potential. Since the windmill start regime of turbofan engines generally requires airspeeds in excess of that which can be achieved at reasonable dive angles with all engines out, an airstart assist capability may be required.

REQUIREMENT GUIDANCE (3.4.3.3.3)

As a minimum, a single-engine air vehicle should be provided in-flight starting capability. Regardless of the number of engines, if normal start equipment is on-board, air vehicle survivability would be enhanced if this equipment were to be made air operable and capable of providing power assist to the engine. The parameters that should be considered in providing this capability are as follow:

a. Air vehicle flight envelope

b. Accessory drag characteristics

c. Engine starting characteristics

d. Engine susceptibility to flameout

e. Aerodynamic-installation characteristics

f. Air vehicle speed

g. Air vehicle descent profile

h. Minimum engine speed

i. Probability of a re-light.

TBS should specify the applicable engine - air vehicle ICD that should contain “assisted airstart” envelope of the engine.

REQUIREMENT LESSONS LEARNED (3.4.3.3.3)

(TBD)

C.4.4.3.3.3 In-flight starting assist.

In-flight starting assist capability shall be verified by __(TBS)__ and air vehicle flight tests at the specified envelope extremes.

VERIFICATION RATIONALE (4.4.3.3.3)

Verification is needed to verify the specified engine in-flight starting assist envelope. Flight tests are required since experience shows variations between actual and predicted performance are probable.

VERIFICATION GUIDANCE (4.4.3.3.3)

TBS: Verification should generally be accomplished by a combination of bench and cell tests of the subsystem including simulated altitude and temperature extreme tests, air vehicle flight testing, and analysis of data from these tests and from the engine manufacturer’s test stand, cell, and ground tests to extend results to all specified conditions.

Assisted air starts should be conducted at the extremes of the altitude versus speed envelope. The APS should deliver the power required to assure that the engine core rotor can be maintained at sufficient speed for a properly operating engine to reach idle RPM.

VERIFICATION LESSONS LEARNED (4.4.3.3.3)

(TBD)

C.3.4.3.3.4 Start cycle control.

Control of the start cycle shall be automatic from initiation to starter cutout, including start system re-engagements during main engine spooldown restarts.

REQUIREMENT RATIONALE (3.4.3.3.4)

This requirement defines the means for starting the engines based on operational requirements.

REQUIREMENT GUIDANCE (3.4.3.3.4)

Generally, start initiation is by means of a single switch in the cockpit that provides automatic starter operation from initiation to starter cutout. The starter should be provided a speed responsive cutout device that will terminate the power supplied to the output shaft at the speed at which the engine no longer requires starter assist. A device should be designed to be fail-safe in the event of loss of activation signal. An automatic engagement-disengagement mechanism should be used to limit the burden on the crew and assure that distraction of the crew during the starting sequence will not result in catastrophic failure. The overriding parameters of concern within this area should be safety and human factors.

It is desirable for engines requiring air start assist that the starter mechanism be designed to engage at all engine speeds. Turbine starters with clutch limitations should at least be capable of re-engaging an engine that is at the maximum steady state windmilling speed or 30 percent (30%), whichever is higher. Most current air turbine starters are capable of engagements at speeds of 30 percent (30%). This capability enhances engine in-flight starting capability and air vehicle survivability by allowing faster engagement for quicker engine starts with less altitude loss. This margin should also be adequate for ground restarts in the event the start switch is activated prior to rotor stoppage. (Refer to SAE AS943 for additional information.)

REQUIREMENT LESSONS LEARNED (3.4.3.3.4)

(TBD)

C.4.4.3.3.4 Start cycle control.

Verification of the start cycle control capability shall be by __(TBS)__.

VERIFICATION RATIONALE (4.4.3.3.4)

Verification is needed to insure the capability of the engine starting control system including associated logic functions.

VERIFICATION GUIDANCE (4.4.3.3.4)

TBS: Verification should consist of component bench tests of controller logic and starter engagement-disengagement mechanisms, system-vehicle integration facility tests and air vehicle ground and flight tests. System-vehicle integration laboratories and facilities are generally desired to evaluate the control logic interactions between the various subsystems on the air vehicle prior to actual installation and test on the air vehicle. An air vehicle main engine start test should be conducted utilizing the initiation and control methods specified.

Engine starting is generally verified by air vehicle ground testing to assure proper and safe operation of the integrated system.

Air vehicle spooldown engagement testing should be minimized to limit potentially more expensive damage to the equipment. Running engagements should be accomplished at the maximum permissible speeds. Inertia loads comparable to expected engine inertia should be applied to the starter output shaft. (Refer to SAE AS943 for additional information.)

VERIFICATION LESSONS LEARNED (4.4.3.3.4)

(TBD)

C.3.4.3.3.5 Start cycle termination.

It shall be possible to terminate the starting cycle at any time without damage to APS equipment.

REQUIREMENT RATIONALE (3.4.3.3.5)

A significant potential for start cycle interruption exists. Equipment damage from such a probable occurrence is economically and operationally unacceptable.

REQUIREMENT GUIDANCE (3.4.3.3.5)

Generally, no special features are necessary to meet this requirement. (Refer to SAE AS943 for additional information.)

REQUIREMENT LESSONS LEARNED (3.4.3.3.5)

(TBD)

C.4.4.3.3.5 Start cycle termination.

Termination of the starting cycle any time during the start cycle without damage to APS equipment shall be verified by bench and air vehicle ground testing.

VERIFICATION RATIONALE (4.4.3.3.5)

Verification is needed to insure the capability to terminate a start cycle without damage to the APS.

VERIFICATION GUIDANCE (4.4.3.3.5)

Testing of APS components, such as auxiliary power unit, jet fuel starter, and air turbine starters, should include start cycle interruptions. Start cycle interruptions to APS should be made during air vehicle ground testing.

Bench and test stand tests should be used until equipment integrity is verified to prevent air vehicle damage or development schedule delays.

VERIFICATION LESSONS LEARNED (4.4.3.3.5)

(TBD)

C.3.4.3.3.6 Start duty cycle.

The APS shall be capable of performing __(TBS 1)__ consecutive main engine starts on the ground, with a maximum time interval of __(TBS 2)__ seconds from the completion of one cycle to the initiation of the next, followed by the ability to meet the motoring requirements of "Engine motoring" in this appendix. In flight, the starting function shall be capable of providing continuous main engine assist for a period consistent with a worst case all engines out scenario.

REQUIREMENT RATIONALE (3.4.3.3.6)

This requirement is needed to define system capabilities as a result of mission, reliability and safety performance requirements. Air vehicles on "ALERT" status must be mission ready continuously. The capability to accomplish a main engine start following an aborted attempt or the ability to motor the engine following a hot or hung start must not be degraded by start system limitations.

REQUIREMENT GUIDANCE (3.4.3.3.6)

TBS 1 should be filled in with the number of consecutive starts to be required.

TBS 2 should be filled in with the maximum number of seconds permitted between starts.

Generally, with the capability of conducting at least two consecutive main engine starts on the ground within 30 seconds of each other should be required. The actual criteria for this requirement should be based on expected usage scenarios resulting from mission completion and engine reliability and failure mode criteria.

REQUIREMENT LESSONS LEARNED (3.4.3.3.6)

(TBD)

C.4.4.3.3.6 Start duty cycle.

APS start duty cycle capability shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.3.3.6)

Verification is necessary to insure the APS has the capability to perform and endure the engine starting and motoring function for the duty cycle specified.

VERIFICATION GUIDANCE (4.4.3.3.6)

TBS: Verification should be by analysis of in-flight engine out scenarios, bench testing, and air vehicle testing.

VERIFICATION LESSONS LEARNED (4.4.3.3.6)

(TBD)

C.3.4.3.4 Emergency power.

Emergency power shall be provided as follows: __(TBS)__.

REQUIREMENT RATIONALE (3.4.3.4)

Many air vehicle systems require emergency power such as the flight control system, fuel system, electrical system, and engine start system, in the event of normal power failure. There are conditions where the capabilities of the emergency power source may be restricted by extreme attitudes (inverted flight or uncontrolled flight). The period of time that emergency power can be provided (for example, the power level and duration) affects pilot and air vehicle survivability.

REQUIREMENT GUIDANCE (3.4.3.4)

TBS: The emergency power may be required to provide emergency hydraulic and electrical power for primary flight control in the event of primary power failure anywhere in the permissible envelope. Individual accessories such as a generator or hydraulic pump may fail. Loss of the total secondary power system due to engine failure, power takeoff shaft failure, gearbox damage, or such, is also possible. Emergency power should at minimum provide the quantity and duration of power required to recover an air vehicle to a safe ejection envelope. It is generally desirable to provide adequate power to permit stable air vehicle control for attempted assisted engine restart, air vehicle decent and recovery. The emergency power source can be a means of providing for assisted main engine air starts (single attempt or multiple attempt capability). Air vehicle design and mission requirements should be considered when defining emergency power requirements.

REQUIREMENT LESSONS LEARNED (3.4.3.4)

(TBD)

C.4.4.3.4 Emergency power.

Emergency power capability shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.3.4)

Adequate quality and quantity of power for flight control and other functions necessary for safe operation of the air vehicle during designated emergency conditions must be assured. Bench and ground testing provide operability and performance levels. Flight testing verifies functional capabilities for defined emergency situations.

VERIFICATION GUIDANCE (4.4.3.4)

TBS: Verification of emergency power capability should include analyses of various simulated air vehicle emergency scenarios, bench tests, system-vehicle integration facility tests, and air vehicle ground and flight tests.

Simulated emergency power demands should be placed on the APS. Extreme flight conditions should be simulated in test cells.

VERIFICATION LESSONS LEARNED (4.4.3.4)

(TBD)

C.3.4.3.4.1 Emergency power operation.

Emergency power operational characteristics shall be as follow:

a. Emergency power shall be provided automatically upon detection of a critical power loss. The capability for manual activation by the flight crew shall be provided.

b. Transition to emergency power shall not interrupt flight critical control systems operation or result in unstable air vehicle operation.

c. __(TBS)__.

REQUIREMENT RATIONALE (3.4.3.4.1)

This requirement establishes critical operational characteristics of providing emergency power should it be required. Many current day air vehicle systems cannot tolerate even momentary power interruptions such that detection of a critical power loss and activation of the emergency power source must be accomplished automatically. Since all emergency situations cannot be foreseen, a manual activation capability should also be provided. The activation and transition to emergency power should be transparent to operation of critical flight control systems.

REQUIREMENT GUIDANCE (3.4.3.4.1)

The requirements “a” and “b” should usually apply depending upon the design of the air vehicle “power” architecture.

TBS should define other critical operational characteristics as appropriate for the application.

REQUIREMENT LESSONS LEARNED (3.4.3.4.1)

(TBD)

C.4.4.3.4.1 Emergency power operation.

Emergency power operational characteristics shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.3.4.1)

Verification is needed to insure that specified initiation and control functions perform as required to provide the types and quantities of emergency power.

VERIFICATION GUIDANCE (4.4.3.4.1)

TBS: Verification should include component and subsystem bench tests, system-vehicle integration facility tests, air vehicle ground tests, and air vehicle flight tests. Anticipated operational conditions such as extreme attitudes, load transients, and intermittent operation should be simulated.

Laboratory and ground testing should be used to verify control function and overall operability with minimum risk. Flight testing should be used as the means of demonstrating installed emergency power performance.

VERIFICATION LESSONS LEARNED (4.4.3.4.1)

(TBD)

C.3.4.3.5 APS operation for air vehicle ground support.

The APS shall have the capability to provide self-sufficient (no ground support equipment) air vehicle ground operations and maintenance support to the extent specified. The capability to use ground support equipment for maintenance shall be included in the design.

REQUIREMENT RATIONALE (3.4.3.5)

This requirement establishes a key functional capability to support ground maintenance activities without the use of ground support equipment.

REQUIREMENT GUIDANCE (3.4.3.5)

The need for self-sufficiency should be dependent upon the maintainability philosophy established in the Operational Requirements Document and JSSG-2001, as well as logistic and deployment requirements. Self-sufficient capability should typically require the system to start, operate, and provide electrical, hydraulic and pneumatic power, as applicable and without assistance from ground support equipment, in support of performing ground maintenance activities such as interfacing subsystem diagnostic and functional checkouts, air vehicle servicing and weapons loading. Considerations associated with such a requirement should include:

a. Duty cycle and heat load definition.

b. An operational noise level which would permit maintenance personnel to communicate with each other.

c. Exhaust and inlet location and design that allows access to applicable areas of the air vehicle.

REQUIREMENT LESSONS LEARNED (3.4.3.5)

(TBD)

C.4.4.3.5 APS operation for air vehicle ground support.

The capability of the APS to support self-sufficient ground operations and maintenance support shall be verified by __(TBS)__. The capability to use support equipment shall be verified by inspection of design drawings and air vehicle demonstration.

VERIFICATION RATIONALE (4.4.3.5)

Verification is needed to insure the capability of the APS to support air vehicle self-sufficiency during ground maintenance.

VERIFICATION GUIDANCE (4.4.3.5)

TBS: Verification should include analysis, subsystem bench tests, and air vehicle ground demonstrations and tests.

Anticipated loads, duty cycle and heat rejection requirements should be analyzed and defined. Subsystem bench testing should validate capability of performing under the required conditions and duration. Air vehicle demonstrations and tests of the integrated system should be accomplished to validate that the system functions properly in the installed environment and does not create an unsuitable environment for the maintainer.

VERIFICATION LESSONS LEARNED (4.4.3.5)

(TBD)

C.3.4.3.5.1 Engine motoring.

The APS shall provide the capability for motoring the main engine at speeds and duration required to meet any engine operational, maintenance or emergency scenarios using power from either of the following power sources: __(TBS)__.

REQUIREMENT RATIONALE (3.4.3.5.1)

Motoring capability may be required before normal engine starts, for engine cooling after a hung start, and to accomplish maintenance checkouts, and engine washing.

REQUIREMENT GUIDANCE (3.4.3.5.1)

Engine motoring requirements generally should be based upon the operational and maintainability needs of the selected main propulsion engine. Engine requirements, maintenance procedures and emergency (for example, hung start) scenarios should be analyzed to define the proper speed and duration requirements. Generally, five minutes of motoring should be used to accomplish engine maintenance checkout and cleaning. The specific engine specification or the engine - airframe ICD may address any specific requirements. The Engines Joint Service Specification Guide, JSSG-2007, may be consulted for general guidance.

TBS should be filled in by specifying the power sources (such as APS pneumatic, hydraulic or electrical; ground cart pneumatic, hydraulic or electrical; operating engine pneumatic, hydraulic or electrical; or facility pneumatic, hydraulic or electrical) that will be utilized in performing this capability.

REQUIREMENT LESSONS LEARNED (3.4.3.5.1)

(TBD)

C.4.4.3.5.1 Engine motoring.

The capability of main engine motoring system by the specified power sources shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.3.5.1)

Verification is to insure that the engine motoring system has the motoring capability required to perform the necessary tasks.

VERIFICATION GUIDANCE (4.4.3.5.1)

TBS: Verification should be accomplished by analysis, bench tests, and air vehicle ground tests as follow:

a. Analysis of any engine requirements, maintenance procedures and emergency scenarios that establish the required motoring speeds and duration.
b. Analysis of predicted system performance from the various power sources using estimated system losses and efficiencies.
c. Component bench tests validating component efficiencies and endurance capabilities.
d. Analysis that extends the test results to all specified environmental conditions.
e. Air vehicle ground testing that validates estimated system losses and demonstrates integrated system functionality and capability.

VERIFICATION LESSONS LEARNED (4.4.3.5.1)

(TBD)

C.3.4.3.5.2 Systems ground operational power.

The APS shall provide the necessary power combinations of hydraulic, electrical and pneumatic power required to perform uninterrupted __(TBS)__.

REQUIREMENT RATIONALE (3.4.3.5.2)

Specifying the type of maintenance activities to be performed on an uninterrupted basis is required such the APS can be sized to meet to maintainability and mission readiness requirements.

REQUIREMENT GUIDANCE (3.4.3.5.2)

TBS should be filled in with consideration given to the following scenarios:

a. any single avionics, vehicle management system, flight control, hydraulic, or electrical system checkout

b. servicing and corrective maintenance

c. weapons loading.

REQUIREMENT LESSONS LEARNED (3.4.3.5.2)

(TBD)

C.4.4.3.5.2 Systems ground operational power.

The capability of the APS to provide the necessary power combinations of hydraulic, electrical and pneumatic power required to perform the specified tasks on an uninterrupted basis shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.3.5.2)

Verification is needed to ensure the APS can supply adequate power for performing the tasks specified.

VERIFICATION GUIDANCE (4.4.3.5.2)

TBS: Verification should be accomplished by analysis, bench and air vehicle ground tests as follows:

a. Analysis of power requirements, duration and installed system interface necessary to accomplish the maintenance activities specified.

b. Analysis of predicted component and installed system performance

c. Component bench tests validating component efficiencies and endurance capabilities.

d. Analysis that extends the test results to all specified environmental conditions

e. Air vehicle ground tests that validate estimated system losses and demonstrate integrated system functionality and capability.

VERIFICATION LESSONS LEARNED (4.4.3.5.2)

(TBD)

C.3.4.3.5.3 Maintenance limitations.

APS operating time shall not limit maintenance tasks performed using onboard power with the exception that engine motoring shall be no less than that specified in “Engine motoring” in this appendix.

REQUIREMENT RATIONALE (3.4.3.5.3)

Establishing duration requirements is necessary such that the APS can be designed for proper endurance. Maintenance tasks must be able to be performed on an uninterrupted basis.

REQUIREMENT GUIDANCE (3.4.3.5.3)

Requirement applies to systems with self-sufficiency requirements.

REQUIREMENT LESSONS LEARNED (3.4.3.5.3)

(TBD)

C.4.4.3.5.3 Maintenance limitations.

The capability of the APS to not constrain the performance of maintenance tasks as a result of operating time limitations shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.3.5.3)

Verification is needed to assure that there are no APS operating time limitations that will impact the performance of maintenance tasks.

VERIFICATION GUIDANCE (4.4.3.5.3)

TBS: Verification should be accomplished by analysis, bench and air vehicle maintenance ground demonstrations as follows:

a. Analysis of power requirements, duration and installed system interface necessary to accomplish the maintenance activities specified.
b. Analysis of predicted component and installed system performance.
c. Component and subsystem bench tests validating endurance capabilities.
d. Analysis that extends the test results to all specified environmental conditions.
e. Air vehicle maintenance ground tests and demonstrations that validate integrated system endurance capability.

VERIFICATION LESSONS LEARNED (4.4.3.5.3)

(TBD)

C.3.4.3.5.4 Noise.

The APS noise level shall be consistent with the human factor requirement specified in air vehicle specification __(TBS 1)__. Mission-related noise level requirements shall be as follow: (TBS 2)__.

REQUIREMENT RATIONALE (3.4.3.5.4)

This is required to prevent injury to personnel and to establish noise level requirements for specific mission needs.

REQUIREMENT GUIDANCE (3.4.3.5.4)

From the personnel safety perspective, noise level requirements should be specified at the air vehicle level ("Acoustic noise" of JSSG-2001).

TBS 1 should specify the applicable air vehicle document and paragraph for this air vehicle system. Typically, this should require that personnel exposure to acoustic noise not exceed the levels stated in AFR 161-35.

TBS 2 should specify any more restrictive noise level requirements that would be associated with a particular mission. The need to conduct a conversation in the immediate area of the air vehicle with the APS operating, as may be the case for a high level diplomatic mission, would be an example where more restrictive requirements would be applicable.

REQUIREMENT LESSONS LEARNED (3.4.3.5.4)

(TBD)

C.4.4.3.5.4 Noise.

Compliance with the noise requirements specified shall be by air vehicle ground tests and analysis.

VERIFICATION RATIONALE (4.4.3.5.4)

Verification is required to insure personnel safety and capability of meeting mission requirements.

VERIFICATION GUIDANCE (4.4.3.5.4)

Control of noise levels are highly dependent upon the installation design, hence ground tests and analysis of the data thereof should be performed on the air vehicle.

VERIFICATION LESSONS LEARNED (4.4.3.5.4)

(TBD)

C.3.4.3.5.5 Decoupling.

Means shall be provided to prevent unintentional disengagement and reengagement of the APS power transmission system from the main engine(s) when decoupling capability is provided as an alternative method of driving the air vehicle accessories (hydraulic pumps and generators) for ground maintenance.

REQUIREMENT RATIONALE (3.4.3.5.5)

Requirement is necessary for air vehicle and personnel safety. Unintentional disengagement of a decoupling system during flight could result in loss of primary and hydraulic power and place the air vehicle at risk. Likewise, unintentional reengagement of the decoupling system on the ground while maintenance personnel may be working in the area represents a serious personnel hazard.

REQUIREMENT GUIDANCE (3.4.3.5.5)

An APU, jet fuel starter (JFS), or a ground power cart may be used to drive the remote gearboxes via pneumatic (such as an air turbine starter), or mechanical link. Decoupling may facilitate use of the secondary power source and remote gearboxes for ground checkout and munitions loading. If such design solutions are incorporated, the stated requirement should be applied.

REQUIREMENT LESSONS LEARNED (3.4.3.5.5)

Decoupling mechanisms have been shown to add increased complexity to a gearbox and to adversely impact the transmission system's reliability.

C.4.4.3.5.5 Decoupling.

The capability of a means to prevent unintentional disengagement and reengagement of the APS transmission components from the main engine shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.3.5.5)

Verification is needed to insure that decoupling is possible, that inadvertent engagement and disengagement will not occur and that the specified functions can be successfully accomplished.

VERIFICATION GUIDANCE (4.4.3.5.5)

TBS: Verification should consist of component bench tests, air vehicle ground tests and maintenance operation demonstrations. Testing should be conducted to verify that unintentional engagement and disengagement is not possible.

VERIFICATION LESSONS LEARNED (4.4.3.5.5)

(TBD)

C.3.4.3.6 Fuels.

The APS shall meet the performance specified herein when supplied with fuels as follows: (TBS) .

REQUIREMENT RATIONALE (3.4.3.6)

This requirement is needed to specify fuel characteristics by which auxiliary power subsystem performance will be based and the performance limitations resulting from use of other fuels which may have to be used in the event that the primary fuel is not available.

REQUIREMENT GUIDANCE (3.4.3.6)

TBS: Generally, most auxiliary power generating equipment should use the same fuel as the main engine. Reference should be made to appendix E, "Fuel designation" and "Fuel contamination". APS performance differences when operating with other than the primary fuel, such as alternate or emergency fuels, should be specified. The APS should start and operate using the alternate fuels specified. There should be no effect on the established overhaul time for the APS. Limits on operating time and storage time with alternate fuels should be specified. If fuels other than the air vehicle primary type are selected to power the APS, they should be specified as appropriate. When using fuels other than that used for the primary air vehicle, factors such as logistics, maintenance, handling, storage, and availability should be considered.

REQUIREMENT LESSONS LEARNED (3.4.3.6)

(TBD)

C.4.4.3.6 Fuels.

The capability of the APS equipment to meet performance on the specified primary fuel(s) shall be verified by test. The capability of the APS to meet performance using fuels other than the primary fuel(s) shall be verified by (TBS) .

VERIFICATION RATIONALE (4.4.3.6)

Verification is needed to certify the capability of APS equipment to meet performance on the specified primary fuels and other fuels as specified. Quantitative data, obtainable only through testing, is required to assess performance on the primary fuel types.

VERIFICATION GUIDANCE (4.4.3.6)

Testing to verify APS performance requirements should be conducted using the specified primary fuel(s).

TBS should be filled in with respect to the effects on APS performance characteristics, changes in starting time and effects on the air vehicle mission(s) when using an alternate fuel should be assessed. This, however, may not always necessitate testing.

VERIFICATION LESSONS LEARNED (4.4.3.6)

(TBD)

C.3.4.3.7 Lubricating oil.

The APS shall meet the performance specified herein with lubricating oil(s) conforming to __(TBS 1)__ except for the following variations in the specified characteristics: __(TBS 2)__.

REQUIREMENT RATIONALE (3.4.3.7)

This requirement is needed to specify oil characteristics by which auxiliary power subsystem performance will be based.

REQUIREMENT GUIDANCE (3.4.3.7)

TBS 1 should be completed with consideration that lubricating oils which conform to MIL-PRF-7808 and MIL-PRF-23699 should be used as standard lubricants.

TBS 2 should be completed considering that special lubricants may be required for unusual or nonstandard situations.

Generally, the APS equipment oil should be the same as the main engines to minimize logistics impacts. Limits on special conditioning may be required to restrict reduction in mission readiness and limit unnecessary burden on the user.

REQUIREMENT LESSONS LEARNED (3.4.3.7)

(TBD)

C.4.4.3.7 Lubricating oil.

The capability of the APS to meet performance utilizing the specified lubricating oil(s) shall be verified by test.

VERIFICATION RATIONALE (4.4.3.7)

Verification is necessary to insure the capability of APS equipment to start and operate at temperature extremes utilizing the specified oil.

VERIFICATION GUIDANCE (4.4.3.7)

Performance testing to verify APS requirements should be conducted using the specified lubricant.

VERIFICATION LESSONS LEARNED (4.4.3.7)

(TBD)

C.3.4.3.8 APS controls and indicators

C.4.4.3.8 APS controls and indicators

C.3.4.3.8.1 APS controls.

Controls for the APS shall be as follows:

a. Cockpit crew: The pilot(s) shall have the means to initiate the following actions: (TBS 1) .

b. Other Flight crew: The (TBS 2) shall have the means to initiate the following actions: (TBS 3) .

c. Maintenance crew: The maintenance crew shall have the means to initiate the following: (TBS 4) .

REQUIREMENT RATIONALE (3.4.3.8.1)

This requirement establishes the control requirements of the user based on mission, maintenance, and safety requirements.

REQUIREMENT GUIDANCE (3.4.3.8.1)

TBS 1, TBS 3, and TBS 4 should be filled in with consideration given to the following. Describe the control functions that the various crew members require. Typical functions to consider should be:

a. Main Engine(s) start-stop

b. APS start-stop

c. APS Arm for emergency power activation

d. APS "safetying" from inadvertent activation

e. Engine decouple – recouple

f. Motor engine

g. Motor Gearbox.

TBS 2 should be filled in with the specific crew member(s), such as the loadmaster or flight engineer, that requires specific functions.

Generally, APS start sequencing and control is automatic upon actuation of a single switch. Stable operation under all anticipated operational conditions, including starting and load transients, is essential. Requiring APS control functions for crew other than the pilots will result in external APU activation and shutdown controls, such as load master control in cargo bay, or switch at crew entrance ladder.

REQUIREMENT LESSONS LEARNED (3.4.3.8.1)

(TBD)

C.4.4.3.8.1 APS controls.

Controls for the APS shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.3.8.1)

Verification is needed to insure that controls for the APS are properly located as determined by mission, maintenance and safety requirements.

VERIFICATION GUIDANCE (4.4.3.8.1)

TBS: Verification should be by review of analysis to determine that mission, maintenance and safety requirements are met and by test, inspection and demonstration during ground tests to determine that the controls function as required.

VERIFICATION LESSONS LEARNED (4.4.3.8.1)

(TBD)

C.3.4.3.8.2 APS status and health indications.

The APS shall provide operating status and health information as follows: ___(TBS)___. If required, some or all of the elements of status and health information shall be configured for incorporation with other subsystems into any planned integrated diagnostic system.

REQUIREMENT RATIONALE (3.4.3.8.2)

This requirement is needed to identify parameters essential for monitoring APS operation, such as EGT and RPM.

REQUIREMENT GUIDANCE (3.4.3.8.2)

TBS should be filled in with the parameters to be provided with consideration given to the following:

a. Information to the cockpit required to assess the integrity of the APS during normal air vehicle operational control.

b. Information to other air vehicle systems to advise of APS status.

The parameters to be sensed, their expected operating range, and required display range should be defined and documented in applicable Interface Control Documents or interface requirements paragraph.

REQUIREMENT LESSONS LEARNED (3.4.3.8.2)

(TBD)

C.4.4.3.8.2 APS status and health indications.

The capability of the APS to provide the required status and health information shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.3.8.2)

Verification is required to insure that proper information is being sent to the flight and maintenance crews.

VERIFICATION GUIDANCE (4.4.3.8.2)

TBS should be filled in with inspection and demonstration during air vehicle ground and flight tests, as applicable.

VERIFICATION LESSONS LEARNED (4.4.3.8.2)

(TBD)

C.3.4.3.9 Power interruptions.

The APS equipment shall remain safe and operating, during any condition of operation, in the event of a momentary interruption of electrical power resulting from electrical power source transfers. The APS equipment shall remain safe in the event of any momentary or total loss of electrical power. Any APS limitation resulting from momentary interruption of electrical power to APS shall be defined.

REQUIREMENT RATIONALE (3.4.3.9)

The APS may be providing critical power to the air vehicle. Its operation should not be compromised or terminated as result of an electrical power transfer from an external to internal, internal to external or internal to internal power source.

REQUIREMENT GUIDANCE (3.4.3.9)

The interruption of electrical power may result from internal functions of the air vehicle electrical system, or from the transfer to or from externally supplied power (ground power source). A momentary interruption of power may be defined as that which can be reasonably expected on the air vehicle in question, or in terms of a specific time span.

If the APS is providing a flight critical function, consideration should be given to having uninterruptible power for the system.

REQUIREMENT LESSONS LEARNED (3.4.3.9)

(TBD)

C.4.4.3.9 Power interruptions.

Safe operation in the event of momentary interruption of electrical power shall be verified by (TBS) .

VERIFICATION RATIONALE (4.4.3.9)

Verification is necessary to insure safe operation of the APS in the event of interruption or loss of electrical power.

VERIFICATION GUIDANCE (4.4.3.9)

TBS: APS performance with loss of external electrical power should normally include bench and air vehicle ground testing and, if applicable, flight testing. Subsystem bench and test stand testing should verify:

a. The capability of the APU, JFS, or such, to remain safe, as applicable.

b. Limitations of functions following loss of external electrical power.

VERIFICATION LESSONS LEARNED (4.4.3.9)

(TBD)

C.3.4.3.10 APS unique integrity

C.4.4.3.10 APS unique integrity

C.3.4.3.10.1 Rotating equipment and containment.

The failure of APS high speed rotating equipment shall not result in a hazard to personnel or damage to adjacent equipment. Containment shall be provided for any portion of the rotating equipment that does not demonstrate adequate damage tolerance and control.

REQUIREMENT RATIONALE (3.4.3.10.1)

This requirement is needed to preclude injury to personnel and damage to equipment resulting from the failure of high speed rotating parts such as cooling and ventilation fans, multiple disk clutch and brake assemblies, or high speed gearing.

REQUIREMENT GUIDANCE (3.4.3.10.1)

A damage tolerance design approach can be utilized in some cases as a means of ensuring high speed component integrity. If such an approach cannot demonstrate adequate design margin, containment should be provided.

REQUIREMENT LESSONS LEARNED (3.4.3.10.1)

Experience has shown that APS turbine equipment normally needs additional containment protection for the compressor and turbine since there is a probability that failures will occur and the normal high operating speed generates high energy fragments if failure does occur. With the unit being used for ground power there is a high probability that personnel would be near the air vehicle and therefore, exposed to these fragments.

Expectations of compressor-turbine failures can be attributed first to the inability to confidently predict all conditions of usage, and second, the non-accountability of total rotor cycles. Failure to accurately track cycles can allow rotating groups to remain in the inventory until fatigue failure occurs. In addition, even with state-of-the-art inspection techniques, material flaws are possible. When failures do occur, the time required to incorporate the proper repairs results in exposure of personnel to a hazardous working environment and expensive damage to equipment.

C.4.4.3.10.1 Rotating equipment and containment.

Personnel safety and adjacent equipment protection from failure of APS high speed equipment shall be verified by __(TBS)__. Containment requirements shall be verified by analysis and test.

VERIFICATION RATIONALE (4.4.3.10.1)

Verification is necessary to insure that neither hazardous conditions to personnel nor damage to adjacent equipment are encountered due to rotating equipment. Verification is also necessary to insure proper containment is provided by the APS for rotating equipment that does not demonstrate adequate damage tolerance and control.

VERIFICATION GUIDANCE (4.4.3.10.1)

TBS: Damage tolerance designs should be verified by analysis, material characterization tests, temperature and stress surveys, inspection demonstrations, and component tests. Containment capability should be verified by analysis and test.

VERIFICATION LESSONS LEARNED (4.4.3.10.1)

(TBD)

C.3.4.3.10.2 Critical speeds.

All rotating APS equipment in the installed configuration shall be free of damaging resonance conditions at all speeds in the operating range. Any damaging critical speeds existing above the operating range shall be at least __(TBS 1)__ above the maximum operating speed. Any damaging critical speeds existing below the operating range shall at least __(TBS 2)__ below the minimum operating range. Adequate damping and appropriate balancing shall be provided so that any critical speed existing from zero speed to __(TBS 1)__ above maximum speed shall be traversed safely with smooth operation.

REQUIREMENT RATIONALE (3.4.3.10.2)

Resonant conditions existing within the operating range of rotating equipment typically create large dynamic loads, which adversely impact the life of equipment and surrounding structure. Subsequent failure may result in personnel injury, major air vehicle secondary damage, or possible air vehicle loss.

REQUIREMENT GUIDANCE (3.4.3.10.2)

TBS 1 should be filled in with a percentage value. Note that TBS 1 is used in two different places.

TBS 2 should be filled in with a percentage value.

Generally a critical speed margin of at least 20 percent (20%) above and below the operating range should be required. Larger margins may be required if the system has numerous uncontrolled variables that impact critical speed response.

REQUIREMENT LESSONS LEARNED (3.4.3.10.2)

(TBD)

C.4.4.3.10.2 Critical speeds.

Verification of critical rotating speed requirements shall be by analysis, component and subsystem bench tests, and air vehicle ground and flight test.

VERIFICATION RATIONALE (4.4.3.10.2)

Verification is necessary to insure that rotating equipment is free of damaging resonance conditions at all speeds in the operating range. Verification is also necessary to insure if any damaging critical speeds do exist, they are at the dictated values above and below the operating range.

VERIFICATION GUIDANCE (4.4.3.10.2)

Verification should be accomplished by:

a. Analysis predicting and updating system critical speed margins and its sensitivity to piece part and assembly variabilities.

b. Component tests validating part and assembly stiffness characteristics

c. Bench tests that include a special structural resonance test conducted on an operating power take off system.

d. Air vehicle ground and flight tests validating installed system response characteristics.

VERIFICATION LESSONS LEARNED (4.4.3.10.2)

(TBD)

C.3.4.3.11 Exhaust systems.

Exhaust systems shall be designed, constructed, and located to prevent the leakage, ingestion and damaging impingement of hot, corrosive, toxic, or combustible exhaust gases into or upon the air vehicle, engine(s), APS inlet(s), ground or ramp.

REQUIREMENT RATIONALE (3.4.3.11)

The purpose of this requirement is to prevent exhaust gases from becoming a hazard to the aircrew or having a detrimental impact to air vehicle structure, adjacent and interfacing subsystems and facilities. Ingestion of exhaust gases through APU or engine inlet(s) provides a means via the bleed ports for toxic fumes to enter the Environmental Control System. Impingement of hot or corrosive gases upon unprotected air vehicle structure could lead to failure of that structure.

REQUIREMENT GUIDANCE (3.4.3.11)

Generally, APS exhaust duct runs are short. The high velocity exhaust gas can be used as the motive force for operation of an eductor. Compartment ventilation and cooling air flow are established by the eductor. Skillful eductor design should preclude or minimize the effects of exhaust gas leakage. Location of APS inlet and exhaust openings should be suitably chosen to avoid exhaust gas ingestion and impingement under the anticipated field conditions. Design attention should also be paid to potential compartment leak paths such as those established at the duct and fuselage interface.

REQUIREMENT LESSONS LEARNED (3.4.3.11)

(TBD)

C.4.4.3.11 Exhaust systems.

Capability to preclude APS exhaust gas leakage, ingestion or damaging impingement into the air vehicle and ground or ramp shall be verified by: __(TBS)__.

VERIFICATION RATIONALE (4.4.3.11)

Verification assures APU exhaust gases do not enter the air vehicle or cause damaging impingement upon the air vehicle and ground.

VERIFICATION GUIDANCE (4.4.3.11)

TBS: Verification should be by analysis of exhaust plume and by using inspection, flow visualization, temperature and gas measurement techniques during ground and, if applicable, flight testing of the air vehicle.

VERIFICATION LESSONS LEARNED (4.4.3.11)

(TBD)

C.3.4.3.12 APS safety

C.4.4.3.12 APS safety

C.3.4.3.12.1 Protective features.

The APS shall incorporate protective features to preclude hazards to personnel and equipment without the need for constant crew (flight and ground) monitoring. Shutdowns caused by protective features shall have no detrimental effects to the equipment.

REQUIREMENT RATIONALE (3.4.3.12.1)

Preventing injury to personnel and damage to equipment requires the capability to automatically shut down; this capability also permits autonomous operation of the APS. Damage precipitated by sequencing necessary to automatically shut down equipment is contradictory to the intent of protective features (preclude damage to equipment).

REQUIREMENT GUIDANCE (3.4.3.12.1)

See table C-I for a list of some APS protective features.

Other related features that should be considered include:

a. Providing a convenient shutdown method external to the air vehicle for ground crew use.

b. Manual override provisions for emergency use to allow APS operation subsequent to an automatic shutdown for a duration sufficient to meet critical mission requirements. If such a provision is provided, it should be designed to be used only for those automatic shutdown functions where continued operation of the APU will not result in injury or death.

c. In flight when the system is providing a flight-safety critical function, automatic shutdown should only be provided for those faults in which continued operation of the APS will result in probable loss of the air vehicle.

Mission requirements may take precedence over protecting equipment (overriding automatic shutdown features) when continued operation of the APU will not result in injury or death.

REQUIREMENT LESSONS LEARNED (3.4.3.12.1)

(TBD)

C.4.4.3.12.1 Protective features.

Protective features shall be verified by laboratory or system ground tests.

VERIFICATION RATIONALE (4.4.3.12.1)

Prudent engineering dictates that safety features be proven highly reliable through thorough testing. The capability to preclude hazards to personnel and equipment must be demonstrated before utilization.

VERIFICATION GUIDANCE (4.4.3.12.1)

Testing should simulate the possible condition, such as overspeed, overtemperature, or fire, which may occur. Protective features should shut down equipment at the limiting speed, temperature, and such.

Safety provisions should be functionally verified in a controlled environment.

VERIFICATION LESSONS LEARNED (4.4.3.12.1)

(TBD)

TABLE C-I. APS protective features.

AIR VEHICLE	EGT	LOW OIL PRESSURE	SPEED	FIRE DETECTION	FIRE EXTINGUISHER
C-5 (GTCP 165-1)	Light in Cockpit Auto Shutdown	Shutdown switch, No Indication	Auto Shutdown 100% - No Indication	1 Fire Pull light Loadmaster Panel 2 Light - Cockpit 3 Audible	Manual Loadmaster Panel Cockpit
C-130H (GTCP-85-180) C-130 (GTCP-85-71)	Auto Shutdown	(During Starting) Acceleration Inhibited	110% Auto Shutdown	No Provision	No Provision
C-141 (GTCP-85-106)	Auto Shutdown Light at Flt Engr Station	Auto Shutdown No Indication	110% Overspeed Switch. No Indication	Fire Pull Light Crew Entry Door Light - Flt Engr Audible - Ground Only	Manual Crew Entry Door Flt Engr
AWACS (GTC 165-6)	Auto Shutdown	Auto Shutdown - No Indication	110% Auto Shutdown		
*B-1 (GTCP 165-7)	Auto Shutdown	Auto Shutdown	110% Auto Shutdown Run Light	Auto Shutdown Audible Warning	Button, Switch
F-15 (JFS-190)					
F-16 (T-62T-40)	Auto Shutdown		110% Auto Shutdown Run Light		
F-18 (GTCP 36-200)	Auto Shutdown	Auto Shutdown	Auto Shutdown (110% 5ms)	Yes w/cockpit indication	Manual (airborne) Auto (W.O.W.)
V-22 (T-62T-46-2)	Auto shutdown with "APU FAIL" cockpit indication	Auto shutdown with "APU FAIL" cockpit indication	Auto shutdown with "APU FAIL" cockpit indication	Yes w/Auto Shutdown of APU	"FIRE SUPPRESSOR DISCHARGED" Cockpit Indication

*external controls also provided

C.3.4.3.12.2 Fuel accumulation.

Accumulation of fuel in combustion chambers due to false starts and other probable occurrences shall not cause a hazard nor result in damage to the equipment or air vehicle. Seal leakage shall be handled in accordance with the Fire and Explosion Protection requirements of (TBS) .

REQUIREMENT RATIONALE (3.4.3.12.2)

This is required to prevent injury to personnel and damage to equipment.

REQUIREMENT GUIDANCE (3.4.3.12.2)

The design should prevent accumulations of fuel in the combustion chamber from creating a hazard to equipment or the air vehicle. Accumulations from occurrences such as leaking fuel nozzles or incomplete combustion should be automatically and immediately drained from the unit.

TBS should be filled in with reference to the applicable fire and explosion section of the air vehicle specification.

REQUIREMENT LESSONS LEARNED (3.4.3.12.2)

(TBD)

C.4.4.3.12.2 Fuel accumulation.

Hazard prevention due to accumulations of fuel in combustion chambers and seal leakage shall be verified by (TBS) .

VERIFICATION RATIONALE (4.4.3.12.2)

Verification is necessary to insure that fuel is sufficiently drained from the combustion chamber so that a hazardous condition does not exist.

VERIFICATION GUIDANCE (4.4.3.12.2)

TBS should be filled in with an appropriate combination of analysis, tests, and inspections. This requirement may be verified by acceptable operation through the development program.

VERIFICATION LESSONS LEARNED (4.4.3.12.2)

(TBD)

C.3.4.3.13 APS non-operating conditions.

There shall be no APS non-operating conditions within the permissible ground and flight envelopes and environmental conditions that would damage or render the subsystem incapable of performing its required functions when commanded.

REQUIREMENT RATIONALE (3.4.3.13)

This requirement establishes criteria for non-operating performance. In many air vehicles, the APS equipment is non-operating during the majority of the flight and may be subject to such phenomena as windmilling or freezing of moisture and condensate in sensitive pneumatic control mechanisms. Proper lubrication to APU bearings and seals generally cannot be provided during windmilling. Reverse windmilling may impact starting performance or damage turbomachinery. The APS must be capable of operating properly when commanded and should not experience damage under such conditions.

REQUIREMENT GUIDANCE (3.4.3.13)

Generally, inlet and exhaust doors are provided to prevent airflow through the APU. APU windmilling should be minimized or prevented.

REQUIREMENT LESSONS LEARNED (3.4.3.13)

(TBD)

C.4.4.3.13 APS non-operating conditions.

The capability of the APS to withstand the non-operating conditions and environments shall be verified by analysis, test and demonstration.

VERIFICATION RATIONALE (4.4.3.13)

Verification is necessary to insure that damage from such conditions as windmilling does not occur.

VERIFICATION GUIDANCE (4.4.3.13)

Verification should be accomplished by:

a. Analysis of predicted installed subsystem non-operating characteristics and environments throughout the flight envelope.

b. Component and subsystem bench tests validating endurance and environmental capabilities.

c. Analysis of design and component and subsystem bench test data.

d. Air vehicle flight tests and demonstrations that validates predicted installed system non-operating characteristics and environments throughout the flight envelope, as applicable.

Windmilling characteristics can be assessed only by flight testing.

VERIFICATION LESSONS LEARNED (4.4.3.13)

(TBD)

C.3.4.3.14 Interfaces.

The interfaces between the air vehicle and the APS shall be established and controlled to allow the APS equipment and all interfacing air vehicle systems and subsystems to perform their intended functions to the extent specified within this specification and applicable supporting specifications. All APS and air vehicle interfaces shall be detailed in __(TBS)__.

REQUIREMENT RATIONALE (3.4.3.14)

This requirement is necessary to achieve proper installed integrated subsystem performance. It insures that interface requirements which can impact subsystem design performance and functionality are established up front and are not changed without the knowledge and concurrence of the interfacing subsystems. This helps preclude any change by one subsystem to that specified from impacting a second subsystem to the extent that a physical (or functional) interface becomes unsatisfactory.

REQUIREMENT GUIDANCE (3.4.3.14)

TBS: The interfaces can be shown in an ICD, or for programs that do not have an ICD, the interfaces can be put into the specification paragraph. Interface definitions that should be considered are as follow:

a. Other air vehicle subsystems interfaces:
   1. Fuel
      (a.) Physical
         (1.) Connection Type and size
         (2.) Connection loads
         (3.) Connection location
      (b.) Fuel Conditions
         (1.) Types
         (2.) Temperature (max, min)
         (3.) Viscosity (max)
         (4.) Pressure (max, min)

(5.) Flow rate (max)

(6.) Vapor Liquid Ratio (V/L) (max)

(7.) Fuel contamination (Type, Size, Quantity)

2. Electrical

(a.) Input Power

(1.) Voltage (min, max)

(2.) Current (Max)

(3.) Quality

(b.) Output Power (if applicable)

(1.) Voltage (min, max)

(2.) Current (Max)

(3.) Quality

(c.) Physical

(1.) Connector(s) type

(2.) PIN assignments

3. Hydraulic

(a) Physical

(1.) Connection type and size

(2.) Connection loads

(3.) Connection location

(b) Fluid conditions

(1.) Types

(2.) Temperature (maximum, minimum)

(3.) Viscosity (maximum)

(4.) Pressure (maximum, minimum)

(5.) Flow rate (minimum, maximum)

(6.) Fuel contamination (type, size, quantity)

4. Pneumatic

(a.) Environmental Control System interface requirements:

(1.) Connection Type and size

(2.) Connection loads (shear, moments, blow off)

(3.) Connection location

(4.) Pressure

(5.) Temperature

(6.) Flow

(7.) Contamination (See additional guidance, below.)

(b.) Other pneumatic interface requirements

5. Mechanical

(a.) Mounts

(1.) Loads

(2.) Locations

(b.) Accessory Pads (Generator(s), Hydraulic pump(s), Power Takeoff Shaft)

(1.) Direction of rotation and Speed (continuous, peak, limit)

(2.) Torque (continuous, peak, limit)

(3.) Shear loads

(4.) Weight

(5.) Over hung moments

(6.) Mass moment of inertia

(7.) Acceleration rate

(8.) Spring rates (Torsional, bending, axial, as applicable)

(9.) Envelope

(10.) Alignments

(11.) Mounting flange details

(12.) Spline details (Style, size, loading, concentricity, lubrication)

(13.) Lubrication interface requirements (Physical, flow, temperature)

(14.) Materials

(15.) Anti-rotation pin tolerances

(16.) Duty cycle

6. Vehicle Management System Interface

(a.) Communication port definition

(b.) Signal or Word definitions

7. Thermal

(a.) Heat rejection from lube system

(b.) Heat rejection to bay

(c.) Bay temperature (max, min)

8. Lubrication system interface

(a.) Physical (Location, size, loads)

(b.) Pressures (Pressure drops, peaks/pulsation, scavenging pressurization)

(c.) Contamination and filtration levels

9. Envelope

b. Propulsion system interfaces

c. Non airframe peculiar auxiliary power system physical and functional interfaces:

1. Ground support equipment

2. Other

d. The conducted and radiated magnetic and electronic interface limits

Interface control documents and drawings should be prepared. Deviations from the required interfaces should be approved by all parties. Standard mount pads, fittings, and such, should be used. Refer to APS Defense Specifications for additional information. For air vehicle, engine, and accessory drive and flange standards, refer to the industry standard SAE AIR1160 and the legacy Air Force-Navy Aeronautical Design Standard AND10230 for additional information.

Ground power sources available at the specified operational bases should be considered (refer to legacy Industry Standard SAE AS44).

For interface with the ECS, APS-generated substances contained in the bleed air that may be used for cabin air conditioning should be within the threshold limit values specified in table C-II.

The bleed air should not contain a total of more than 5.0 mg (0.3 lbm x 10^{-6}) of engine generated particles per m^3 (ft^3) of bleed air.

REQUIREMENT LESSONS LEARNED (3.4.3.14)

(TBD)

C.4.4.3.14 Interfaces.

Interface requirements shall be verified by: __(TBS)__.

VERIFICATION RATIONALE (4.4.3.14)

Verification is needed to insure the compatibility of controlled interface such as, airframe and non-airframe supplied equipment, with the auxiliary power subsystem.

TABLE C-II. Threshold limit values.

SUBSTANCE	PARTS PER MILLION
Carbon dioxide	5000.0
Carbon monoxide	50.0
Ethanol	1000.0
Fluorine (as HF)	0.1
Hydrogen peroxide	1.0
Aviation fuels	250.0
Methyl alcohol	200.0
Methyl bromide	20.0
Nitrogen oxides	5.0
Acrolein	0.1
Oil breakdown products (for example, aldehydes)	1.0
Ozone	0.05

VERIFICATION GUIDANCE (4.4.3.14)

"TBS" should be filled in by disclosing the progressive method(s) that should be used for verification. Past verification methods have included inspection, analysis, demonstrations and tests. Test, demonstration, or both should typically be necessary since an analysis may not reveal all possible problems. Verification that all interfaces are established and controlled should be by inspection of applicable documents. Analyses may be used for conditions that may not be adequately demonstrated or tested. The compatibility of interfaces should be verified by test and demonstration throughout the air vehicle and engine development program.

For sophisticated subsystems, a separate integration test is recommended to avoid costly changes and schedule delays that could be encountered by waiting to perform an air vehicle verification.

VERIFICATION LESSONS LEARNED (4.4.3.14)

For the B-1, complete nacelle simulator (2 engines, 2 remote gearboxes, APU and associated drive equipment) testing was accomplished prior to first flight and precluded potential delay to the program. The F-15 and F-16 APS integrated laboratory testing was also conducted prior to first flight. The requirement to conduct integration testing depends upon the development schedule and the complexity of the APS.

C.5 PACKAGING

C.5.1 Packaging.

For acquisition purposes, the packaging requirements shall be as specified in the contract or order (see 6.2). When packaging of materiel is to be performed by DoD or in-house contractor personnel, these personnel need to contact the responsible packaging activity to ascertain packaging requirements. Packaging requirements are maintained by the Inventory Control Point's packaging activities within the Military Service or Defense Agency, or within the military service's system commands. Packaging data retrieval is available from the managing Military Department’s or Defense Agency's automated packaging files, CD-ROM products, or by contacting the responsible packaging activity.

C.6 NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

C.6.1 Intended use.

The auxiliary power subsystem descriptions in this appendix are intended for use in air vehicle systems developed to perform combat and combat-support missions in environments unique to military weapon systems.

C.6.2 Acquisition requirements.

Acquisition documents should specify the following:

a. Title, number, and date of the specification.

C.6.3 Acronyms.

The following list contains the acronyms/abbreviations contained within this document.

APS	Auxiliary Power Subsystem
EGT	Exhaust Gas Temperature
ICD	Interface Control Document
JFS	Jet Fuel Starter
RPM	Revolutions Per Minute
WOW	Weight On Wheels

C.6.4 Subject term (key word) listing.

Engine

Exhaust

Fuel

Power

C.6.5 International standardization agreement implementation.

This specification implements STANAG 3372, Low Pressure Air and Associated Electrical Connections for Aircraft Engine Starting. When amendment, revision, or cancellation of this specification is proposed, the preparing activity must coordinate the action with the U.S. National Point of Contact for the international standardization agreement, as identified in the ASSIST database at https://assist.dla.mil/online/start.

C.6.6 Responsible engineering office.

The office responsible for the development and technical maintenance of this appendix is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL. Requests for additional information on this appendix can be obtained from AFLCMC/ENRS, BLDG 28 RM 118, 2145 MONAHAN WAY, WPAFB OH 45433-7017 USA; DSN 674-5476; COMMERCIAL (937) 904-5476; ENGINEERING.STANDARDS@US.AF.MIL.

C.6.7 Amendment notations.

The margins of this specification are marked with vertical lines to indicate modifications generated by this amendment. This was done as a convenience only and the Government assumes no liability whatsoever for any inaccuracies in these notations. Bidders and contractors are cautioned to evaluate the requirements of this document based on the entire content irrespective of the marginal notations.

APPENDIX D

AIR VEHICLE ENVIRONMENTAL CONTROL SUBSYSTEM

REQUIREMENTS AND GUIDANCE

D.1 SCOPE

D.1.1 Scope.

This appendix provides the requirements, verifications, tailoring guidance, and background information for the Environmental Control Subsystem provided for in Part 1 of this specification. The appendix has been developed and coordinated by technical personnel from the Air Force, Navy, and Army and has been approved as an official guide for use by Government personnel for assistance in tailoring the air vehicle subsystems specification for acquisition and model specifications. This appendix is a mandatory part of the specification. The information contained herein is intended for compliance.

D.1.2 Structure.

The appendix structure replicates the structure of the Air Vehicle Subsystems Specification except it places each corresponding section 3 requirement and section 4 verification together.

D.1.3 Appendix.

This appendix provides tailoring guidance and background information for individual paragraphs of the Air Vehicle Subsystems Specification. Guidance gives recommendations on how to tailor the specification paragraph. Where __(TBS)__ appears, the guidance paragraph provides recommended values or text that the using service may use to insert in the __(TBS)__. When contractors are expected to complete the __(TBS)__, the Guidance paragraph will so state. The Using Service makes the final decision on whom completes the __(TBS)__ in the specification. Finally, Lessons Learned are provided to give insight to past events that could impact the tailoring of the specification.

D.1.4 Deviations.

Projected designs for given applications which will result in improvement of the system performance, reduced life cycle cost, or reduced developmental cost through deviations from this guidance, or where requirements of the specification results in compromise in operational capability, should be brought to the attention of the using service.

D.1.5 Environmental impact.

Air Vehicle Subsystems will be designed such that their operation, maintenance, and repair may be accomplished without violating the most stringent environmental regulations applicable to locations where subsystems are used or supported. Compliance with environmental regulations will not prevent subsystems from achieving and sustaining mission performance capability. Materials, processes, and environmental control equipment necessary to meet these environmental requirements must currently be available in the Using Service's maintenance and supply system. The design will not use environmentally unsuitable materials such as ozone depleting fluorocarbons, chlorofluorocarbons, and halons, or highly volatile organic compounds in solvents and coatings during development, production, operation, maintenance, or repair. The Environmental Protection Agency maintains an online list of toxic chemicals and hazardous substances on its Ozone Layer Depletion Website at http://www.epa.gov/ozone/snap/ that should be consulted. The Significant New Alternatives Policy (SNAP) Program available thereon identifies substitutes for ozone depleting chemicals.

The contractor will conduct an environmental analysis of air vehicle subsystems.

D.1.6 Responsible engineering office.

The responsible engineering office (REO) for this appendix is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL.

D.2 APPLICABLE DOCUMENTS

D.2.1 General.

The documents listed in this section are specified in sections 3 and 4 of this handbook. This section does not include documents cited in other sections of this guide specification or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3 and 4 of this handbook, whether or not they are listed.

D.2.2 Government documents

D.2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this appendix to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

INTERNATIONAL STANDARDIZATION AGREEMENTS

NORTH ATLANTIC TREATY ORGANIZATION

STANAG 3208	Air Conditioning Connections

STANAG 3212	Diameters for Gravity Filling Orifices
STANAG 3315	Aircraft Cabin Pressurizing Test Connections
STANAG 3372	Low Pressure Air and Associated Electrical Connections for Aircraft Engine Starting

(Copies of these documents are available at http://quicksearch.dla.mil, http://nso.nato.int, and www.ihs.com to qualified users.)

DEPARTMENT OF DEFENSE SPECIFICATIONS

MIL-PRF-7808	Lubricating Oil, Aircraft Turbine Engine, Synthetic Base
MIL-PRF-23699	Lubricating Oil, Aircraft Turbine Engine, Synthetic Base, NATO Code Numbers: O-152, O-154, O-156, and O-167

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-464	Electromagnetic Environmental Effects Requirements for Systems
MIL-STD-810	Environmental Engineering Considerations and Laboratory Tests
MIL-STD-1472	Human Engineering
MIL-STD-2218	Thermal Design, Analysis, and Test Procedures for Airborne Electronic Equipment
MS33561	Connection, Aircraft Ground Air Conditioning, 5 Inch, Minimum Requirements
MS33562	Connection, Aircraft Ground Air Conditioning, 8 Inch
MS33740	Nipple, Pneumatic Starting, 3-inch ID, Outline Dimensions of

DEPARTMENT OF DEFENSE HANDBOOKS

MIL-HDBK-221	Fire Protection Design Handbook for U.S. Navy Aircraft Powered by Turbine Engines
MIL-HDBK-310	Global Climatic Data for Developing Military Products
MIL-HDBK-454	Electronic Equipment, General Guidelines for
MIL-HDBK-5400	Electronic Equipment, Airborne, General Guidelines for

(Copies of these documents are available online at http://quicksearch.dla.mil or from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia PA 19111-5094 USA.)

D.2.2.2 Other Government documents, drawings, and publications.

The following other Government documents, drawings, and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

USAF MANUAL

AFMAN 48-155	Occupational and Environmental Health Exposure Controls

(Copies of this document are available at www.e-publishing.af.mil to qualified users.)

USAF TECHNICAL ORDER

TO 42D4-1-4	Rain Repellent for Application to Windshields—All Aircraft

(Copies of this document are available at http://www.tinker.af.mil/technicalorders/index.asp to qualified users.)

FEDERAL AVIATION ADMINISTRATION

FAA Report DOT/FAA/CT-88	Aircraft Icing Handbook, Volumes 1-3

(Copies of this document are available at www.dtic.mil to qualified users; the Defense Technical Information Center (DTIC), 8725 John J. Kingman Rd., Suite 0944, Ft. Belvoir VA 22060-6218 USA); and from www.ntis.gov; the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield VA 22161-2103 USA.)

D.2.3 Non-Government publications.

The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

SAE INTERNATIONAL

SAE AIR1102	Transparent Area Washing Systems for Aircraft
SAE AIR1204	Control of Water Carryover from the Environmental Control System and Condensation on the Structure
SAE AIR1277	Cooling of Military Airborne Electronic Equipment
SAE AIR1539	Environmental Control System Contamination
SAE AIR1609	Aircraft Humidification
SAE AIR1667	Rotor Blade Electro Thermal Ice Protection Design Considerations
SAE AIR1811	Liquid Cooling Systems

SAE AIR4766/2	Airborne Chemicals in Aircraft Cabins
SAE-AMS-I-7171	Insulation Blanket, Thermal-Acoustical
SAE ARP85	Air Conditioning Systems for Subsonic Airplanes
SAE ARP699	High Temperature Pneumatic Duct Systems for Aircraft
SAE ARP731	General Requirements for Application of Vapor Cycle Refrigeration Systems for Aircraft
SAE ARP986	Guide for Qualification Testing of Aircraft Air Valves
SAE ARP1270	Aircraft Cabin Pressurization Control Criteria
SAE ARP1796	Engine Bleed Air Systems for Aircraft
SAE AS4073	Air Cycle Air Conditioning Systems for Military Air Vehicles
SAE AS5498	Minimum Operational Performance Specification for In-flight Icing Detection Systems
SAE AS6882	Water Repellent, Window and Windshield, Glass and Plastic

(Copies of these documents are available from www.ihs.com to qualified users, and from www.sae.org; SAE International, 400 Commonwealth Drive, Warrendale PA 15096-0001 USA.)

D.2.4 Order of precedence.

Unless otherwise noted herein or in the contract, in the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

D.2.5 Streamlining.

The Air Vehicle Subsystems Specification has been streamlined. The documents listed in this appendix which are required for acquisition have the same status as those referenced directly in section 2 (first tier). All other documents referenced through tiering may be used for guidance and information only.

D.3 REQUIREMENTS

D.4 VERIFICATIONS

D.3.1 Definition

D.4.1 Definition

D.3.2 Characteristics

D.4.2 Characteristics

D.3.3 Design and construction

D.4.3 Design and construction

D.3.4 Subsystem characteristics

D.4.4 Subsystem characteristics

D.3.4.1 Landing subsystem

D.4.4.1 Landing subsystem

D.3.4.2 Hydraulic subsystem

D.4.4.2 Hydraulic subsystem

D.3.4.3 Auxiliary power subsystem

D.4.4.3 Auxiliary power subsystem

D.3.4.4 Environmental control subsystem.

The environmental control subsystem (ECS) provides temperature, humidity, ventilation, and pressure control to occupied spaces, equipment, and airframe. The system must be able to provide this control under any flight or ground condition of the air vehicle in any environment in which the air vehicle is intended to operate. Critical viewing areas of air vehicle transparencies are maintained clear of dirt, rain, ice and fog as required to meet air vehicle safety and mission requirements. Power is extracted to operate the system. Air is conditioned to meet occupied compartment needs and possibly to perform other functions. This air may be from internal (engine or auxiliary power unit (APU)) or external (ground cart) sources or an ECS dedicated compressor(s). Other fluids may be conditioned as required by air vehicle needs. Heat is rejected overboard normally through the use of a heat sink. The temperature of the heat sink needs to be controlled to meet air vehicle mission, airworthiness, and safety requirements. Functions may include, but are not limited to: pressurization heating, cooling, ventilating, moisture control, bleed air systems, ram air supply, pressure and anti-g suit control, defogging, defrosting, anti-icing, rain removal, windshield washing, electronic and electrical thermal management, heat sink thermal management, and boundary layer control.

REQUIREMENT RATIONALE (3.4.4)

The environmental control subsystem provides a safe and comfortable environment for the crew and provides the required environment necessary for proper air vehicle operation and surface integrity. This permits the successful completion of the mission without loss of personnel or air vehicle.

REQUIREMENT GUIDANCE (3.4.4)

The air vehicle mission(s) should be analyzed to design the ECS to its expected percentage usage in identified environments. Sufficient ECS capacity should be available for all known conditions, including:

a. Ground operations
b. Taxi, takeoff, and landing
c. All flight attitudes within structural limitations
d. Zero gravity or negative gravity
e. All altitudes within the flight envelope
f. Structural deflection
g. Loss of engine propulsive power
h. Emergency operation.

When used, air cycle systems, including cabin pressurization control valves, should be in accordance with SAE AS4073. The equipment design requirements of section 5 of SAE ARP85 should also be applied. Vapor cycle system should comply with paragraph 3.5, Failure Protection and Safety, of SAE ARP731. The SAE ARP731 was prepared by a technical specialist in vapor cycle systems with many years of experience with military and commercial systems and is strongly recommended for the establishment of requirements for vapor cycle refrigeration system. These systems were not widely used until recently on military air vehicles; therefore, there are not many military guidelines on them.

The following recommendations should be considered for specifying vapor cycle systems:

a. Suction pressure should not be greater than 14.7 psia (10.1 kPa) for charging.

b. Compressors, especially centrifugal ones, should be hermetically sealed. This can be accomplished by integrating motor with compressor or using a magnetic drive.

A systems engineering approach is helpful in achieving proper integration of the environmental control, environmental protection, and engine bleed air provisions.

REQUIREMENT LESSONS LEARNED (3.4.4)

(TBD)

D.4.4.4 Environmental control subsystem.

Verification shall encompass planning, procedure preparation, and reporting, and shall be accomplished incrementally by inspection, analysis, similarity, demonstration, or test, or a combination of these methods.

VERIFICATION RATIONALE (4.4.4)

Verification is required to assure that performance interface and functional requirements are met.

VERIFICATION GUIDANCE (4.4.4)

Operating performance should be shown by appropriate laboratory and subsystem tests, and applicable ground, taxi and flight tests. Pass criteria are based on successfully meeting all test objectives.

For Army rotary-wing air vehicles, system design and performance analysis should use Aeronautical Design Standard ADS-9C, available from the US Army Materiel Command at www.redstone.army.mil, as a guide.

Testing should also be accomplished and should consider the following guidelines.

a. If the cockpit is not simulated (not geometrically similar and does not have the distribution ducting of the air vehicle) during laboratory testing then the air vehicle cockpit should be instrumented with thermocouples capable of recording the dry bulb temperature located at the crewmember's head, torso, and foot levels. These thermocouples should be the basis for demonstrating that the required cockpit temperatures are achieved. Furthermore, the Globe Temperature should also be measured in the presence of maximum solar radiation, and the recorded value should be extrapolated to the design condition as required.

b. The cockpit should also be instrumented to record the wet bulb temperature in the vicinity of the crew member(s). These temperatures should be used as required to demonstrate that the cockpit environment is maintained as required.

c. Laboratory testing should include all aspects of the ECS. This includes, but is not necessarily limited to:

   1. the bleed air ducting, valves, and heat exchangers
   2. the refrigeration package which includes the heat exchangers, valves, air cycle machine or vapor compressor, sensors, interconnecting ducting, simulated ram air scoops, and controller
   3. the nuclear, biological, and chemical contamination (NBC) control subsystem components
   4. components comprising the Microclimate cooling of crewmembers wearing NBC protective gear
   5. the distribution ducting down to the equipment interface. The cockpit distribution ducting need not be included, but the cockpit volume and the cockpit distribution ducting pressure drop should be simulated.

The laboratory system test rig described above is necessary for a variety of reasons. It is the chief means to show that the ECS has the required heating and cooling capacity; it is used to demonstrate that the software control algorithms properly function and the ECS can be controlled safely; it is used to uncover and investigate control and design problems; and it is used to demonstrate NBC requirement compliance.

VERIFICATION LESSONS LEARNED (4.4.4)

(TBD)

D.3.4.4.1 Pressurization.

The environmental control subsystem shall provide pressurization to all compartments, bays, and equipment requiring a pressure controlled environment.

REQUIREMENT RATIONALE (3.4.4.1)

The total barometric pressure and the oxygen partial pressure in the environment are prime considerations for the design of pressurization systems. Eight thousand feet is the maximum altitude for prolonged flights without undue fatigue from mild hypoxia. Ten thousand feet is the threshold for increasingly severe hypoxia, and is the maximum without supplemental oxygen. Twenty thousand feet is the threshold for occasional symptoms of decompression sickness including abdominal gas pains.

REQUIREMENT GUIDANCE (3.4.4.1)

Pressurization systems should be used for manned air vehicles flying above 20,000 ft to avoid these physiological problems and those that occur at higher altitudes. In addition, the use of supplemental oxygen should be considered for any air vehicle where the cabin pressure exceeds 8,000 ft.

In this paragraph, the compartments that will require pressurization should be specified. This paragraph should be deleted for unmanned vehicles or vehicles with a service ceiling below 20,000 ft. and which do not require positive pressure for NBC protection.

REQUIREMENT LESSONS LEARNED (3.4.4.1)

(TBD)

D.4.4.4.1 Pressurization.

The capability of the environmental control subsystem to provide pressurization to all compartments, bays, and equipment as required shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.4.1)

Verification is necessary to ensure the ECS is capable of providing pressurization to the compartments, bays, and equipment as required.

VERIFICATION GUIDANCE (4.4.4.1)

TBS should be filled in with engineering analyses, demonstrations, and flight tests.

All measurements of rate of pressure change should be done to a standard. The worst (highest) slope should be taken over a 1-sec interval (□P/sec).

Laboratory tests may be useful to ensure there is no undesirable interaction between the regulators before proceeding to the flight test.

For pressure measurements, all pressure taps should be located so as to minimize the effect of turbulence caused by valves, elbows, or orifices in the system, and to determine all pressures required for a complete evaluation of system operation.

If the air vehicle fuselage or any equipment bay is pressurized, the ability to pressurize the volume to the required level should be demonstrated by testing, and the testing should show that the required pressure level is achieved with the design air flow-rate. Furthermore, if the air used to pressurize the fuselage or equipment is collected internally to the air vehicle structure and routed to a single or various destinations for added cooling of equipment, the contractor should demonstrate, by test, that the required amount of air (1.6 times the amount required for cooling the destination avionics or equipment) is provided. The factor 1.6 is used to compensate for development of in-service leakage.

VERIFICATION LESSONS LEARNED (4.4.4.1)

(TBD)

D.3.4.4.1.1 Occupied compartment pressure schedule.

The environmental control subsystem shall automatically maintain the following nominal pressure schedule: __(TBS 1)__. The environmental control subsystem shall maintain this nominal pressure schedule within __(TBS 2)__.

REQUIREMENT RATIONALE (3.4.4.1.1)

Pressure schedules are specified to minimize the discomfort (due to pressure changes) to the crew and passengers, and to prevent hypoxia. The pressurization system must be capable of reacting quickly to changes in flight conditions, air conditioning flow rates, and such, to maintain the pressure schedule and avoid annoying or painful pressure bumps. This function can be accomplished only by a fast acting, automatic system.

REQUIREMENT GUIDANCE (3.4.4.1.1)

Pressurization system requirements should be established based upon minimum physiological limitations. Environmental thresholds and physiological limitations used in establishing the pressurization system requirements should be considered by the project engineer when completing those portions where the requirements are dependent upon the mission of the air system under consideration. (SAE ARP1270 is an excellent reference and provides guidelines to the pertinent technology relative to the physiological considerations, technical system requirements, and design objectives for air vehicle pressurization control systems.)

TBS 1: The engineer should select the type of schedule to be specified, based upon the mission and operational requirements of the air vehicle. For combat and combat trainer air vehicles, the desired pressure schedule is unpressurized for sea level to 8,000 ft, and then 8,000 ft isobaric to the operational ceiling. For high performance, high altitude fighter or interceptor-type air vehicles, a substantial weight increase can be incurred by maintaining an 8,000-ft pressure schedule to the operational ceiling of the air vehicle. This weight increase is due to the additional structure incurred by the high differential pressures. In these cases, a 5-psi differential pressure schedule above 23,000 ft is typically used. (See figure D-1.) Selection of pressure schedule should be closely coordinated with oxygen system engineers to ensure crew always has an acceptable breathing environment. The 5-psi differential is usually chosen since it will maintain the cabin pressure below 30,000 ft—the threshold for high incidence of decompression sickness. Other differential pressure schedules may be chosen depending upon the cabin pressure requirements of the system under consideration. This type of schedule generally imposes the minimum penalty on the air vehicle and meets the minimum physiological requirements. If an NBC collective protection system is to be used, the pressure schedule will need to be modified to maintain a differential pressure at sea level. The absolute pressure should be greater than the maximum external pressure on the air vehicle skin. This pressure should be relieved prior to crew exit to prevent damage and injury.

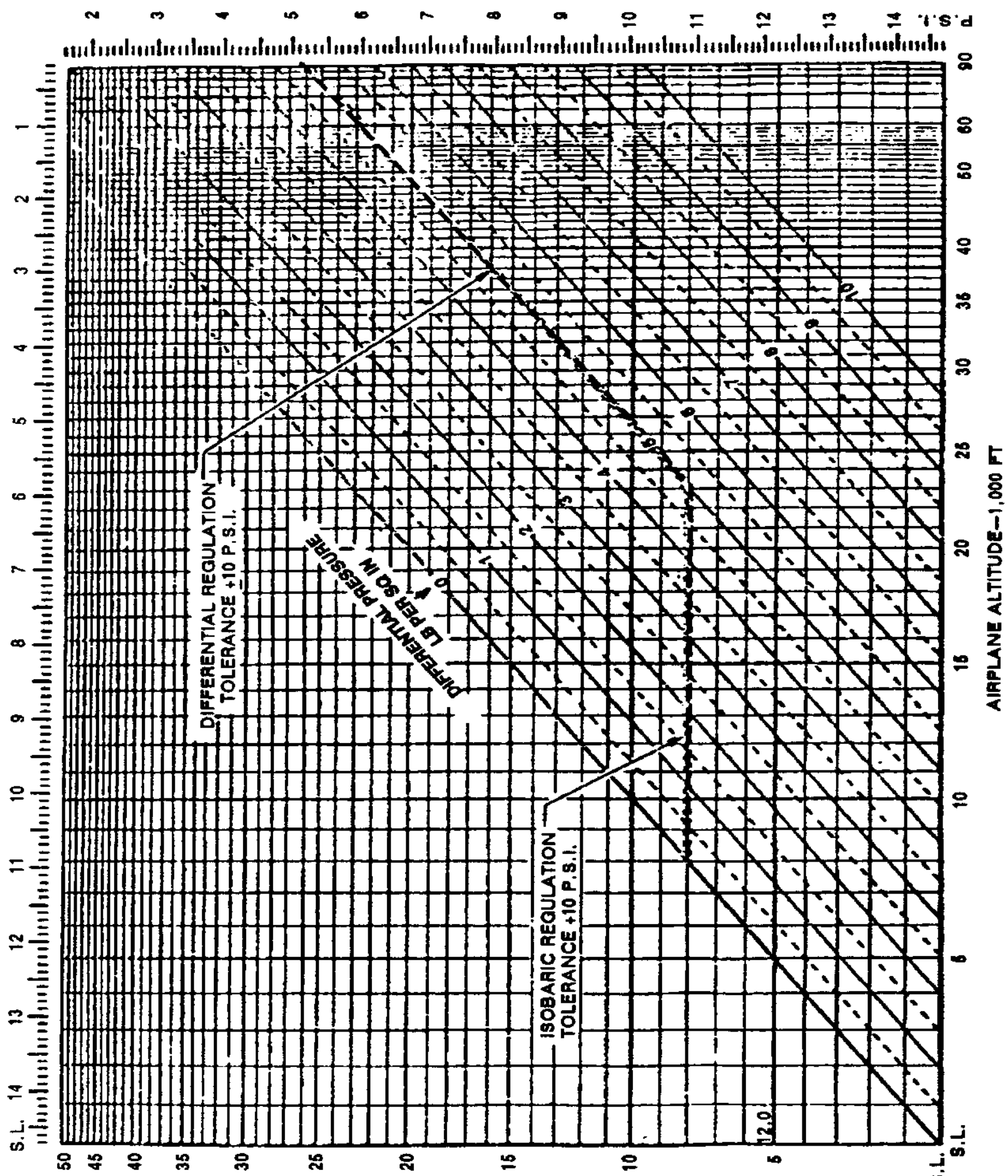

FIGURE D-1. Cabin pressure for combat air vehicles.

For non-combat air vehicles, a pressurization system that allows the crew to select any cabin altitude between -1,000 and +10,000 ft is desirable. The maximum altitude chosen is 10,000 ft, as oxygen systems are generally not desired or provided (except for emergency use). This system is particularly applicable for air vehicles that frequently carry personnel who are not regular crewmembers, as discomfort can be minimized by selecting the schedule that minimizes changes in cabin altitude. Air vehicles operating at or near sea level cabin pressures with this system can be used to transport patients suffering from medical conditions where a decrease in environmental pressure could be serious or even fatal. Pressurization systems for air vehicles with this type of schedule are usually designed for cabin pressure differentials of 8 to 9 psi. The maximum differential is established as that differential required to maintain an 8,000-ft cabin altitude at the maximum cruise altitude of the air vehicle. If an NBC collective protection system is to be used, the pressure schedule will need to be modified to maintain a differential pressure at sea level. The differential pressure should be greater than the maximum external pressure on the air vehicle skin. Means need to be incorporated to relieve this pressure prior to crew exit without causing discomfort in the ears.

As an example, assuming a maximum cruise altitude of 45,000 ft, the maximum differential is found to be 8.75 psi when the intersection of the 8,000-ft cabin altitude line with the 45,000-ft airplane altitude line is referenced on figure D-1. The system would then be designed to maintain a sea-level cabin altitude up to an airplane altitude of about 23,000 ft and then would follow the 8.75 psi differential to the operational ceiling. Any cabin altitude between -1,000 and +10,000 ft could be chosen by the crew and would be maintained up to the 8.75 psi differential. To summarize, this type of pressurization system is normally used for air vehicles with the following mission requirements:

a. The continuous use of oxygen is impractical or undesirable.

b. The air vehicle will be used for medical evacuation.

c. The air vehicle will frequently carry non-crewmember personnel.

Air vehicles such as rotorcraft that require pressurization only to meet NBC protection requirements should have their pressurization schedule set high enough that he external air pressure on the skin of the air vehicle is always less than the occupied compartment air pressure. If an NBC collective protection system is to be used, the pressure schedule will need to be modified to maintain a differential pressure at sea level. The absolute pressure should be greater than the maximum external pressure on the skin of the air vehicle. This pressure should be relieved prior to crew exit to prevent discomfort in the ears, personal injury, or structural damage.

Special mission requirements may require maintenance of different compartment pressures within the air vehicle. In these cases, a separate pressure regulator should be installed in each portion of the air vehicle where pressure can be maintained independently, and where safety measures (over pressure protection, decompression, and such) are provided.

TBS 2 should be filled in with a tolerance value at which the pressure schedule is maintained. The pressurization system should be designed to follow the pressure schedule within reasonable limits. Closer tolerances are possible in the pressurized range than in the unpressurized range. The normally accepted tolerances are 0.2 psi in the pressurized range and from 0.0 to 0.5 psi in the unpressurized range. The tolerances in the pressurized range are mainly a function of the design of the overall system—both the automatic control and the provisions incorporated upstream in the environmental control subsystem to minimize or prevent excessive changes in flow rate. Therefore, a tolerance of 0.2 psi in the pressurized range is easily attainable in a properly designed system, and is selected so any pressure variations due to the dynamic design of the pressurization system (overshoot, steady-state error, under-damped response, and such) are small enough that they are unnoticeable and therefore not distracting or annoying to the crew. In the unpressurized range, the tolerance is generally a function of flow path for the outflow valve (or cabin) to overboard. The more complex the path (such as using cabin exhaust for equipment cooling and then dumping it overboard), the higher the unpressurized cabin steady-state pressure (and therefore higher tolerance). The maximum tolerance in the unpressurized range is usually 0.5 psi. Negative pressure differentials are easily avoidable, and the lower tolerance limit is usually 0.0 psi.

REQUIREMENT LESSONS LEARNED (3.4.4.1.1)

Relaxation of pressure schedule requirements has been deemed appropriate for certain air vehicles that did not have mission requirements necessitating prolonged flight at high altitudes. For example, significant cabin structural and canopy weight was saved on the A-10 air vehicle by allowing the air vehicle to be unpressurized up to 10,000 ft, isobaric 10,000 ft cabin to 18,000 ft flight altitude, and then maintain a 2.75 psi differential up to the service ceiling of 40,000 ft, which corresponds to a 25,000 ft cabin altitude.

Pressure schedules have been referenced to ambient pressure but have not accounted for fluctuations encountered in measuring the ambient pressure. The measuring equipment and bays have been susceptible to pressure variations which should have been taken into account. For example, the F-15 pressure regulator sensed its reference pressure in a bay which was typically 0.3 psi above ambient. Therefore, in an effort to use off-the-shelf pressure regulators, the differential control pressure was 5.3 psi in lieu of 5.0 psi.

D.4.4.4.1.1 Occupied compartment pressure schedule.

Engineering analyses and flight tests shall be conducted to verify the pressure schedule and tolerance requirements for occupied compartments. The analyses shall consider the operating condition with the least air inflow to the cockpit or that condition for which the required pressurization is the most difficult to achieve. Flight tests shall be made at high and low altitudes and speeds throughout the flight envelope. Transient conditions shall include ground static, taxi, takeoff, slow and rapid climbs and dives, accelerations, rapid throttle bursts, maneuvers, and landings. Steady-state conditions shall include both high and low altitudes and speeds.

VERIFICATION RATIONALE (4.4.4.1.1)

While some requirements can be verified by engineering analysis, certain pressurization requirements and system performance can be verified only by flight testing. The dynamic response and interaction of the engine bleed system, pressurization system, and flight conditions cannot be simulated in the laboratory. Flight tests for both steady-state and transient conditions are required, with particular emphasis on the transient conditions where pressurization problems are most frequently encountered.

VERIFICATION GUIDANCE (4.4.4.1.1)

Established crew station interfaces should be listed here for verification. If a warning of system abnormality is provided, flight testing should demonstrate that the warning activates at the correct time.

Flight testing for pressure transients should include any possible changes in system operating modes and the actuation of all applicable valves and system controls to uncover any interactions between components that could generate excessive transients.

Although flight testing is the generally preferred method of verification, analysis is sufficient for requirements difficult to safely verify in flight, such as the effects of pressure source failure.

VERIFICATION LESSONS LEARNED (4.4.4.1.1)

During rapid throttle bursts, use maneuvers which cannot be misunderstood when finally documented in an updated to flight test analysis. In F-5F pressurization flight tests, the pilots used a MIL-IDLE-MIL throttle burst that resulted in a large tolerance in the schedule and was considered realistic. However, for formal documentation purposes (updated to flight test analysis), the contractor used a MIL-MINIMUM POWER SETTING TO MAINTAIN LEVEL FLIGHT-MIL burst that resulted in a smaller (tighter) tolerance in the schedule and looked better contractually.

D.3.4.4.1.2 Unoccupied compartment, bay, and equipment pressure schedules.

The environmental control subsystem shall provide pressurization or pressurized air for (TBS 1) and automatically maintain the following nominal pressure schedule: (TBS 2). The environmental control subsystem shall maintain this nominal pressure schedule within (TBS 3).

REQUIREMENT RATIONALE (3.4.4.1.2)

Depending upon the operational needs of the air vehicle, equipment compartment, or other pressurization requirements may be specified.

REQUIREMENT GUIDANCE (3.4.4.1.2)

TBS 1 should be filled in by identifying the compartments, equipment, and subsystems that will require pressurization or pressurized air from the ECS. The following should be considered.

a. Equipment compartments. Equipment compartments that are separate from pressurized, occupied compartments may need to be pressurized for proper equipment operation. Coordination with other engineering areas is necessary to determine if pressurization is required or desirable. Trade studies may be necessary to evaluate the impact of pressurized compartments on life cycle cost to aid in the design approach if pressurization is required or is considered a possible design approach of the potential contractors. The following requirements should be considered and included, as appropriate:

    1. Compartment pressure should be regulated automatically.

2. If the pressure schedule is not specified, it should be compatible with the most critical unit contained within the compartment.
3. Safety valves or other provisions should be provided for positive and negative pressure relief, as required by structural considerations.
4. Protection against air vehicle damage due to decompression should be provided.
5. Provisions to protect against detrimental residual pressure differentials should be provided, as necessary.
6. The pressurization system should be designed to allow for in-service leakage rates of 1.6 times the production leakage rates.
7. The pressurization medium should be supplied at temperature, moisture, and contamination levels compatible with the equipment specifications. Multiple sources may be required based upon the equipment requirements and emergency capabilities desired.
8. Instruments to indicate loss of equipment pressurization to the crew may be required.
9. Design failure modes may need to be specified.
10. Provisions to test the pressurization system and compartment leakage should be provided. These requirements are similar to those for occupied compartments and are based on the same rationale. Other requirements, depending upon unique requirements of the air vehicle under consideration, may also be needed.

b. Equipment pressurization. Some pieces of equipment require internal pressurization from an external source. Those requirements should be included here. The engineer should work closely with the avionics engineers to establish the pressurization requirements to complete this requirement. The following is provided as a guide to establishing the appropriate requirements:

1. The air should be supplied at pressure, moisture, and contamination levels compatible with the equipment specification.
2. Pressure relief provisions to prevent overpressurization of the equipment should be provided.
3. When two or more units are pressurized by the same source, loss of pressurization by one should not cause loss of pressurization to the other units.
4. Provisions that allow ground checkout of pressure regulators, relief provisions, and system leakage should be incorporated.
5. Test fittings should be in accordance with an equivalent to the legacy Military Standard MS33565. A detailed description of the test fittings (dimensions, general characteristics) is contained in that standard.
6. Consideration should be given to providing a means for indicating loss of equipment pressurization to the crewmembers.

c. Subsystems. Other pressurization requirements, such as on-board oxygen generating system (OBOGS), on-board inert gas generating system (OBIGGS), hydraulic reservoir canopy seal or fuel pressurization, can be included here, as appropriate, with consideration given to the various requirements discussed above under equipment compartments and equipment pressurization.

TBS 2 should be filled in with the appropriate pressure schedule for the identified compartments, equipment, and subsystems.

TBS 3 should be filled in with the appropriated tolerance for maintaining the identified pressure schedule.

REQUIREMENT LESSONS LEARNED (3.4.4.1.2)

(TBD)

D.4.4.4.1.2 Unoccupied compartment, bay, and equipment pressure schedules.

The capability of the ECS to provide pressurization for the identified compartments, equipment, and subsystem at the required schedule and level of tolerance shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.4.1.2)

Verification is necessary to ensure that the ECS has the capability to provided pressurization to the proper locations at the required schedule and level of tolerance.

VERIFICATION GUIDANCE (4.4.4.1.2)

TBS: Flight tests should be conducted to verify the pressure schedule and tolerance requirements for unoccupied compartments. Flight tests should be made at high and low altitudes and speeds throughout the flight envelope. Transient conditions should include ground static, taxi, takeoff, slow and rapid climbs and dives, accelerations, rapid throttle bursts, maneuvers, and landings. Steady-state conditions should include both high and low altitudes and speeds.

The requirements should be verified by cost effective method. In general, pressurization system performance can be properly verified only by flight test. However, some aspects can be verified by analysis, laboratory and air vehicle ground test, and inspection. Flight test costs can also be reduced by performing the tests concurrent with other tests.

VERIFICATION LESSONS LEARNED (4.4.4.1.2)

(TBD)

D.3.4.4.1.3 Rate of occupied compartment pressure change.

The rates of change of pressure in all occupied compartments shall be controlled within the following limits:

a. The maximum rate of pressure change under all normal operating conditions, including transients, shall be __(TBS 1)__.

b. The capability shall be provided to select and control automatically a pressure change rate anywhere in the range of __(TBS 2)__.

c. For emergency pressure release, the maximum rate of pressure decrease shall be __(TBS 3)__.

d. For emergency repressurization, the maximum rate of pressure increase shall be __(TBS 4)__.

REQUIREMENT RATIONALE (3.4.4.1.3)

Pressure regulation, particularly the rate of pressure change, is based on the ability of the ear to compensate for pressure changes. The objective of this requirement is to ensure pressure bumps (short duration cabin pressure changes) and pressure changes (due to flight altitude changes or schedule changes) are regulated to prevent or minimize crew and passenger discomfort.

REQUIREMENT GUIDANCE (3.4.4.1.3)

TBS 1 should be filled in with the value for the rate of change of pressure.

TBS 2 should be filled in with the value of an acceptable range in which the pressure change rate can be selected and automatically controlled.

These values should be based on physiological data that suggest the average person can compensate for increasing pressure rate changes as high as 0.2 psi/sec without conscious effort. For rates greater than 0.2 psi/sec, some conscious effort is required to maintain equilibrium, and for rates 0.5 psi/sec and higher, discomfort is experienced even by experienced crewmembers while attempting to maintain equilibrium across the eardrum. Therefore, 0.2 psi/sec is typically the maximum acceptable rate of pressure change for normal operation. This includes all transient conditions.

The body is more tolerant to decreasing pressures and the 1.0 psi/sec is specified to minimize problems due to decompression. These requirements are realistic and attainable. Commercial systems are routinely designed for rates of 500 ft/min (0.004 psi/sec) for decreasing pressure, and 300 ft/min (0.003 psi/sec) for increasing pressure (sea-level conditions). The commercial standards should be considered for air vehicles designed for medical transport, since the patients, due to ear blockages, may be more susceptible to the pressure changes. Automatic controllers that allow for selection and control of the rate of pressure change anywhere in the range of 100 to 2,000 ft/min are frequently required for non-combat air vehicles. This type of control, along with a non-combat pressure schedule in “Occupied compartment pressure schedule” in this appendix, allows the crew to select the most comfortable pressurization control for the particular mission being flown. The values given above are applicable to all systems.

TBS 3 should be filled in with an appropriate value for the maximum rate of pressure decrease during emergency release. This value should not exceed 1.0 psi/sec.

TBS 4 should be filled in with an appropriate value for the maximum rate of pressure increase during emergency repressurization. This value should not exceed 0.5 psi/sec.

REQUIREMENT LESSONS LEARNED (3.4.4.1.3)

In consideration of pressurization transients, significant problems have been experienced due to dynamic incompatibilities between the major components of the pressurization system. These examples include the following cases:

a. Lack of a pressure regulator upstream of the cabin has resulted in severe cabin pressure surges since cabin outflow regulators often have not responded adequately to engine bleed air transients during throttle maneuver.

b. Exhausting cabin outflow into the avionics compartment has caused enough back pressure to the cabin airflow to prevent proper cabin pressure regulation during transients.

c. Experience has shown the pressure regulator valves upstream of the cabin should be dynamically matched to engine transient characteristics and the effective downstream volume throughout the full range of airflow and pressures to prevent unsatisfactory cabin transients.

d. Experience has shown the modification of an air vehicle's ECS to increase cabin flow rate necessitates careful analysis of the pressurization system dynamics to preclude severe cabin pressure surges. In some cases, a mock-up may have been necessary to evaluate adequately the major system modifications.

D.4.4.4.1.3 Rate of occupied compartment pressure change.

Rate of pressure change requirements shall be verified during flight test.

VERIFICATION RATIONALE (4.4.4.1.3)

Verification is necessary to ensure the rate of pressure change in the occupied compartment(s) is within the limits specified.

VERIFICATION GUIDANCE (4.4.4.1.3)

Verification of rate of pressure change requirements should be made during the test conditions of "Occupied compartment pressure schedule", "Unoccupied compartment, bay, and equipment pressure schedules" in this appendix, and during periods of emergency pressure release and repressurization at steady-state cruise conditions. All measurements of rate of pressure change should be done to a standard. The worst (highest) slope should be taken over a 1-sec interval (Δ P/sec).

VERIFICATION LESSONS LEARNED (4.4.4.1.3)

(TBD)

D.3.4.4.1.4 Compartment positive and negative pressure relief.

Personnel injury and structural damage due to excessive positive or negative pressure within compartments shall be prevented.

REQUIREMENT RATIONALE (3.4.4.1.4)

Protection from excessive pressure differentials and partial decompression is necessary for crew safety and to prevent air vehicle structural damage.

REQUIREMENT GUIDANCE (3.4.4.1.4)

Some means should be provided to protect against over-pressurization should the primary control valve malfunction. Protection of occupied compartments from excessive positive and negative pressures should be provided. Blowout panels or sufficient flow areas between compartments should be provided to prevent personnel injury and structural failure in the event of sudden decompression. The amount of protection required will vary depending upon the mission of the vehicle and other factors. For example, on a wide-body air vehicle with many compartments (such as the E-4B), requiring no structural damage due to rapid decompression would impose a massive penalty on the air vehicle (structural weight). Instead, the requirement should be, “Prevent structural damage which would preclude the safe return of the air vehicle”. For example, floor collapse that severs control cables or hydraulic lines would be unacceptable, but small, localized failures should be acceptable. A primary concern should be the prevention of personal injury due to collapsing partitions, flying debris, or such. There are several factors that should be considered in establishing these requirements. The cause of the rapid decompression is an important factor (for example, loss of a cargo door, loss of a window, or hull damage due to an engine disk failure). The larger the pressurized hull hole size specified, the more difficult this requirement is to meet. For combat air vehicles, the type of oxygen system being used and whether or not pressure suits are being used are also important factors. The maximum altitude of the air vehicle is also a factor.

On special purpose air vehicles, further requirements or more detailed requirements may be necessary to ensure vehicle safety and adequate performance.

The need for this pressure relief is proportional to the level of pressurization, and it is necessary for crew safety. In cases where the actual pressurization is small (for example, 0.5 psid or lower), it may be very difficult to generate higher pressure differentials even if there is a component or system failure. In this instance it would not be logical to include additional components to meet this requirement. But, if significant pressure forces can be generated, the need for the requirement is also significant. Each system should be examined for this possibility.

Multi-compartment air vehicles should be protected from excessive positive and negative pressures, during both normal operation and in the event of sudden decompression.

REQUIREMENT LESSONS LEARNED (3.4.4.1.4)

Sudden decompressions have resulted in the loss of one DC-10 air vehicle and damage to several others. The most serious DC-10 decompression resulted from the loss of a cargo compartment door. The sudden loss of pressure created an excessive pressure differential across the floor and the floor collapsed. The collapsing floor severed control cables, which resulted in loss of air vehicle control and subsequent crash of the air vehicle. The DC-10 incidents have dramatically emphasized the need to provide sufficient flow paths to prevent damage or injury. This is an important safety-of-flight requirement.

D.4.4.4.1.4 Compartment positive and negative pressure relief.

Analyses shall be conducted to verify that personnel injury and structural damage will not occur as the result of sudden decompression of one compartment for multi-compartment pressurized volumes. The analysis shall assume a __(TBS)__ square feet hole is opened in the fuselage of cargo and transport air vehicles to cause the rapid decompression. Analysis shall be conducted to verify adequacy of positive and negative pressure relief settings. Laboratory and ground tests shall verify positive pressure relief function. Laboratory and flight tests (rapid descent) shall verify the negative pressure relief function.

VERIFICATION RATIONALE (4.4.4.1.4)

Analyses are the only feasible means of verifying many of these requirements because of the inherent danger of personnel injury or air vehicle damage while simulating a rapid decompression. This is especially the case since the requirement may permit some damage to occur during extreme rapid decompression emergencies. Ground and flight tests can easily verify most normal pressure relief functions.

VERIFICATION GUIDANCE (4.4.4.1.4)

TBS should be filled in with a value indicating the size (square feet) of the hole to be used for analysis purposes associated with rapid decompression.

The decompression hole size considered for sudden decompression should be a function of the cross-sectional area of the fuselage. FAR 25.365, Amendment 25-87 states, “Any opening in the compartment up to size H_0 in square feet; however, small compartments may be combined with an adjacent pressurized compartment and both considered as a single compartment for openings that cannot reasonably be expected to be confined to the small compartment.” The size H_0 should be computed by the following formula:

$$H_0 = PA_s$$

where

H_0 = maximum opening in square feet, not to exceed 20 square feet.

$$P = \frac{A_s}{6240} + .024$$

A_s = maximum cross-sectional area of the pressurized shell normal to the longitudinal axis, in square feet.

For pressurized rotary-wing air vehicles, the contractor should demonstrate by analysis that no damage to flight controls, flight surfaces, or other air vehicle parts which could adversely affect safety of flight and landing can occur as a result of sudden decompression, over-pressurization, pressure differential, or negative pressure. For decompression analysis the contractor should assume a hole size which results in the most severe condition. Hole sizes should be derived from:

a. a door or canopy opening as a result of a faulty latch
b. a window
c. a failed engine turbine disk
d. enemy fire with subsequent loss of pressurization. For this analysis the contractor should determine the maximum hole size sustainable (with respect to pressurization problems) for vulnerability purposes and verify that the vulnerability requirement is not compromised as a result of enemy fire and the loss of pressurization.

Analysis should be conducted to verify adequacy of positive and negative pressure relief settings. Laboratory and ground tests should verify positive pressure relief function. Laboratory and flight tests (rapid descent) should verify negative pressure relief function.

VERIFICATION LESSONS LEARNED (4.4.4.1.4)

(TBD)

D.3.4.4.1.5 Occupied compartment pressure release.

The pressurization system shall have the capability for both normal and emergency pressure release. The normal pressure release shall be capable of dumping pressure without shutting off the pressurizing air source. The emergency pressure release shall be capable of dumping pressure from maximum differential to ___(TBS 1)___ within ___(TBS 2)___ seconds with the pressurizing air source shut off automatically at the initiation of the emergency dump. Pressure differential following landing or following normal pressure release in flight shall not exceed values that can result in personnel injury or air vehicle damage when hatches or doors are opened when the pressurizing air source is operating.

REQUIREMENT RATIONALE (3.4.4.1.5)

Provisions for pressure release are required to quickly purge the occupied compartments of smoke, fumes, toxic gases, and such contaminants; to allow in-flight air drop of cargo; to allow the use of ram air for emergency ventilation; and to permit emergency escape. The normal pressure release provisions are intended to clear the occupied compartments of smoke, fumes, and such contaminants, when the ECS or other pressurization source is not the source of the problem. This permits the most rapid clearing of the compartments. The emergency provisions are intended for use when the pressurization air or ECS is the smoke or fume source, when total ECS failure occurs and ram air ventilation is required, or an emergency condition exists that requires emergency escape.

REQUIREMENT GUIDANCE (3.4.4.1.5)

TBS 1 should be filled in with the desired pressure to be reached in an emergency pressure release.

TBS 2 should be filled in with the desired time to reach that pressure from the maximum differential pressure.

The maximum possible rate of depressurization (not to exceed 1.0 psi/sec) is desired. However, for air vehicles with large, pressurized volumes (1,000 cu ft or more), special provisions, such as blowout panels, may be required to achieve a 0.5 to 1.0 psi/sec rate. In these cases, the rate can be lower, but 60 seconds is generally considered a maximum acceptable release time.

For this requirement, the engineer should determine if a maximum acceptable time for pressure relief is to be specified, and if so, what it should be. This value will be influenced by mission requirements, emergency procedures to be used on the vehicle. When other guidance is not available, the following requirements should be considered:

a. For small, pressurized volume air vehicles: “The release time to dump from maximum pressure differential to within 1 psi of ambient pressure should be within the range of 0.5 to 1.0 psi/sec.”

b. For large, pressurized volume air vehicles: “The release time to dump from maximum cabin pressure differential to within 1 psi of ambient pressure should be not greater than 60 sec.”

One psi is used as the lower limit to establish the requirement because the rate of pressure release will taper off rapidly at pressure differentials of less than 1.0 psi.

Air vehicle upgrades may result in increased flow rates of the pressurizing air source. When this occurs, the pressurization system needs to be evaluated to determine if the outflow capability can handle the increased flow without degrading the ground pressure differential beyond acceptable limits.

Small residual differential pressures, across large surface areas, can result in forces that can injure personnel and damage the air vehicle when hatches or doors are released under those conditions. The contractor should evaluate his design and the air vehicle mission to determine if and where provisions are necessary to relieve possible residual pressures before opening any hatches, canopies, or doors.

This requirement should be met with the ECS operating, because under normal operating procedures it is not desirable to turn off the ECS before operating canopies, hatches, or doors.

REQUIREMENT LESSONS LEARNED (3.4.4.1.5)

Some pressure release systems have failed to provide for canopy seal pressure release when electrical power is off. This is a concern when procedures require electrical power to be shut off immediately after emergency landing and canopy seal pressure must be released in order to manually open the canopy.

D.4.4.4.1.5 Occupied compartment pressure release.

Flight tests at steady-state cruise conditions and following landing shall verify pressure release provisions. Further, if doors or canopies are not fully latched, these tests shall demonstrate that appropriate action, as determined by a safety hazard analysis, can be taken to preclude an unsafe condition from developing.

VERIFICATION RATIONALE (4.4.4.1.5)

Verification is necessary to ensure that the ECS is capable of providing the appropriate pressure release for normal and emergency operations. Flight-testing is the most accurate, practical method of verifying most pressurization related requirements.

VERIFICATION GUIDANCE (4.4.4.1.5)

Pressure release provisions that must function for emergency escape or smoke evacuation should be verified by analysis to be capable of functioning independently of the cause of the emergency (such as an ECS fire), or in conjunction with the loss of the capability to shut off the pressurization source in the event that the pressurization source is the cause of the emergency.

VERIFICATION LESSONS LEARNED (4.4.4.1.5)

Experience on wide-body air vehicles has shown that laboratory tests of emergency pressure relief provisions have been necessary to verify their proper and consistent function.

D.3.4.4.1.6 Occupied compartment leakage rate.

The maximum allowable leakage rate of pressurized compartments, including leakage through the Environmental Control System, shall not exceed __(TBS)__.

REQUIREMENT RATIONALE (3.4.4.1.6)

Leakage rates are specified in order to ensure minimum safe pressure levels can always be maintained.

REQUIREMENT GUIDANCE (3.4.4.1.6)

TBS should specify the maximum allowable leakage rate. A study of inventory air vehicles has shown leakage rates typically increase up to 1.6 times the rate existing during production acceptance. Therefore, the in-service maximum allowable leakage rate included in field maintenance manuals should use the maximum allowable leakage rate for production air vehicles, as determined below, and multiplied by the 1.6 factor. The 1.6 may be adjusted if there is more appropriate data on the increase of leakage rate in service for the particular type of air vehicle being developed.

Seals themselves are part of the airframe. The ECS provides air for pressurizing the seals. Therefore, an interface exists between the ECS and airframe. This interface should be closely coordinated between the ECS engineers and airframe engineers.

Several approaches can be taken to establish maximum leakage rates. Generally, it is specified as the lesser rate that will result from the following considerations:

a. The maximum allowable leakage rate should not exceed one-half (1/2) the rate that will ensure the compartment pressure altitude will not exceed a specified number of feet during a maximum rate of descent without engine power, or at idle from maximum operating ceiling with the compartment initially pressurized at a specified value, with the pressurization air source shut off. The leakage rate for engine idle or without engine power will ensure cabin pressurization is maintained until the air vehicle can reach a safer altitude, thereby preventing physical injury to the occupants.

b. The maximum allowable leakage rate should not exceed one-half (1/2) the rate that will ensure the required pressure schedule can be maintained with engines at idle speed.

c. If more than one air conditioning unit is supplying air to the pressurized compartment, the maximum allowable production leakage rate should not exceed one-half (1/2) the rate that will ensure the required pressure schedule can be maintained with one air conditioning unit inoperative.

d. The maximum allowable leakage rate should not exceed 0.07V0.667 + 0.5 lb/min, where V is the volume of the pressurized enclosure in cubic feet. The 0.5 lb. allows for the leakage from outflow valves and air conditioning units.

For non-combat air vehicles, it is undesirable for the cabin altitude to exceed 30,000 ft, as that is the threshold for a high incidence of decompression sickness, and the time of useful consciousness without breathing oxygen is about 55 sec. Maximum cabin altitudes of 20,000—25,000 ft are much safer and should be design goals. With the 100 percent (100%) factor of safety that is required ("one-half ($^1/_2$) the rate"), the desired goals will generally be met, and the minimum requirements will always be met even with the in-service leakage rates. An initial cabin pressure of 10 psia is usually specified, as this is equivalent to a cabin altitude of 10,000 ft—the usual set point for cabin pressurization warning systems, (see "ECS crew station interface" in this appendix) and is the expected cabin pressure at the time the crew is alerted to the problem.

For combat air vehicles, it is not desirable for the cabin altitude to exceed 42,000 ft, as that is the maximum for continuous use of pressure breathing, and altitudes above 50,000 ft require use of pressure suits. An initial cabin pressure of 35,000 ft is usually specified, as this is equivalent to the usual 3 psi warning

light set point (reference "ECS crew station interface" in this appendix) and is the expected pressure at the time the pilot is alerted to the problem. In summary, when using these criteria, the engineer should complete the requirement based upon the type of air vehicle and the pressurization warning instruments being specified. Typical requirements are:

a. Combat air vehicles. Will not exceed 42,000 ft when initially pressurized at 35,000 ft cabin altitude—based on 3 psi warning set point (see "ECS crew station interface" in this appendix).

b. Non-combat air vehicles. Will not exceed 30,000 ft when initially pressurized at 10 psi—based on 10,000 ft cabin altitude warning set point.

If the warning set points are different than above, the requirements should be adjusted accordingly.

REQUIREMENT LESSONS LEARNED (3.4.4.1.6)

Experience has shown that an adequately designed system will be capable of maintaining the required pressure schedule with the engines at idle speed, and in the case where there is more than one air conditioning unit, with one of the units inoperative. The 100 percent (100%) factor of safety ("one-half ($^1/_2$) the rate") ensures these requirements will be met under in-service leakage rates.

The formula suggested in the guidance was empirically derived by the US Navy several years ago. Use of these criteria over the years by both the Navy and Air Force has proved more than adequate. It is usually used for large pressurized volume air vehicle.

Some fighter air vehicles in-flight leakage rates have been much higher than ground leakage rates. Two causes have been identified:

a. Air loads may have caused sufficient displacement of the canopy to allow leakage around the canopy seal.

b. If engines were operated at idle at high altitude, the engine bleed pressure may not have been high enough to fully pressurize the seal. In some cases, this problem might have been alleviated by a check valve, which retains the seal pressurization.

D.4.4.4.1.6 Occupied compartment leakage rate.

Leakage rates shall be established by analysis and measured during ground and flight tests on each air vehicle to demonstrate acceptable leakage.

VERIFICATION RATIONALE (4.4.4.1.6)

Verification is necessary to ensure that the ECS does not permit occupied compartment leakage at a rate exceeding the maximum allowable limit.

VERIFICATION GUIDANCE (4.4.4.1.6)

A manufacturing assessment of the expected maximum cockpit leakage area compared to the engineering established maximum limit should be a part of the analysis. Air vehicle factory functional and flight tests should be conducted to verify pressurization system performance and capability. A factory functional test should be conducted to determine the leakage rate and effective leakage area by pressurizing the air vehicle to the maximum required pressure differential. Usually, one of two methods is used for measuring leakage. Either the constant pressure flow method or the time pressure drop method is employed. The constant pressure flow method is normally used in all applications except those cases involving a large, pressurized volume. The constant pressure flow method provides a consistent and accurate leakage value.

Flight tests should be instrumented to recorded cockpit pressure and rate of pressure change.

VERIFICATION LESSONS LEARNED (4.4.4.1.6)

Experience has shown that restoring fighter air vehicles to delivery configuration after being used in flight testing has resulted in leakage rates that were higher than initial delivery, and may have exceeded the in-service leakage rate earlier than expected. This has been especially true when the pressure bulkheads have been penetrated several times in different places during the flight test program.

D.3.4.4.1.7 Occupied compartment pressure source.

The pressurization source shall provide a minimum flow rate to the pressurized compartment(s) for all flight conditions of at least __(TBS 1)__ times greater than the maximum allowable production leakage rate. If required to meet the contamination requirements of "Occupied compartment contamination" in this appendix, the pressure source shall be filtered. If stored gas is used for pressurization, the partial pressure of oxygen shall be __(TBS 2)__. No single failure of a supply or control component shall result in __(TBS 3)__ . Means shall be incorporated to seal all pressurization supply inlet openings into the occupied compartments to prevent rapid loss of compartment pressure in the event of pressure source failure. For multiple pressure sources, the pressure schedule shall be maintained with one inoperative source.

REQUIREMENT RATIONALE (3.4.4.1.7)

The purpose of this requirement is:

a. To ensure the pressurization system will perform satisfactorily throughout the operational life of the air vehicle and to ensure the extra capacity is built in that is required to overcome the additional leakage that occurs as air vehicles age or undergo modifications.

b. To ensure the air supply meets minimum requirements for health and safety reasons.

c. Stored gas systems are rarely encountered in manned air vehicles. However, they may occur in special applications and provisions must be made to ensure adequate oxygen levels are maintained.

d. To ensure the safety of the crew and passengers under failure conditions.

e. More than one pressurization source is desirable on multi-engine air vehicles so single engine failure will not result in loss of pressurization.

REQUIREMENT GUIDANCE (3.4.4.1.7)

TBS 1: In-service leakage rates are as high as 1.6 times production leakage rates on current air vehicles. The minimum flow should therefore be established based on the maximum allowable in-service rate so pressurization can always be maintained. The greater the allowable leakage rate, the greater the minimum requirements will be.

TBS 2: The rationale and supporting physiological data given for escape capsules can be used to establish minimum oxygen levels.

TBS 3: Failure requirements can be approached many ways. The following should certainly be considered when systems designs are established and reviewed:

a. No single failure of any control component should result in an occupied compartment pressure altitude in excess of 12,000 ft on air vehicles without a diluter demand pressure breathing oxygen system.

b. On air vehicles with diluter demand pressure breathing oxygen systems, no single failure of any control component should result in an occupied compartment pressure altitude in excess of 35,000 ft.

c. Ideally, no single failure should result in failure of any other component.

d. Simultaneous failure of the pressure regulator and the safety valve should not occur as a result of a single component failure, a sensor or control line failure, or a sensor or control line leak.

e. Provisions should be made to ensure safe pressure levels are maintained in the event of probable failures such as interruption of electrical power or loss of pneumatic control pressure.

f. Provisions should be provided for emergency pressurization if any single failure causing loss of pressurization air source occurring at maximum altitude could result in crewmembers being incapacitated before the air vehicle can descend to 42,000 ft with pressure breathing.

The approach to this requirement that most simply and directly addresses the true requirement is specifying the probability of the failure and the resulting impact. It is undesirable for low probability failures (such as a duct rupture) to impact the design adversely. Conversely, with more likely failures (such as a pressure regulator failure) it is desirable that proper safety provisions be made. The desired result is to prevent the cabin altitude from exceeding safe levels for sufficient time for the crew to take appropriate corrective action.

Under failure conditions, a maximum altitude of 35,000 ft is usually specified for air vehicles with diluter demand oxygen systems, as that is the maximum altitude for continuous use of demand oxygen systems. For air vehicles without a diluter demand oxygen system, a maximum altitude of 12,000 ft is usually specified. Twelve thousand feet corresponds with the normal FAA requirements for passenger-carrying air vehicles, and is within the range of 10,000 ft (maximum without continuous use of oxygen) and 18,000 ft (maximum for emergency use without oxygen). For air vehicles with high altitude missions, particularly single-engine air vehicles where the engine is the only source of pressurization air, loss of the pressurization source will require rapid descent to below 42,000 ft (unless pressure suits are used). Under some circumstances it may not be feasible to attain a low enough leakage rate, or some other requirement might exist that would make an emergency pressurization source a mandatory requirement or a more desirable approach. The objective is to ensure adequate cabin pressures are maintained for emergency descents.

With two engines, the system should be designed so either engine can independently maintain pressurization. With two or more engines, the system should be designed to maintain pressurization with any one engine failed. Controls should be provided to permit isolating failed engines and to give the crew flexibility in selecting the pressurization source or sources.

Use of check valves in place of shut-off valves at the engines should be discouraged. A shut-off valve gives more confidence that the valve will function properly (fail closed) in maintaining pressurization.

Filtration adds weight and maintenance requirements. The ECS engineer should coordinate with the engine project engineer or the cognizant engineer for other possible pressure sources to ensure that appropriate contamination levels are specified for the air supply from those sources. Sometimes, however, the engines or other pressure sources may be government-furnished equipment (GFE) or already designed prior to the air vehicle award. In this case filtration may be the only alternative. (SAE AIR1539 and SAE AIR4766/2 are good references on possible sources of contamination that could enter the occupied compartment through the ECS.)

REQUIREMENT LESSONS LEARNED (3.4.4.1.7)

(TBD)

D.4.4.4.1.7 Occupied compartment pressure source.

The capability of the ECS

a. to provide the required minimum flow rate to the required locations for all flight conditions shall be verified by __(TBS 1)__.

b. to meet the required contamination requirements shall be verified by __(TBS 2)__.

c. to provide the required partial pressure of oxygen (if applicable) shall be verified by __(TBS 3)__.

d. to limit damage to the maximum allowable resulting from a single failure shall be verified by __(TBS 4)__.

e. to seal all pressurization supply inlet openings in the event of pressure source failure shall be verified by __(TBS 5)__.

f. to maintain the pressure schedule with one inoperative pressure source (for multiple pressure sources subsystems) shall be verified by __(TBS 6)__.

VERIFICATION RATIONALE (4.4.4.1.7)

Verification is necessary to ensure that the pressure sources of the ECS functions are required.

VERIFICATION GUIDANCE (4.4.4.1.7)

TBS 1: Analysis and flight tests should be used to verify the minimum flow rate to pressurized compartments.

TBS 2: Air source contamination levels should be verified during qualification testing of the pressure source. Any filtration required to meet the requirement should be verified.

TBS 3: The partial pressure of stored gas sources should be verified during qualification testing of the pressure source.

TBS 4: Failure mode and effects analyses should be used to verify that no single failure results in damage greater than the maximum allowable.

TBS 5: Inspection of drawings and the air vehicle should be used to verify incorporation of means in air supply inlet openings to prevent rapid loss of compartment pressure in the event of pressure source failure.

TBS 6: For multiple pressure source applications, analysis should be used to verify the ability to maintain the pressure schedule with one source inoperative.

VERIFICATION LESSONS LEARNED (4.4.4.1.7)

(TBD)

D.3.4.4.2 Temperature control

D.4.4.4.2 Temperature control

D.3.4.4.2.1 Cooling

D.4.4.4.2.1 Cooling

D.3.4.4.2.1.1 Occupied compartment in-flight cooling.

The air conditioning subsystem shall be capable of in-flight cooling as follows: __(TBS)__.

REQUIREMENT RATIONALE (3.4.4.2.1.1)

A proper thermal environment is necessary for the passengers and crew to prevent or minimize the performance degradation due to heat stress. Any equipment contained in the occupied compartments must be maintained within a suitable environment to operate satisfactorily as well as to have an acceptable reliability and interface with passenger and crew occupants.

REQUIREMENT GUIDANCE (3.4.4.2.1.1)

TBS: The following should be considered, and specified as appropriate:

a. Type of cooling requirement approach
    1. Pilot envelope
    2. Average compartment
    3. Combination
b. In-flight cooling requirement
    1. Factor (dry bulb, WBGT, or such)

2. Temperature limits (including touch temperature limits)

c. Active or ram air cooling

Cooling requirements will usually be established based upon the type of air vehicle and its unique operational requirements. The cooling requirements are also a reflection of the thermal balance for the air vehicle to insure thermal stability for airworthy operations. The thermal conditioning of the crew is cognitive to sustaining the maximum or nominal skills required for optimum performance and execution of mission functions in a thermally stressed environment. The ECS is a required thermal conditioner for performance of weapon systems operation. Manned air vehicles can generally be divided into three categories. The first is fixed wing air vehicles with small volume compartments where the crew members are essentially restricted to their seats; fighter, attack, trainer and observation air vehicles typify this category of air vehicle. The second category is the fixed wing air vehicles with larger volume compartments where the crew or passengers can move from their seats; cargo, transport, navigation training, command and control, patrol, electronic counter measure, and similar air vehicles typify this category. The third category is typically rotorcraft including helicopters and tilt rotor fixed wing air vehicles.

a. Small volume (combat) air vehicles. Generally, the “average compartment temperature” has been used to define and establish cooling requirements. This approach has been unsatisfactory because it is very difficult to distribute the cooling air adequately to obtain reasonable minimal temperature gradients while at the same time obtaining the desired temperatures. The real requirement is to cool the pilot and other crewmembers. Experiences on the F-15, A-10, and F-5, along with many discussions with pilots, have resulted in the conclusion that pilots prefer a cooling system where the cooling air is blown across their envelope and where they have control over the direction of the airstreams. This has led to the development of the “Pilot Envelope Temperature” approach to specifying cooling requirements. The Pilot Envelope Temperature is defined as the arithmetical average of temperature measurements taken about the envelope occupied by the crewmember and should include measurements taken at the ankle, knees, hips, chest, shoulders, and head. For early design and analysis purposes, and until test data is available, formulas of the following form have been found to be an acceptable predictor of the Pilot Envelope Temperature:

$$T_{pe} = .85\,(T_{out} - T_{in}) + T_{in}$$

where

T_{pe} = Pilot Envelope Temperature

T_{in} = Air Supply Inlet Temperature

T_{out} = Compartment Discharge Temperature.

This empirical equation does not take into account any heat added as a result of using the air for avionics cooling before discharging from the compartment (such as on the F-15, where after cooling the pilot the air is used to cool avionic equipment on the deck behind the pilot before being discharged), and should be adjusted accordingly.

By specifying the pilot envelope temperature, the true requirement is then addressed (cooling the pilot). The dry bulb temperature has been the factor most often used to specify cooling and heating performance requirements because it is readily understood and easy to measure. However, there are many factors that influence how a person feels thermally—ambient temperature, air velocity, humidity, solar radiation, and such. As a result, many factors have been proposed and used as predictors of human stress, including Effective Temperature, and Wet Bulb Globe Temperature (WBGT). The WBGT has been shown to be a better indicator of these various factors, and is defined as:

$$WBGT = .7T_{wb} + .2T_{bg} + .1T_{db}$$

where

T_{wb} = Wet Bulb Temperature

T_{bg} = Black Globe Temperature from a 5 cm sphere

T_{db} = Dry Bulb Temperature.

The WBGT should be specified to be met and measured in the vicinity of the crew member's head and shoulders. Historically, the Air Force has used 90°F as the maximum limit for the WBGT value. Although the WBGT is a better measure of crew comfort, it is difficult to predict and the measurements are more difficult and costly. Other factors can enter into establishing the cooling requirements, such as clothing worn by the crew members. The development and use of ventilation garments could reduce the requirements for cockpit cooling.

b. Large volume air vehicles (non-combat). On large volume air vehicles, the crew members and passengers may be able to leave their positions and move about the air vehicle. In these cases, temperature limits should be established for all areas of the air vehicle which personnel may enter. The "average compartment temperature" is generally used in this case, thereby assuring that reasonable temperatures are maintained throughout each compartment. The average compartment temperature is the arithmetical average of dry bulb temperatures taken throughout the compartment, excluding areas such as within 6 in. of the floor, where severe temperature gradients occur due to typical 60°F floor temperature requirements. Specifying the average compartment temperature, along with appropriate distribution requirements, will result in the desired environment. Again, other factors, such as the WBGT, may be appropriate in some circumstances rather than dry bulb temperature. Many other requirements, such as clothing, may influence the cooling requirements.

A combination of Pilot Envelope Temperature and Average Compartment Temperature may be the best approach for many air vehicles. A Pilot Envelope Temperature could be specified for crewstations, with an Average Compartment Temperature specified for the remainder of occupied areas.

c. Rotorcraft. The approach taken on rotorcraft will depend on its usage. Generally, rotorcraft were not actively cooled. More recently attack type helicopters and anti-submarine helicopters have had active cooling for the crew to reduce heat stress and improve crew performance. Transport helicopters, particularly in the cabin are not usually actively cooled; however, recent requirements for both the crew and passengers to wear NBC protective clothing may add to the heat stress and may require active cooling. Typically the cockpit of these air vehicles are cooled to the same requirements as the cockpits of combat air vehicles. The cabins of rotorcraft with active crew such as anti-submarine helicopters are cooled to the same extent as non-combat air vehicles. Troop transport rotorcraft generally have no active cooling‘ using only ventilation for heat removal. On air vehicles where use of ram air is restricted because of NBC or other requirements, some active cooling may be needed.

Once the approach to be taken in specifying cooling requirements (Pilot Envelope versus Average Compartment Temperature) is established, the problem becomes one of determining the maximum temperature limits allowable. This is roughly the equivalent to a 70 to 75°F environment under high humidity conditions and can be as high as 85°F under low humidity conditions. A value of 70°F is the generally accepted ideal temperature. Under supersonic, low altitude, and possibly other flight conditions, maintaining a 70°F environment may impose significant penalties on the vehicle. Therefore, higher limits are frequently used for these flight conditions which are generally of limited duration (less than 30 minutes). Human performance degradation occurs at temperatures above 80 to 85°F. Therefore, under flight conditions of 30 min or less, 80°F is a typical requirement. Under short duration conditions (about 10 min or less), temperatures as high as 90°F may be acceptable without performance degradation. For steady state conditions the compartment discharge temperature should not exceed 95°F.

For air vehicles or portions of air vehicles without an active cooling system, compartment temperatures are typically specified to be within 10°F of outside ambient temperature.

The real objective is to prevent the mental and physical degradation of the crew. Exact determination of temperatures and times where deterioration begins to occur is dependent upon the individual and the circumstances. So, based upon the above discussion, table D-I can be used as a guide to establish cooling requirements for actively cooled air vehicles.

TABLE D-I. Cooling guidelines.

DRY BULB TEMPERATURE	FLIGHT CONDITIONS	DURATION TIME
70°F	All flight conditions	over 30 min. duration
80°F	All flight conditions	10-30 min. duration
90°F	All flight conditions	less than 10 min. duration

On most air vehicles, the ground operation, low level, or supersonic flight conditions will usually be the design points for the ECS and are typically less than 30 minutes in duration, so the 70°F requirement is usually attainable. However, on air vehicles with long supersonic capabilities or other severe flight conditions, 80°F would be acceptable for longer times if it eases the design of the system.

To best determine the dry bulb temperatures to be used, trade studies should be performed. The resultant dry bulb temperatures should meet the above requirements based on the environment specified in the air vehicle specification.

REQUIREMENT LESSONS LEARNED (3.4.4.2.1.1)

Based on in-depth studies of crew performance, the Crew Technology Division, United States Air Force School of Aerospace Medicine (USAFSAM), WRIGHT-PATTERSON AFB OH 45433; http://www.wpafb.af.mil/afrl/711hpw/usafsam.asp, has recommended that the WBGT in the vicinity of a crew member's head and shoulders not be greater than 90°F during flight operations.

D.4.4.4.2.1.1 Occupied compartment in-flight cooling.

The capability of the air conditioning subsystem to provide the required in-flight cooling shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.4.2.1.1)

Verification is necessary to ensure the capability of the air conditioning subsystem to provide the required in-flight cooling.

VERIFICATION GUIDANCE (4.4.4.2.1.1)

TBS: Verification should be accomplished by analyses, qualification and flight testing, or a combination thereof. Flight testing should provide the final verification that the subsystem meets the performance requirements. Flight testing is the only means to verify performance under many conditions, such as transients.

Laboratory tests should simulate as best as possible all critical flight conditions including transients. Laboratory testing is an ideal place to test reaction to failures. Flight testing should be performed to verify computer analyses and laboratory testing. (It may be necessary to rerun computer analyses and laboratory tests to correspond to the flight test conditions.) Conditions not easily simulated in the laboratory should also be flight tested.

There are several factors involved with selecting a maximum temperature difference from the specified ambient for performing testing. The larger the difference the easier it is to find a test location, but the extrapolation to specified conditions will be less accurate. There is less loss of accuracy if the computer model is very detailed, laboratory tests are extensive and the laboratory and flight test instrumentation enables component performance to be evaluated. If the computer model and laboratory testing is limited, the flight test should be performed within 10^{o} F of the specified ambient. With a more accurate computer model and extensive laboratory testing and laboratory and flight instrumentation, a difference of 20^{o} F may be tolerated. If the ground case is determined to be one of the sizing conditions, the use of the Environmental Chamber at Eglin AFB should be considered. This allows use of the actual specified conditions while removing the risk of not being able to reach specified test conditions when the ECS testing is scheduled.

System performance tests should be conducted with a minimum of 75 percent (75%) of the passenger and crew accommodations occupied during cooling tests.

VERIFICATION LESSONS LEARNED (4.4.4.2.1.1)

Government experience has shown that comprehensive analyses are essential early in the development of a system. As a result, the Government has developed several general computer programs for use in the analysis of Environmental Control Systems. These programs are routinely used to evaluate the design and performance of proposed systems and to establish performance requirements for future systems.

During the evaluation of alternative cooling upgrades for a Special Operations Forces program, the user requested a multitude of information and data on system performance for every conceivable environment and location. A fairly simple, “basic" computer model was created based on a simple compartment air vehicle platform. The resultant compartment temperatures were computed using simple heat balance equations. This tool proved invaluable.

Experience has shown that the adequacy of the air conditioning system should be established early in the design of the system to avoid problems and expensive design changes.

Several Navy aircraft have had problems with inlets for heat exchangers or ground air too close to exhausts from engines or APU. The result was that the cooling performance did not meet predictions. Analyses should consider the conditions at inlets and not automatically assume they are at ambient conditions.

D.3.4.4.2.1.2 Occupied compartment ground cooling.

For steady-state, sea level ground operation, the air conditioning subsystem shall be capable of providing cooling at __(TBS 1)__ under the following conditions: __(TBS 2)__.

REQUIREMENT RATIONALE (3.4.4.2.1.2)

Ground cooling system performance must be specified for maintenance of crew and cabin equipment environments. The air vehicle mission requirements for crew ground time and cabin equipment ground operating time will dictate the severity of the requirement.

REQUIREMENT GUIDANCE (3.4.4.2.1.2)

TBS 1 should be completed with the temperature limits required for the air vehicle.

TBS 2 should be completed with the operating conditions at which the ground cooling is to be provided.

Ground cooling that uses the onboard air vehicle system can be a very severe design condition because engine bleed air pressures are generally low at engine idle power settings and APUs generally supply bleed air at relatively low pressure and flows. The system should be capable of providing cooling during ground operation, using the air vehicle propulsion engines operating at idle power, the APU (if one is required for the air vehicle mission), or bleed air supplied from ground support equipment (if bleed air ground connections are required). The actual cooling requirements will depend upon the mission of the air vehicle under consideration. The actual requirements should also contain ground alert requirements if the air vehicle's mission states the air vehicle will be on alert. Occupied compartment temperature requirements for fighter and attack air vehicle have typically been 85 to 95°F, while requirements for transport air vehicles have been 70 to 85°F. Rotorcraft follow the above guidelines where active cooling has been used. The requirements for any equipment contained in the occupied compartment should also be established.

It is essential that high-g cockpits be cooled before takeoff. Trade studies should be performed to match ECS design to ground cooling requirements, based on the maximum ground ambient temperature specified in the air vehicle specification. Trade studies should also be performed to study the use and operation of ground carts to minimize Environmental Control System use.

REQUIREMENT LESSONS LEARNED (3.4.4.2.1.2)

The F-15 did not have an established requirement for cooling the cockpit with a ground cooling cart and thus there were no provisions for doing so. It was later found that it was necessary to run both engines during engine trim. One is the engine being trimmed and the other is to provide cockpit cooling.

D.4.4.4.2.1.2 Occupied compartment ground cooling.

The capability of the air conditioning subsystem to provide appropriate cooling for steady-state, sea level ground operation shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.4.2.1.2)

Verification is necessary to ensure that the air conditioning subsystem is capable of providing the required level of cooling for steady-state, sea level ground operations.

VERIFICATION GUIDANCE (4.4.4.2.1.2)

TBS should be filled in with analyses and air vehicle ground tests.

Ground testing should be performed with the air vehicle painted as it will be when operational. Extrapolating test data could be performed, but many multi-colored paint schemes such as camouflage are difficult to analyze.

VERIFICATION LESSONS LEARNED (4.4.4.2.1.2)

(TBD)

D.3.4.4.2.2 Heating

D.4.4.4.2.2 Heating

D.3.4.4.2.2.1 Occupied compartment in-flight heating.

The air conditioning system shall be capable of heating as follows: __(TBS)__.

REQUIREMENT RATIONALE (3.4.4.2.2.1)

Heating must be provided for occupied compartments in order to provide a proper thermal environment for the passengers and crew to prevent or minimize the performance degradation due to cold stress. The thermal conditioning of the crew is cognitive to sustaining the maximum or nominal skills required for optimum performance and execution of mission functions in a thermally stressed environment.

REQUIREMENT GUIDANCE (3.4.4.2.2.1)

TBS: Either the Pilot Envelope or Average Compartment Temperature approach can be taken to specify heating requirements. Once the approach is established, the problem becomes one of determining the minimum temperature limits allowable. This would be in the range of 75 to 85°F under low humidity conditions (which are most likely under cold day conditions). A temperature range of 70 to 80°F is generally accepted as ideal for heating. Human performance degradation occurs at low temperatures. Skilled motor performance shows a progressive loss with continual cold exposure. A value of 60°F is the lowest temperature recommended for consideration. This lower value is typically used for cabin areas of transport rotorcraft. Clothing and crewmembers' duties and responsibilities are factors that should be considered while establishing these requirements.

The most widely used cold stress indicator is the dry bulb temperature.

REQUIREMENT LESSONS LEARNED (3.4.4.2.2.1)

(TBD)

D.4.4.4.2.2.1 Occupied compartment in-flight heating.

The capability of the air conditioning subsystem to provide the required in-flight heating shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.4.2.2.1)

Verification is necessary to ensure that the air conditioning subsystem is able to meet the in-flight heating requirements of the air vehicle.

VERIFICATION GUIDANCE (4.4.4.2.2.1)

TBS: Analyses, laboratory qualification testing, and air vehicle ground and flight tests should verify the capability of the heating system to meet the specified requirements.

It is difficult to find consistent ambient temperatures which reflect the cold temperatures specified in MIL-HDBK-310, particularly for ground operations. Therefore, ground chamber testing is highly recommended for air vehicle testing. The use of the Environmental Chamber at Eglin AFB should be considered, particularly where heating is known to be an issue based on previous experience. Rotorcraft and external stores typically have difficulties meeting heating requirements. The chamber allows use of the actual specified conditions while removing the risk of not being able to reach meaningful test conditions when and where the ECS testing is scheduled. If testing in the chamber is not possible, constraints should be placed on the maximum temperature envelope allowed for heating tests. At the very minimum, tests should be constrained to the winter months in a climate that has a true winter season. If chamber tests are not to be performed, a more accurate ECS model should be developed and extensive laboratory tests performed to supplement the ground and flight testing.

REQUIREMENT LESSONS LEARNED (4.4.4.2.2.1)

(TBD)

D.3.4.4.2.2.2 Occupied compartment ground heating.

For steady-state, sea level ground operation, the heating subsystem shall be capable of (TBS) .

REQUIREMENT RATIONALE (3.4.4.2.2.2)

Heating must be provided for occupied compartments in order to provide a proper thermal environment for the passengers and crew to prevent or minimize the performance degradation due to cold stress.

REQUIREMENT GUIDANCE (3.4.4.2.2.2)

TBS: Ground heating using the on-board air vehicle system can be a severe condition because engine bleed air pressures and temperatures are lowest at engine idle power settings; APUs supply relatively low pressure and temperature bleed air; and electrical power is limited. The subsystem should be capable of providing heat during ground operation using the air vehicle propulsion engines operating at idle power; from a compressor being driven off the engine; the APU (if one is required for the air vehicle mission); or bleed air supply from ground support equipment (if bleed air connections are required).

For rotorcraft, heating requirements may be met by using an auxiliary combustion, exhaust or electrical heater. If an auxiliary heater is to be used, the ECS engineer should consult with the air vehicle project engineer to determine if it should be provided in a kit for cold weather operations. The actual heating requirement will depend upon the mission of the air vehicle under consideration. Requirements typically fall in the range from 60 to 80°F.

All ground heating requirements should be based upon trade studies to determine the ECS capability relative to the specified environmental conditions. Throttle advancement should be a last resort option that can be used to attempt to fulfill this requirement. If this approach is chosen, a study should be performed to assess the consequences in taking this approach.

REQUIREMENT LESSONS LEARNED (3.4.4.2.2.2)

(TBD)

D.4.4.4.2.2.2 Occupied compartment ground heating.

The capability of the heating subsystem to provide the required heating for steady-state, sea level ground operations shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.4.2.2.2)

Verification is necessary to ensure the heating subsystem is able to meet the heating performance requirements.

VERIFICATION GUIDANCE (4.4.4.2.2.2)

TBS should be filled in with analyses, laboratory qualification testing, air vehicle ground and flight testing, or an appropriate combination of these methods.

VERIFICATION LESSONS LEARNED (4.4.4.2.2.2)

(TBD)

D.3.4.4.2.3 Avionic and equipment compartment temperature control.

The temperature of all avionics (includes all electronic equipment installed on the air vehicle) and equipment compartments shall be maintained as follows:

a. The required avionic ambient temperatures shall be maintained for all continuous, intermittent and short-time ground and in-flight operating conditions as specified (TBS 1) .

b. The inlet cooling or heating fluid temperature and flow rate to forced air and liquid cooled equipment shall be maintained for all continuous, intermittent and short-time ground and in-flight operating conditions as specified __(TBS 2)__.

c. Temperature control for avionic equipment and equipment compartments shall be automatic.

REQUIREMENT RATIONALE (3.4.4.2.3)

Temperature control must be provided for avionic equipment so internal components will always operate within the temperature range used to predict reliability and integrity of the avionics. To achieve desired reliability and integrity, it is necessary to require that proper temperature control be maintained for all statistically significant ground and flight operating conditions and ambient extremes of temperature and humidity. Controls must be incorporated which automatically maintain the desired avionic environment. To prevent adverse effects due to low temperature, it is necessary to limit both minimum inlet cooling air temperature and maximum flow rate to avionic equipment. The inlet cooling or heating fluid temperature and flow rate to forced air and liquid cooled avionics and the compartment temperatures for ambient cooled avionics must always stay within the range to which each equipment is designed for any possible ambient ground and flight operating condition and ambient extremes of temperature and humidity to ensure equipment operates as specified and does not fail.

REQUIREMENT GUIDANCE (3.4.4.2.3)

TBS 1: The ambient temperature surrounding the avionics is to be maintained to insure avionics operating temperatures are maintained as a means of insuring performance requirements and integrity requirements of the equipment and overall air system are met.

Based on this condition, it is highly recommended that a team approach of analyzing and testing the temperature control needs of the avionics be performed jointly with platform system engineers, ECS and environmental engineers, thermal management subsystem engineers, and avionics engineers as a minimum to provide meaningful results.

A comprehensive trade study of avionics reliability and integrity versus ECS cooling capability should be required to meet reliability and integrity requirements. Where there is insufficient information on avionics reliability and integrity versus temperature, a temperature below the maximum allowable temperature should be selected or the avionics contractor consulted. A temperature of 27ºF below the maximum operating temperature was used in the former Navy specification. Several fighter programs have designed the exhaust temperature of forced cooled equipment to be maintained below the maximum ambient temperature, which usually corresponded to the maximum inlet temperature. The following actions should be taken to perform a comprehensive trade study:

a. To provide the needed information from the avionics contractor, the ECS engineer should coordinate with cognizant avionics and environmental engineers for the equipment to be used and recommend that for all newly designed or significantly modified equipment, each avionics contractor conduct a detailed, analytical thermal analysis on each “black box" module early in the design phase. The analysis should predict internal component temperatures for various worse case operational environmental conditions; the conditions being defined by a component life cycle environmental profile (LCEP) per task 402 of MIL-STD-810 (conducted either by the combat/materiel developer staff or contractor). The thermal analysis is necessary to verify that the amount of coolant flow required will maintain internal component temperatures at or below the level necessary to satisfy component environmental qualification requirements which addresses all airworthiness (reliability, integrity and safety) issues. Transient thermal analyzer programs are available to conduct the thermal analysis. This should be followed by a thermal verification test on each piece of avionics. The test should be conducted on prototype or preproduction equipment representative of the design to be released for production. The avionic equipment should be operated at conditions of maximum heat dissipation in the worst-case specified environment with cooling equivalent to that provided on the air vehicle and at the temperature at which reliability and integrity predictions are made. The equipment should be instrumented so that temperatures are monitored (1) for all critical parts, (2) for any part whose individual dissipation is 1 percent (1%) or more of the total equipment dissipation, and (3) such that the sum of the dissipation of the monitored parts is 90 percent (90%) or more of the total unit heat dissipation. The purpose of this test is to verify that the cooling provided and the internal arrangement of components within the “black box" module will result in component temperatures that are at or below the levels necessary to achieve the required reliability and integrity. Where existing GFE or Commercial Off-The-Shelf (COTS) equipment will be used, it may not be possible to obtain an analysis or test data from the avionics contractor. Working with avionics engineers and reliability and integrity engineers, it may be necessary to estimate the required information based on the data available. For further guidance on avionic equipment thermal design, analysis, cooling requirements and test procedures, refer to MIL-STD-2218.

b. The airframe contractor should use the above information to conduct a comprehensive trade study of avionics reliability and integrity versus ECS cooling capability. The trade study should consider all factors affecting life cycle cost and air vehicle penalties. The study should consist of determining the overall avionics reliability and integrity for various levels of avionics cooling. The levels to be considered should be a wide range of coolant inlet temperatures such as 0 to 90°F. For each of the inlet temperatures studied, a range of exit temperatures such as 100 to 160°F should also be considered. For each of the inlet-exit temperature combinations studied, the effect on ECS weight, volume, and development cost, and effect on air vehicle penalties should be determined. The overall effect on life cycle cost should then be determined for each of the combinations and the ECS/Avionics Cooling approach that results in minimum life cycle cost without degrading avionics reliability and integrity requirements should be selected.c. An alternate approach to comprehensive analysis focus and reliability is a system engineering approach focused on the integrated system performance of systems insuring thermal balance conditioning of the air vehicle. Optimization of the avionics system for thermal conditioning can be achieves by making an exergy assessment of the system to insure the thermal conditioning minimizes the adverse entropy effects of the integrated system for thermal conditioning. The purpose of thermal conditioning is not only a reliability issue but a performance function required to insure mission success.

TBS 2: Prevention of overcooling should be considered since particular pieces of avionics equipment may have a limited operating temperature range or may be subject to condensation. Heating may be required for very sensitive equipment.

Change in temperature is just as an important factor in avionics reliability and integrity as the absolute temperature. Consideration should then be given to establishing requirements on the fluctuation of temperature. A firm requirement for fluctuation limits has not been established. Work at the Naval Air Development Center on an earlier avionics technology indicated that the most critical part temperature of the avionics should not vary more than ±11°F at no more than ±11°F per hour. The applicability of this to today's avionics is not clear.

It is important that proper consideration be given to temperature control requirements at the beginning of the program, especially if new avionics are to be designed. A cooperative effort of both avionics and ECS engineers should be established to ensure compatibility between the ECS and avionics equipment. Such consideration should eliminate the need for many future modifications which are caused by failure to consider all aspects of avionics and equipment compartment cooling, such as:

a. Effects on temperature control of changes in air vehicle engine bleed air to ECS, and intermittent operation.
b. ECS performance during operational use and air vehicle maneuvers and possible ECS performance degradation.
c. Magnitude and length of time of air vehicle induced aerodynamic heating on compartment temperatures.
d. Avionics heat load growth factors. (see "Growth" in this appendix)
e. Proper cooling air flow and pressure balancing distribution since all forced air cooled avionics do not have the same pressure drop versus air flow rate characteristics.
f. Equipment duty cycles.
g. Solar radiation.
h. Thermal integrity.

In the future, the coordination of avionics and ECS requirements is expected to become much more difficult. With the emphasis on the use of COTS equipment, there will be large variations in avionics requirements. The ECS engineer should ensure the requirements established for the ECS will meet the requirements of all the avionic equipment. Considerable coordination and compromise may be required. Commercial Off-The-Shelf equipment and GFE should probably not be specified to inlet temperature and flow compatible with the optimum ECS for lowest air vehicle penalty. It may be necessary to negotiate changes to the specifications where possible. For example, the avionics may be designed for a high inlet temperature (many commercial systems use ambient or cabin air) which would require a high flow, but it may be possible for the avionics to be satisfied with a lower flow if a lower temperature can be ensured as with air directly from a refrigeration system (a typical combat air vehicle design). The ECS engineer, however, cannot arbitrarily make this assumption without detail knowledge of the thermal design of the equipment and coordinated discussions and agreement with the avionics engineer and the equipment installer.

(SAE AIR1277 provides excellent background information and guidance in how to establish interfaces between the ECS and avionic equipment.)

REQUIREMENT LESSONS LEARNED (3.4.4.2.3)

Department of Defense (DOD) experience has shown significant improvement in avionics reliability and reduced life cycle cost can be achieved by providing air conditioning for avionics to minimize the environmental extremes experienced by the avionics. The design of hot air vehicle structures requires the input of three, separate, technical disciplines to be successful. Environmental Control System, structures, and aerodynamics engineers all need to be involved. Frequently, only one or two of these disciplines have been involved on past programs. This has led to serious design deficiencies in several, different air vehicle programs. Solution of this problem in the future requires the recognition of the potential problem by the engineers involved and the involvement of all affected disciplines early in the air vehicle design effort.

Past experience has shown the main concern has been to maintain avionics component temperatures within their acceptable minimum and maximum limits. This approach results in designing the avionics cooling system with only sufficient cooling capability to maintain avionics components just at or below maximum allowable temperatures under hot day conditions. Also, many past systems allow the coolant temperature to fluctuate throughout a wide range. Temperatures allowed to fluctuate and reach maximum limits have adversely affected avionics reliability on past systems.

Overcooling of avionics has been a problem on a number of air vehicles and resulted in the need for system changes. Problems resulted due to cold soaking of the equipment at high altitude with extremely cold air. Avionics failed when moisture condensed and froze on the cold avionics when the air vehicle returned to low altitude.

The F-15 incorporated an adjustable avionics flow control to provide the increase in cooling capability to take care of the growth avionics. To maximize the benefits of increasing avionics reliability, the total capability was used to overcool the avionics before the complete complement of growth avionics was added. It was discovered the original system tests were all conducted with predicted distribution system back pressures based on avionic equipment added to the system for the particular flow rates under evaluation. The higher back pressure that resulted from forcing higher flows into a distribution system designed for lower flows caused an instability in the control system. The solution was to degain the cabin flow controller. The solution was easier than the effort involved in identifying the problem.

The F-14 air vehicle was designed to have its forced cooled equipment to exhaust at a maximum of 160°F, the maximum ambient temperature of MIL-HDBK-5400 Class 2 equipment. The reliability was acceptable for that generation of air vehicle. For the F-18 air vehicle, an in-depth study was performed and an exhaust temperature of 140°F was selected as the normal exhaust temperature. Improved reliability was achieved with this approach. As it turned out the 140°F was easy to achieve by installing a valve to the electronic counter measure transmitter, which is closed whenever the transmitter is off or removed, which is the majority of the time. With the transmitter on, the system can maintain all the avionics at 160°F, but when it is off or removed, the flow that would have gone to it is shared with the other avionics, maintaining them at 140°F.

The original Phoenix Missile required heating from the F-14 air vehicle on cold days to achieve its required operating temperature. The design of the heating system assumed that once the required temperature was reached, there would be sufficient internal heating to maintain the temperature. This was not the case. Due to exposure to external temperatures at altitude, the missile cooled below its required temperature, but the heating system did not activate until very cold temperatures were achieved. The problem was corrected by a controller change, which was costly at the late stage at which it was discovered.

D.4.4.4.2.3 Avionic and equipment compartment temperature control.

Avionic and equipment compartment temperature control shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.4.2.3)

To ensure adequacy of temperature control provisions for avionics, both analyses and test are required. Analyses are required early in the program to ensure proper thermal design of the avionics and proper capacity of the cooling system. These analyses then need to be verified by laboratory and flight test after the hardware is available.

VERIFICATION GUIDANCE (4.4.4.2.3)

TBS should be filled in with analyses, component tests, ECS test rig and air vehicle ground and flight tests; as well as allowable deviations from maximum operating conditions.

Analyses should be conducted early in the development program to ensure adequacy of avionics cooling system capacity for all ground and flight conditions. The analysis should itemize the equipment and indicate the required environment for normal, transient, and emergency operating conditions to be maintained for each piece based on the reliability allocations established by the contractor. Furthermore, equipment that is performance sensitive to temperature should be itemized. The analysis should show that transient temperature environments during cold soak start ups and hot soak cool downs for these selected pieces of equipment are consistent with their functional specification requirement (the equipment is allowed to function within the prescribed time and performance tolerance as set forth in the detailed equipment specification). The analysis should be conducted assuming a full complement of equipment (maximum heat load) and soak conditions at the extreme hot and cold day cases for the start up requirements. The validated ECS performance model should be used to predict the equipment flow rate and temperature supply conditions. Then these supply conditions should be used to predict avionics and electrical equipment reliability, and lastly the predicted reliability numbers should be compared to the allocated requirements. A cooperative effort among reliability, air vehicle system, avionic and ECS engineers is required to determine what flight and ground operations, under which environmental conditions, will occur for a sufficient enough amount of time to be considered statistically significant in the reliability calculations. The contractor may consider the equipment duty cycle in the reliability predictions.

Laboratory tests and air vehicle ground and flight tests should verify the ability of the ECS to provide the required coolant (flow rate and temperature) to each piece of forced cooled avionic equipment for all ground and flight conditions. Inspection of drawings and flight demonstration should verify automatic temperature control for avionic equipment and equipment compartments. Laboratory tests and flight tests should verify minimum inlet coolant and maximum flow rate do not result in overcooling avionic equipment.

Ground and flight testing should be performed on the approved design represented by the air vehicle configuration control including the production paint scheme. Testing of any proposed changes to the configuration should only be done after testing of the approved configuration is complete. Suitable instrumentation should be installed to measure the system performance and to allow a computer model of the ECS performance to be validated. Measurements include, but are not necessarily limited to, coolant flow rate, temperature, pressure, humidity, contaminants or contaminant simulants, pressure differential across each major component of the system, airflow (pounds per minute), the temperature differential, and the pressure drop across each major component of the system, including the electronic equipment and equipment bays. The flight test conditions selected should reflect the worst-case ground and flight conditions for the type of air vehicle being developed.

It is usually very difficult, and as a result costly, to find the ambient temperatures specified in the air vehicle specification, but due to the non-linear nature of ECS, it is also difficult to accurately extrapolate test date over large ambient temperature differences. Therefore, some maximum temperature difference from the specified value should be required. Extrapolation cannot be accurately performed unless steady state conditions are reached in the test. There are several factors involved with selecting a maximum temperature difference from the specified ambient for performing testing. The larger the difference the easier it is to find a test location, but the extrapolation to specified conditions will be less accurate. There is less loss of accuracy if the computer model is very detailed, laboratory tests are extensive and the laboratory and flight test instrumentation enables component performance to be evaluated. If the computer model and laboratory testing is limited, the flight test should be performed within 10^{o} F of the specified ambient. With a more accurate computer model and extensive laboratory testing and laboratory and flight instrumentation, a difference of 20^{o} F may be to tolerated. If the ground case is determined to be one of the sizing conditions, the use of the Environmental Chamber at Eglin AFB should be considered. This allows use of the actual specified conditions while removing the risk of not being able to reach specified test conditions when the ECS testing is scheduled.

Often not all avionics are available at the time of the avionic cooling flight test, because of development problems or security requirements. Missing avionics can invalidate the test. An approach to this should be established and provided in the specification. Any missing avionics should be simulated in flow or heat load as applicable. It is difficult to generalize as to how many boxes could be missing before the tests become meaningless. The heat load of the missing boxes is of course important consideration. One approach is to require that all avionics be included in the test. This would require negotiations if boxes are missing as test time approaches, but the specific boxes and their possible impact on the test would be known.

VERIFICATION LESSONS LEARNED (4.4.4.2.3)

During the testing of the F-14 avionic cooling system several deficiencies were noted and changes were made to the flight test air vehicle to correct the deficiencies, such as added insulation. The original configuration was never fully tested. Following the flight test, many of the changes incorporated on the flight test air vehicle were never incorporated in the production air vehicle; therefore, the test data did not reflect the performance of the production air vehicle, which had some reduced but unknown capacity.

Although all testing can be accomplished in ground and flight testing, experience has shown that significant cost can be saved by doing as much as possible in laboratory test. This is particularly true of the distribution system. It is difficult to do a very accurate analysis of a complex duct system with restrictions, changes in geometry, and such. Testing in the laboratory can verify or correct much of the flow distribution problems. The interface with the ECS can also be performed. Flight testing is then required to verify there are no flight interactions that were not anticipated in the laboratory, and to test transients not possible in the laboratory.

For the F-18A/B aircraft, the radar cooling flow was assumed to discharge to near ambient pressure, but it turned out that the compartment to which it discharged was partially pressurized due to ram effects. This resulted in low flow and sometimes reverse flow in this cooling leg. Discharge conditions should be considered when analyzing cooling system performance.

D.3.4.4.2.4 Avionic ground operation.

On the ground with engines operating, the ECS shall provide cooling at the level established in "Avionic and equipment compartment temperature control" in this appendix, except for equipment that does not require ground cooling. Ground check out or maintenance of the avionics without engines operating shall be performed using the following: __(TBS 1)__. Ground operation of __(TBS 2)__ shall be automatically prevented unless coolant is provided to the avionics. Operation of all avionics required during start-up and air vehicle ground servicing shall be possible without requiring refrigerated coolant from ground carts or the onboard cooling system.

REQUIREMENT RATIONALE (3.4.4.2.4)

Avionic failure or degraded reliability can result from operating the avionics on the ground during maintenance without providing proper cooling. Since ground operation can account for 50 percent (50%) or more of the avionics' total operating time and for many air vehicles it is the most severe operating condition, a significant reduction in reliability can result from operating the avionics on the ground without cooling or with inadequate cooling. Therefore, requirements need to be established to provide adequate cooling for avionics that is required to run on the ground and to prevent ground operation of avionics automatically unless proper cooling is provided. Maintenance crews need to perform certain maintenance tasks without using ground carts or running the onboard ECS. Certain avionics may have to be powered during ground servicing. Certain avionics may require operation prior to starting the cooling system.

REQUIREMENT GUIDANCE (3.4.4.2.4)

Historically ground cooling of avionics has been the most overlooked area when ECS requirements are specified. As noted in rationale a significant amount of avionics operation is performed on the ground where ambient conditions are most severe. In addition the commonly used bleed air powered air cycle systems produce marginal or inadequate flow rate and temperature with the engines at ground idle power. Many air vehicles have had no internal ground cooling capability without the engine or APU running. Where there are no ground carts or where they are difficult to use or time consuming to retrieve and start, avionics have been operated with no cooling. As a result of this many-sided ground cooling deficiency, avionics reliability has suffered.

The ground cooling issue is a multidisciplinary problem and an air vehicle system engineering challenge for thermal balance and stability to insure mission and airworthy performance. It is essential that when requirements are being defined that the ECS engineer coordinate with this multidisciplinary group in order to define the ground cooling strategy. The group consulted should include the air vehicle systems engineer to define how the air vehicle will be used, the avionic engineers to determine the ground cooling requirements of the avionics, the maintenance engineer for maintenance requirements, ground support engineers to determine what types and capacity of ground cooling and pneumatic carts, the APU engineer to determine the capacity of the APU for ground cooling and the reliability engineer to determine impact of ground cooling temperatures on avionics reliability. The approach developed will vary greatly with the type of air vehicle and its base of operation. For most air vehicles, during operation on the ground with engines operating, the ECS should provide sufficient cooling to air and liquid cooled avionic equipment including COTS and cockpit equipment, and equipment compartments to meet equipment and reliability requirements.

TBS 1: The major issue to be determined is what source of cooling will be used when air vehicle engines are off. The ECS engineer with guidance from the inter-disciplinary team will have to determine if cooling will come strictly from internal or external sources or from both. The use of an onboard APU is usually desirable for air vehicles to be operated at remote bases or if the APU is already planned to be installed for engine starting. The APU should have enough capacity to provide both the electrical as well as cooling capacity simultaneously for the avionics that will be needed to operate on the ground. Selective running of the avionics on the ground can reduce APU requirements but should be coordinated with the avionic engineers. Adequate air vehicle internal cooling sources that utilize ambient air or internal fuel could eliminate or minimize the need for external cooling sources, such as ground cooling carts. Fans, although a weight penalty, have provided excellent flexibility for carrier based air vehicles providing adequate cooling under all but the most severe operating conditions. The trend toward liquid cooled avionics will make the use of fans less attractive. Connections for standard ground carts should normally be planned. The extra weight for the connections is small in comparison to the benefit and flexibility of being able to use the ground cart. The use of ground carts as the only source of cooling with the engines off reduces the weight impact on the air vehicle, but can be an added burden to maintenance. Note that for carrier-based air vehicles, use of APUs and pneumatic ground carts are very limited on the hangar deck where the majority of avionics checks and maintenance are performed.

TBS 2: Provisions for automatic shut-off of avionic equipment is needed to prevent ground operation when proper cooling is not being provided, except for equipment which have been excluded, such as the inertial navigation system (INS) or equipment required to do ground servicing. Many newer air vehicles use a Vehicle Management System (VMS) to control air vehicle systems such as the ECS. If the VMS does control the ECS or the ground cooling fans necessary to run the avionics, the VMS must be excluded from the automatic ground shut-off. The automatic shut-off provisions should be designed to be inoperable during flight and taxiing on the ground when equipment operation is required. Coordination is required with the avionic engineers to ensure that the equipment that needs to operate for some period without cooling is properly specified.

REQUIREMENT LESSONS LEARNED (3.4.4.2.4)

Experience has shown avionics are often operated on the ground during maintenance without any cooling provided to the equipment. This leads to reduced avionics reliability. The F-15 air vehicle was modified to incorporate an interlock to prevent electrical power to the avionic equipment unless adequate cooling was provided. This change was required because avionics failures were attributed to ground operation without cooling.

At the Critical Design Review (CDR) for the C-17 air vehicle, the using command identified the need to be able to jack the airplane, change tires, fuel or defuel the air vehicle, and such, without wheeling out ground carts or running the onboard ECS off the APU. Operation of certain avionics is required for these maintenance tasks. As a result, the cooling system had to be redesigned so ambient air could be brought into the cooling loop to cool these avionics. If this capability had been identified early in the program, a redesign would have not been required.

On some programs lack of communication between the avionic engineers and ECS engineers has led to inadequate ground cooling of avionics. When terms such as “operating on the ground,” are used, people sometime assume this means normal mission operation only. On one program avionic engineers indicated during the requirements definition phase that the equipment, which had a large heat load, was not required to operate on the ground, forgetting the equipment sometimes requires check-out on the ground. During the development phase, however, the requirement was mentioned. Accommodations were made, but the cooling provisions were not totally adequate, since the APU, which powered the ECS, had already been selected and was under capacity to meet this additional load. This is a common oversight with transmitting devices such as radars, which would be hazards if operated normally on the ground, but these devices will normally need some periodic check or calibration using a dummy load. These uses are infrequent, but cooling is needed when these large powers are dissipated and must therefore be accommodated in the cooling design.

Avionics thermal conditioning in the 21st century has moved ground operation mode to air vehicle operation configuration that has to be defined as a critical parameter for determining operational definition for maintenance operations. Recent air vehicles like the F-35 and F-22 aircraft have made this configuration a serious perspective for the design understanding of the air vehicle because it defines derived requirements for thermal conditioning and air vehicle operations on the ground. The self-sufficiency configuration will be a driver in the development of the air vehicle concept of operations (CONOPS) and maintenance management of the air vehicle to insure mission and turn around times can be sustained to provide proper timelines for maximum effectiveness under extreme environmental conditions.

D.4.4.4.2.4 Avionic ground operation.

The ability of the air vehicle ECS to meet ground avionic operation requirements shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.4.2.4)

An early analysis of the ground cooling provisions is required. Incorporation of provisions late in the program could be costly and delay the program. Ground demonstration tests are required to verify the analysis and to ensure air vehicle cooling provisions have the capacity to cool all air cooled and liquid cooled avionic equipment needed for normal ground operation, servicing and maintenance, including COTS, cockpit equipment, and equipment compartments during hot, humid days with air vehicle engines operating and not operating.

It is necessary to verify that the onboard avionics cannot be operated on the ground during periods of inadequate cooling. This can be verified easily through a ground demonstration. Testing should also demonstrate that the automatic shutoff provisions do not shutoff equipment while the craft is in flight. It is necessary to verify that all avionics required during air vehicle ground servicing can be operated without augmented cooling.

VERIFICATION GUIDANCE (4.4.4.2.4)

TBS should be filled in with analyses, demonstration, inspection, and test.

Demonstration tests should show automatic shut-off provisions are inoperable during flight and taxi when equipment operation is required. An analysis of the proposed approach to ground cooling should be performed and presented at the Preliminary Design Review and updated at CDR to ensure it is reviewed by the full multidisciplinary team involved with this area. The analysis should include all potential ground maintenance and operational scenarios for the air vehicle. It should specify what avionics will be on and what the heat load will be. It should then specify what modes of ground cooling will be used and what their capacities are. Mechanization profile of each thermal conditioning scenario should be incorporated as an intregal part of this verification process to insure sequencing does not create issues from a transient viewpoint as well as steady state.

Demonstration tests are needed to ensure the adequacy of ground cooling capability of air vehicle internal and external ground cooling sources.

The demonstration tests for adequate air vehicle cooling provisions for avionic equipment during normal ground operation, maintenance and servicing procedures should pertain to all avionics used during these operations. Ground demonstration of equipment automatic shut-off provisions when cooling is insufficient, should apply to all of the onboard avionic equipment unless some have been excluded, such as the INS. The demonstration tests should also include verification that equipment automatic shut-off provisions are not operable during flight and during taxiing when equipment operation is required. Compatibility of the ECS design with air vehicle internal ground cooling sources, external cooling sources and carrier deck facilities when required, should be shown. The ECS engineer should coordinate with the avionic engineers to ensure the equipment that is to operate without cooling for certain periods is demonstrated to those requirements.

VERIFICATION LESSONS LEARNED (4.4.4.2.4)

(TBD)

D.3.4.4.2.5 Occupied compartment air distribution.

a. The conditioned air shall be distributed so that __(TBS 1)__.

b. Directional and quantity adjustable air outlets shall be provided for __(TBS 2)__.

c. The air from any outlet into occupied compartments shall not exceed __(TBS 3)__°F for any single failure.

REQUIREMENT RATIONALE (3.4.4.2.5)

Proper air distribution is essential for adequate heating and cooling. Distribution requirements should be specified to prevent excessive temperature differences, limit the velocity of air movement past crew members and passengers, and prevent the airflow from being fixed directly onto crew members' bodies in a distracting or irritating manner.

REQUIREMENT GUIDANCE (3.4.4.2.5)

TBS 1: Distribution requirements should be specified to prevent excessive temperature differences, limit the velocity of air movement past crewmembers and passengers, and prevent the airflow from being fixed directly onto crewmembers' bodies in a distracting or irritating manner.

TBS 2: The following should be considered and specified, as appropriate.

a. Minimum distribution requirements. For air vehicles or positions where the Pilot Envelope Temperature is specified, a minimum of two outlets per crewmember should be provided. Each outlet should be flow- and direction-controllable by the crewmember. Consideration should be given to providing four outlets – two forward facing gaspers and two along side of each crewmember.

b. Maximum temperature variations.

c. Requirements for foot outlets. These can be specified for certain positions, or can be specified as contractor-provided, as appropriate.

d. Requirements for gaspers. This includes the miscellaneous requirement of subparagraph “Miscellaneous” (d), below.

The approach that should be taken on the distribution system depends on the way the heating and cooling requirements are specified (Pilot Envelope Temperature versus Average Compartment Temperature).

a. Pilot Envelope Temperature Approach. For proper cooling (which can be interpreted as adequate pilot comfort), proper flow distribution is essential. Military experience has shown pilots are generally most satisfied when the cooling air is blown across their envelope by controllable outlets they can adjust for both direction and flow rate according to their personal preference.

b. Average Compartment Temperature Approach. In large, occupied compartments, as in passenger or cargo air vehicles, the distribution system should be designed to provide adequate mixing of the air to prevent excessive temperature differences. This is generally accomplished by an overhead distribution duct located along the center or both sides of the compartment. The air is exhausted through the sidewalls near the floor.

In addition to the overall approach to the distribution system, other factors should be considered:

a. Temperature variation. The air should be uniformly distributed to prevent excessive temperature differences. Temperature variation between any two points in the pilot's envelope should not deviate more than an 5 to 10°F from the "Pilot Envelope Temperature." These values are typical, reasonable requirements that minimize the temperature variations across the crewmembers. When using the Average Compartment Temperature, the temperature variation between any two points in the envelope occupied by seated personnel should not deviate more than 10°F from the average compartment temperature. Under certain circumstances, further details may be appropriate, such as excluding the area within 6 inches of the floor because of low floor temperatures and the resulting influence on temperatures near the floor. However, if the floor is excluded, a minimum floor temperature should be specified because the feet are very sensitive to cold. A minimum floor temperature of 55°F is recommended unless it causes a severe weight or power penalty. It may be also be appropriate to specify maximum temperature differences for areas outside the envelope of seated personnel, where movement is possible. Values of +10 to +15°F are typical for the envelope immediately occupied by personnel.

b. Foot outlets. Foot outlets or foot warmers should be considered for proper heating (and cooling) of the crewmembers' feet in many crew positions. This is particularly true of pilot and copilot positions in most air vehicles, aerial refueling operator's stations, and such. The feet are very sensitive to the cold; proper attention to foot outlets is essential.

c. Gaspers. Cold air outlets or "gaspers" are typically provided at crewstations and passenger positions. These are flow-and-direction-controllable outlets that provide cool air (usually 35°F) and can be adjusted to accommodate the individual who occupies the position. Gaspers can be required for crew positions, passenger positions, galleys, lavatories, or other places where individual temperature and flow control is desired.

d. Miscellaneous. The conditioned air, defog air, or anti-fog air should be distributed to prevent the crew's exhalation from fogging or frosting transparencies. This requirement does not apply to non-mission-essential windows. The air flow should not be "fixed" directly into the crewman's eyes or onto the crewman's arms or shoulders. Defog or anti-fog air should not impinge on the crew. The impact of hot avionics around the crew should also be considered in the design of the distribution system.

TBS 3 should be filled in with the maximum allowable air temperature. The temperature of the air entering occupied compartments is normally limited to 200°F for a single failure condition.

REQUIREMENT LESSONS LEARNED (3.4.4.2.5)

Figure D-2 shows the F-5F cockpit air distribution system, which has proved very acceptable. The diffusers forward of the crewmembers are on the right side and the diffusers along side the crewmembers are along the left canopy rail. Both diffusers are controllable for direction and flow rate.

Figures D-3 and D-4 show the F-15 distribution system. This system, although acceptable, had one disadvantage—the continually flowing 88°F +3°F canopy anti-fog air impinged on the pilot's helmet and face, making him feel warm on low altitude, hot day flights. The problem was corrected by providing pilot control of the anti-fog flow temperature and providing a defog temperature setting.

The A-10 air vehicle is another example. Figure D-5 shows the original cockpit distribution system. The cockpit of the air vehicle is essentially a titanium shield "bathtub," and penetrations of the armor shielding were held to the absolute minimum. As a result, the outflow valves and safety valves were located on the deck behind the pilot. The conditioned air supply duct splits into two similar lines which come up and over the titanium armor shielding and deliver the conditioned air from each side of the pilot at about mid-chest level. The holes in these "back warmers" were fixed to provide proper air velocity along the cockpit sidewalls to permit the entire cockpit to be cooled to 80°F. In retrospect, it has been concluded that this distribution system tends to "short circuit" the cabin and pilot with some of the airflow going directly from the back warmers to the outflow valve. During flight testing, surveys and comments indicated pilots were not satisfied with the distribution in the cockpit. As a result, changes were made to the distribution system to improve the overall effectiveness of the ECS and to satisfy the pilots' requirements. The revised distribution system is shown on figure D-6. The back warmer ducts were extended and routed inside the cockpit along both sides forward of the pilot and terminated at aft-facing, multi-directional, adjustable outlets. The adjustable outlets permit the pilot to direct the air on or away from his body. The pilot is able to shutoff the air with the adjustable outlet. Figure D-7 shows the improved flow distribution that received rapid acceptance.

Figures D-8 and D-9 show the E-3 Airborne Warning and Command Systems (AWACS) air conditioning distribution system and the corresponding cabin air distribution systems.

Figure D-10 shows the AWACS flight deck distribution system. It should be noted the distribution system provides for both crew position cooling (using gaspers and shoulder warmers), and general flight deck cooling (using the overhead diffuser).

D.4.4.4.2.5 Occupied compartment air distribution.

a. The conditioned air distribution shall be verified by __(TBS 1)__.

b. Directional and quantity adjustable air outlets shall be verified by __(TBS 2)__.

c. Prevention of high temperature air into the occupied compartments shall be verified by __(TBS 3)__.

VERIFICATION RATIONALE (4.4.4.2.5)

Verification is necessary to ensure that the air distribution requirements are met.

VERIFICATION GUIDANCE (4.4.4.2.5)

TBS 1 should be filled in with laboratory development testing and air vehicle ground and flight tests.

TBS 2: Inspection of drawings should show that each crew member has foot warming outlets and individual air gaspers for cooling at the torso and head levels.

Analysis and flight or laboratory testing should demonstrate the adequacy of the design. The analysis should show that the distribution system is optimized to cool and heat the crewmember's envelope (torso and head) to the system requirement by controlling the air flow and direction. The analysis should also show that the temperature variation in the crewmember's envelope does not vary by more than 10°F. The laboratory or flight test should include sufficient dry bulb thermocouples to determine the conditions in the pilot envelope area. The tests should also show that the air can be directed to optimum locations and that flow-rates can be adjusted.

Adequacy of adjustable outlets can be evaluated by crew comments. A cockpit mock-up is recommended for ECS testing to find possible problems in the duct layout and flow distribution. This mock-up can be integrated with the instrument mock-up by installing the ECS ducting and actually doing flow and distribution tests.

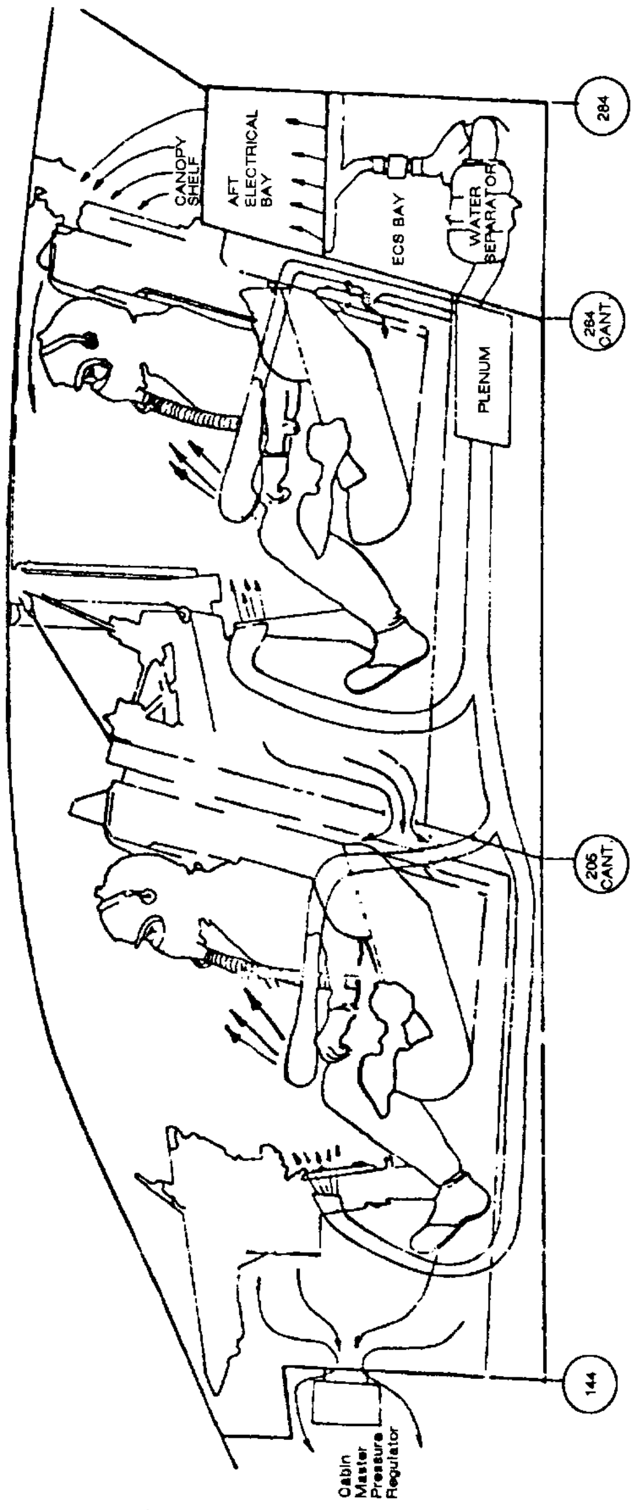

FIGURE D-2. F-5F cockpit air distribution system.

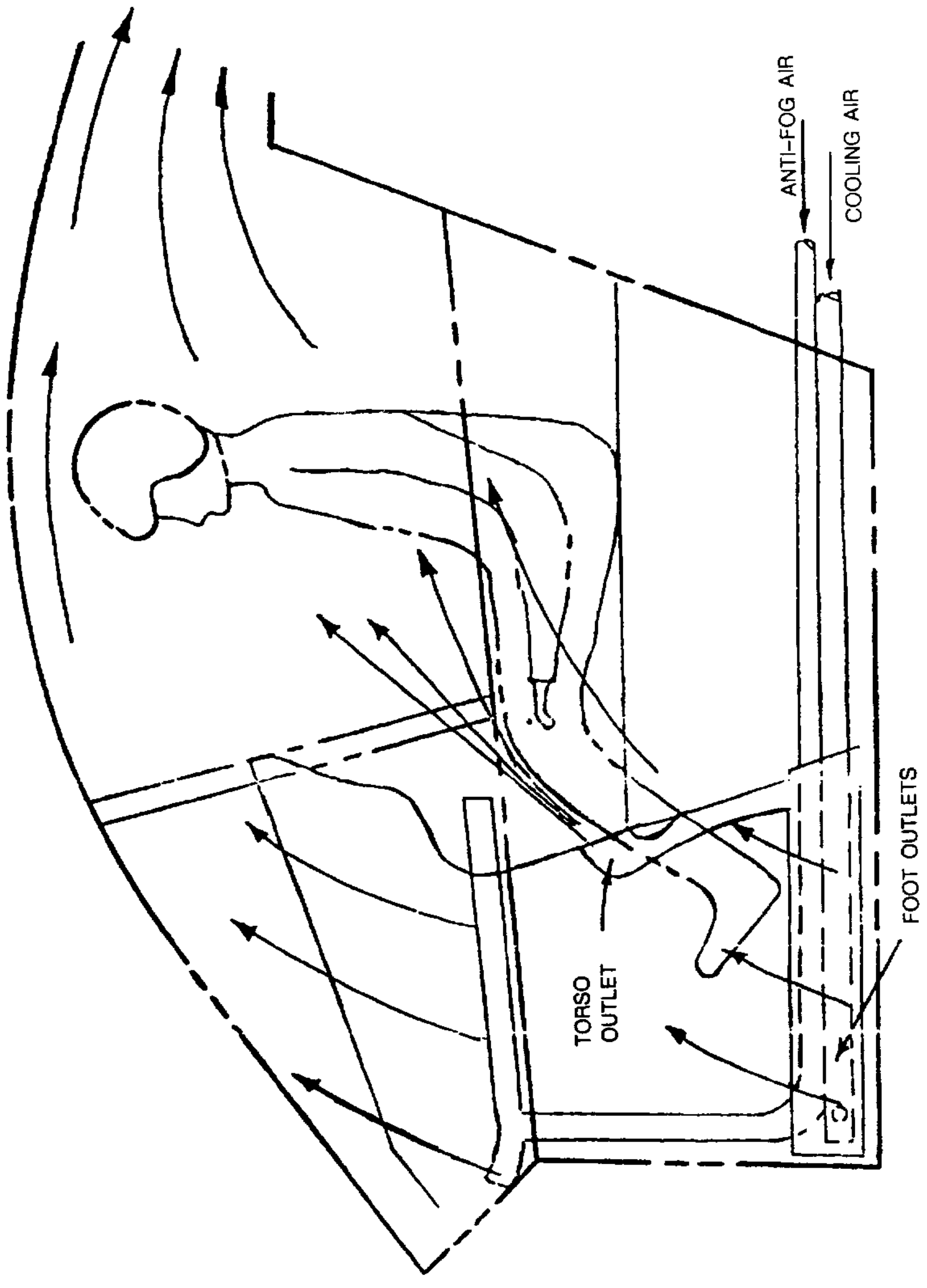

FIGURE D-3. F-15 cockpit air distribution.

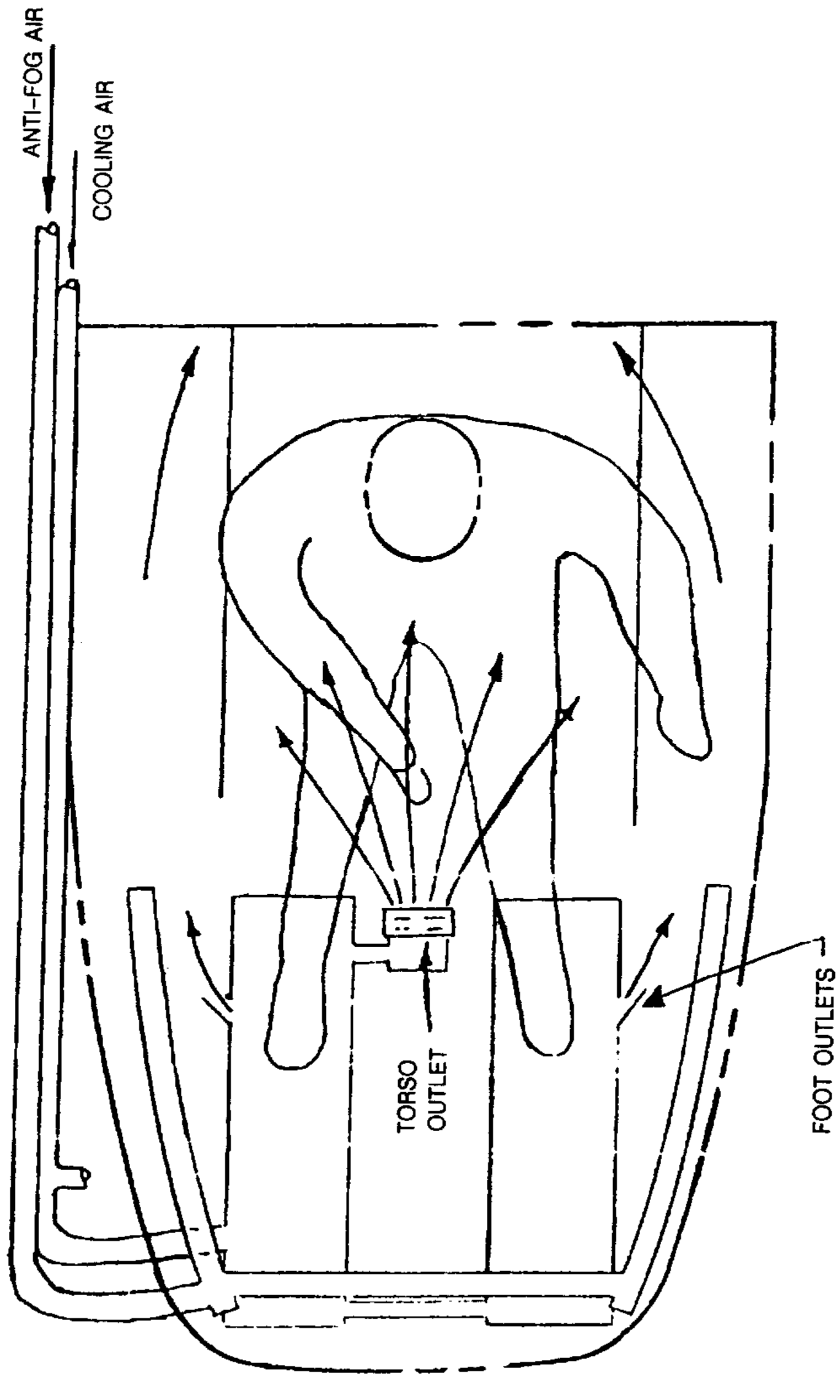

FIGURE D-4. F-15 cockpit air distribution.

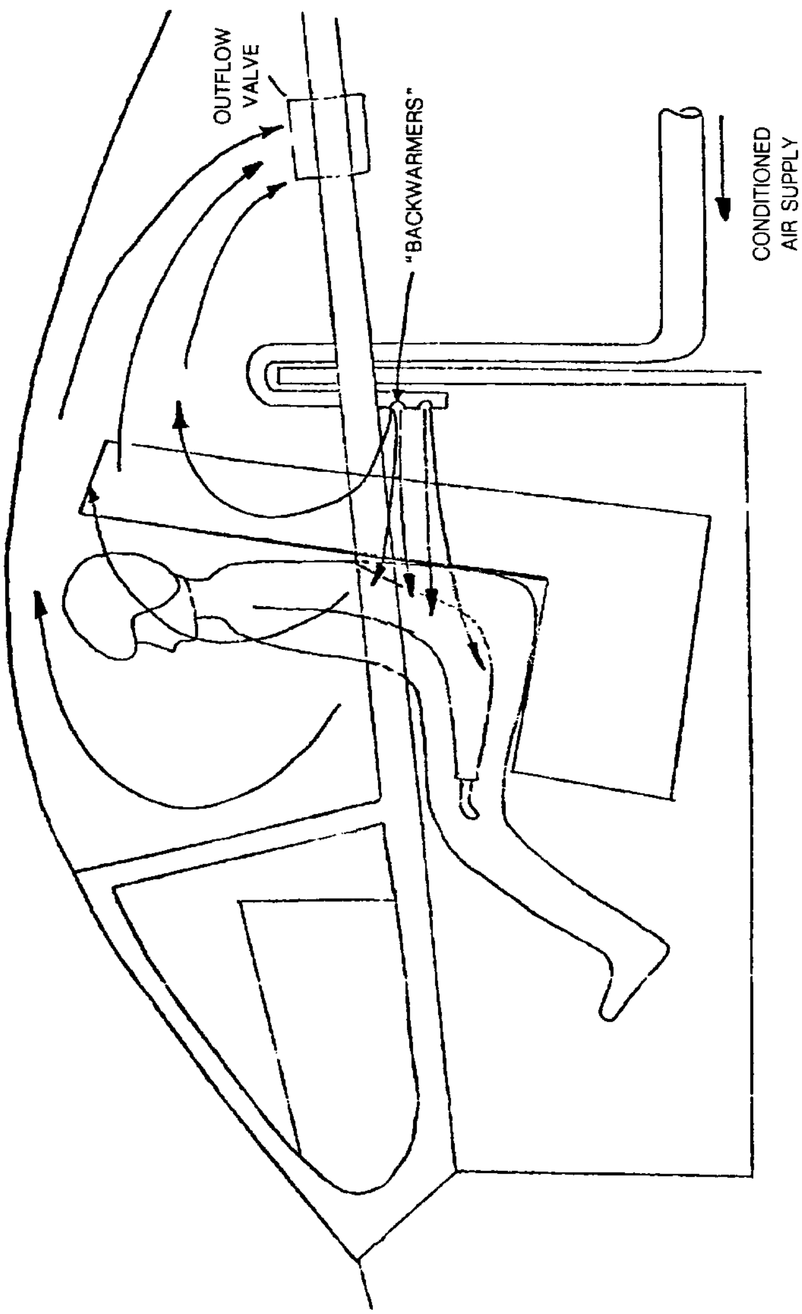

FIGURE D-5. Original A-10 cockpit air distribution.

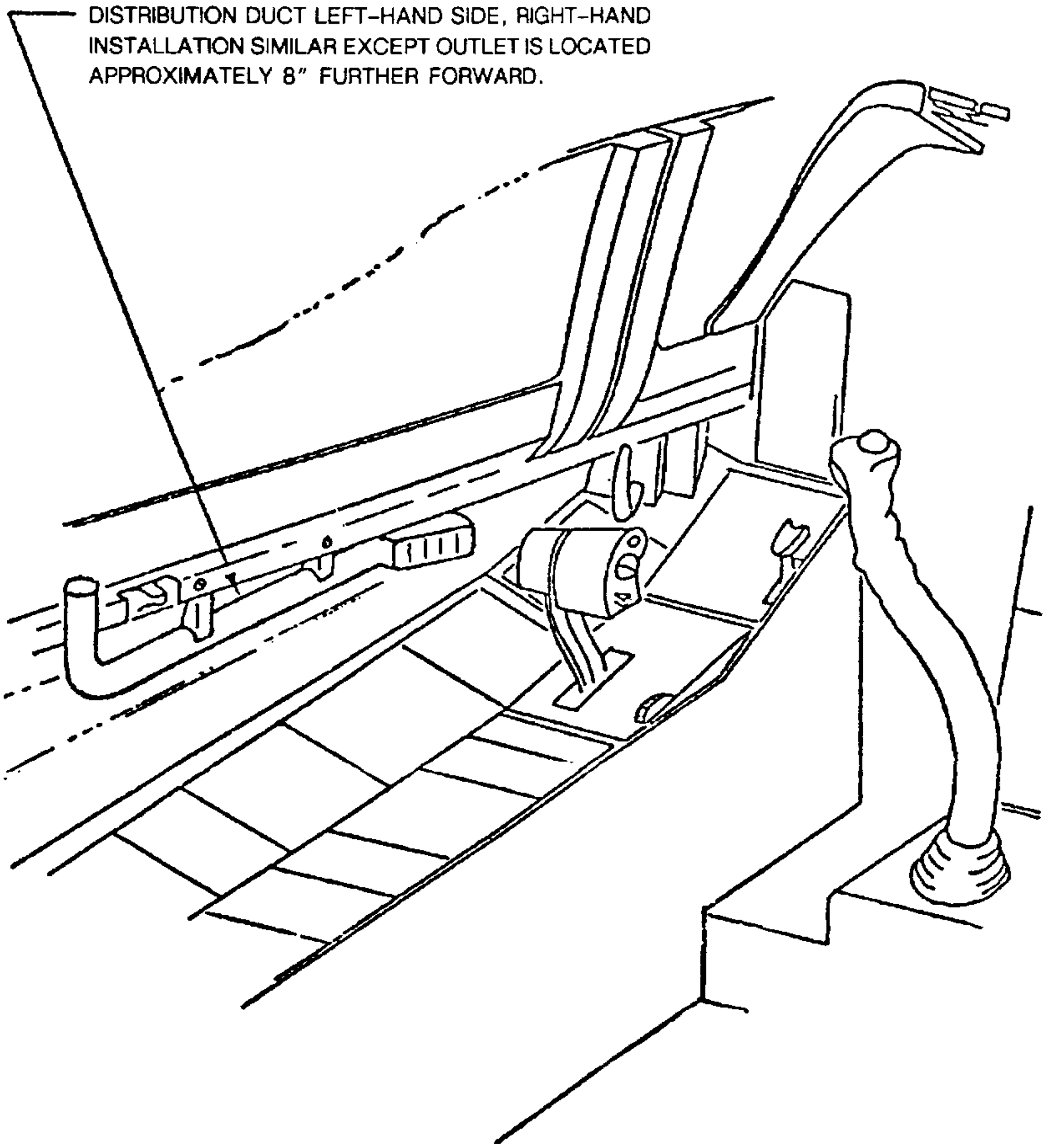

FIGURE D-6. New A-10 distribution duct routing.

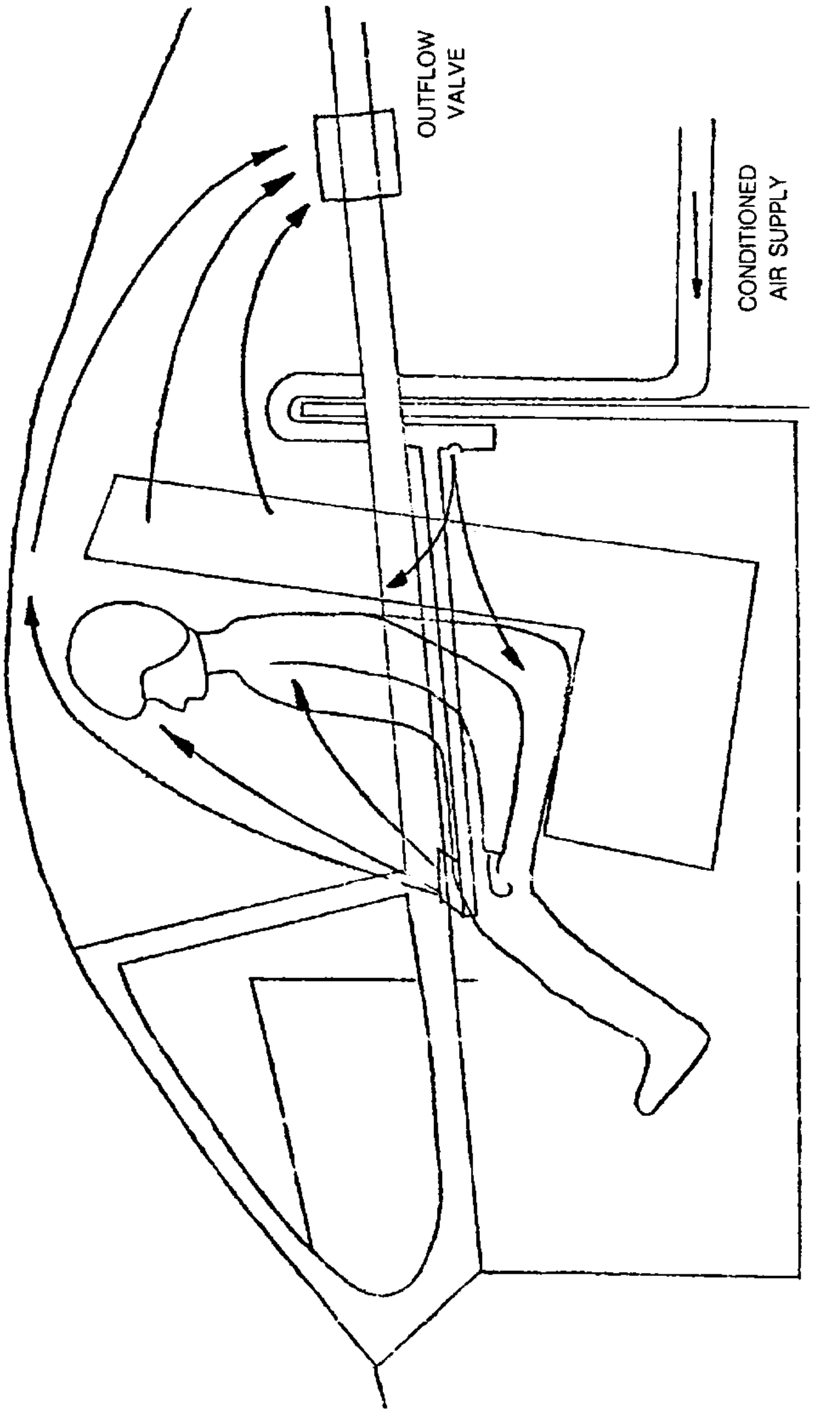

FIGURE D-7. Revised A-10 cockpit flow pattern.

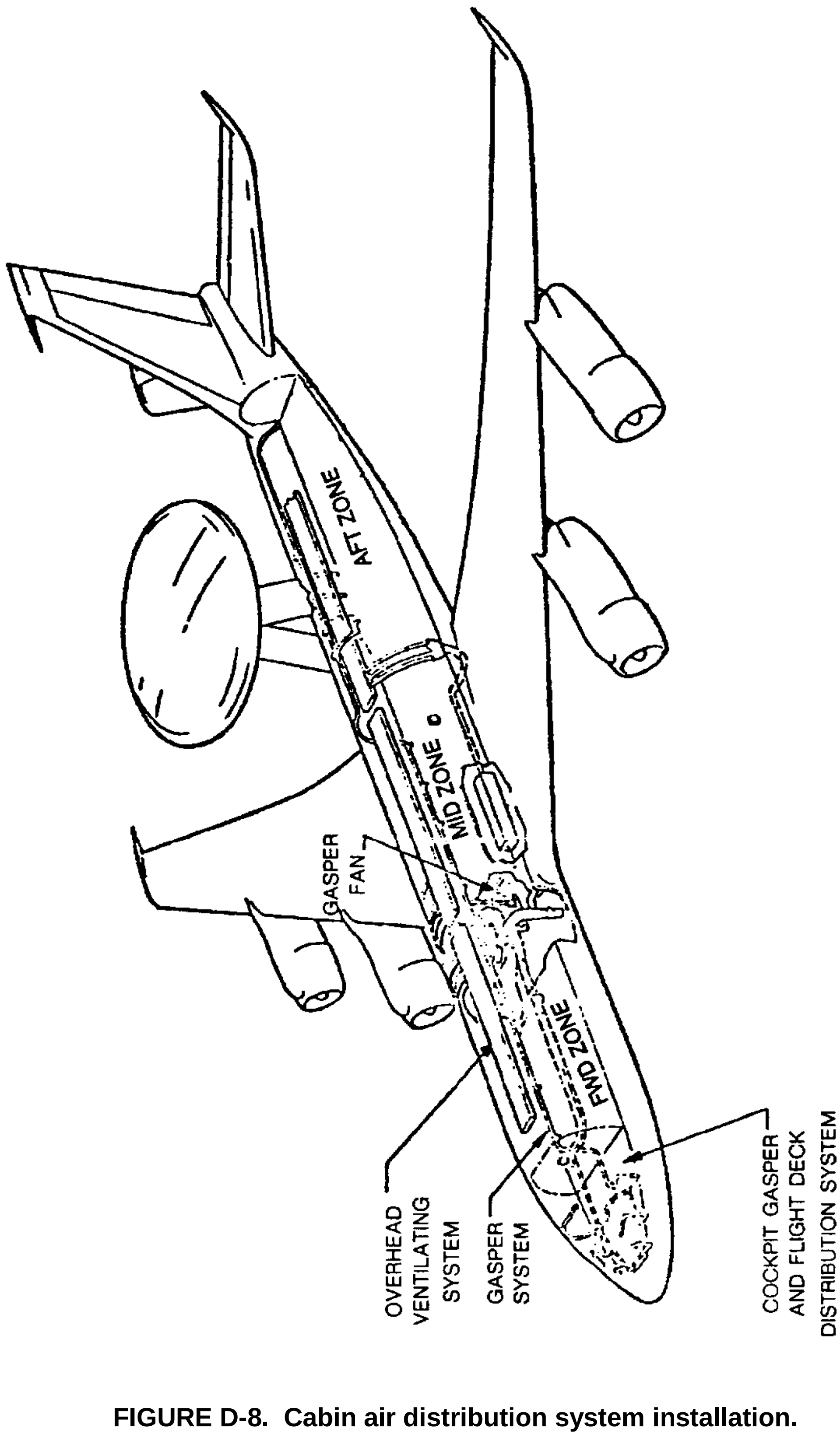

FIGURE D-8. Cabin air distribution system installation.

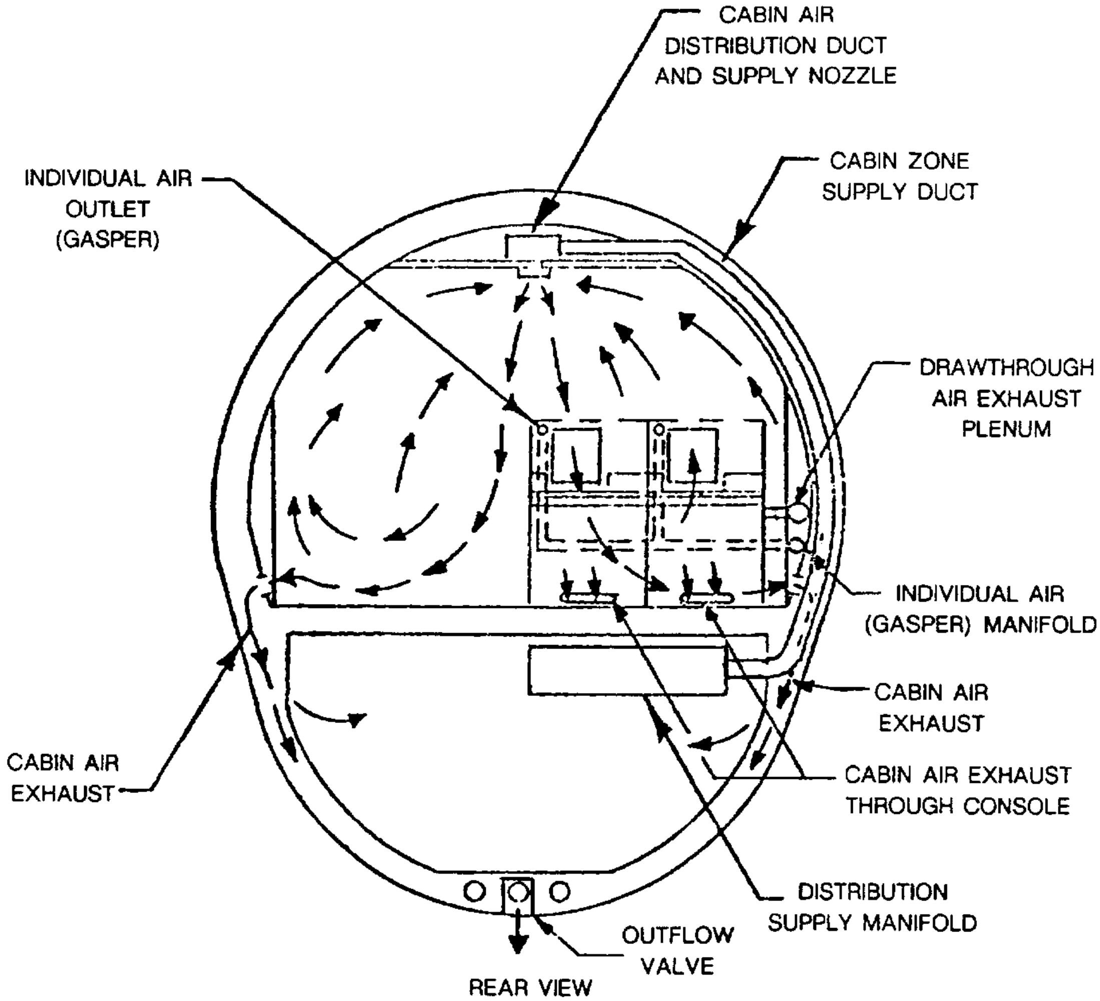

FIGURE D-9. Cabin air distribution.

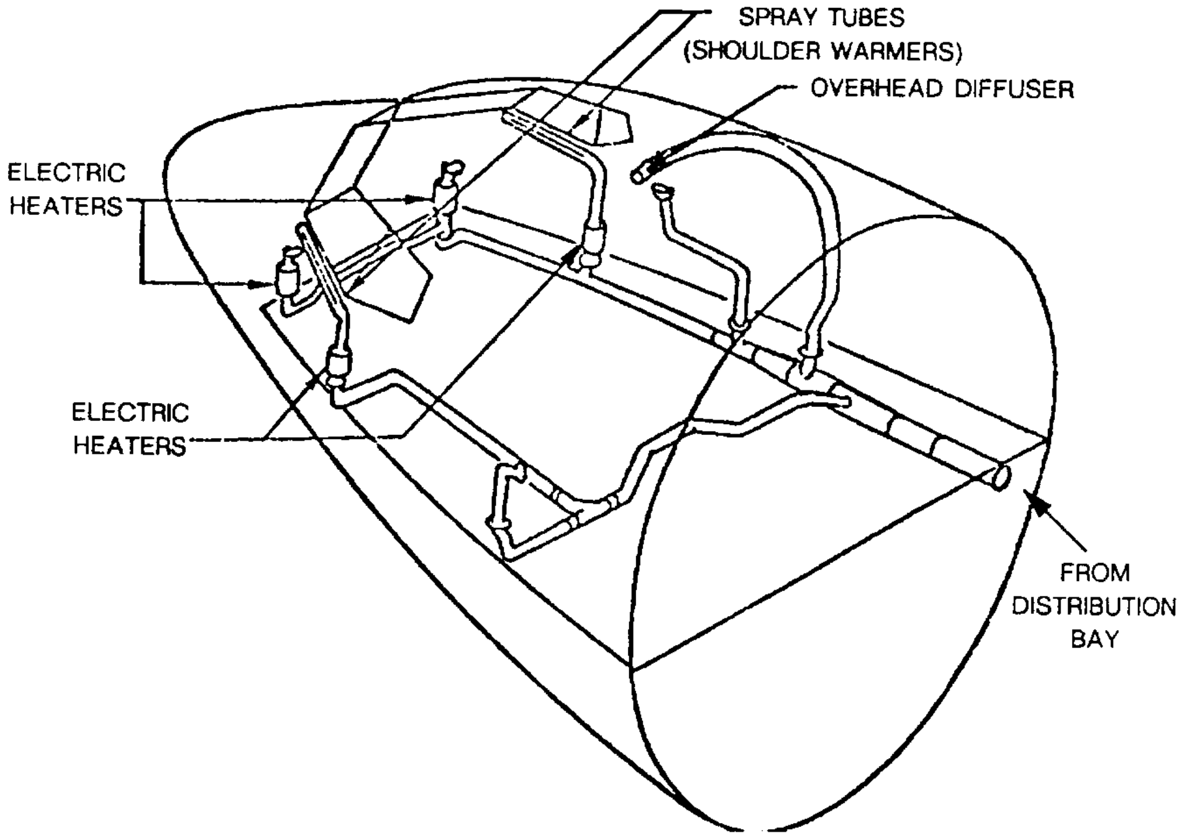

FIGURE D-10. Flight deck conditioned air distribution system.

TBS 3: An analysis should be used to demonstrate that a means exists to prevent harmful or damaging high temperature air from causing equipment damage or personnel injury during normal operation or for a single failure condition. This analysis should be made a part of the System Safety Hazard Analysis and documented.

VERIFICATION LESSONS LEARNED (4.4.4.2.5)

For fighter air vehicles, it has been recommended that a minimum of nine thermocouples be used to determine Pilot Envelope Temperature. Location recommendations are: two at the feet, two at the knees, two at the hips, two at the shoulders, and one at the head above the helmet and shielded from solar influence. An optional tenth thermocouple can be added on the instrument panel (glare shield) center line.

D.3.4.4.2.6 Avionic coolant distribution.

Removal of avionic equipment from their mounting racks during flight and on the ground shall not adversely affect the distribution of air and liquid coolant flow supplied to the remaining avionic equipment.

There shall be no cooling capacity loss due to the removal of equipment from the coolant distribution lines or ducts.

REQUIREMENT RATIONALE (3.4.4.2.6)

Maintaining proper coolant flow to all remaining avionics is necessary when one or more units are removed from their mounting racks, in order to preserve the reliability and operability of those remaining avionics.

REQUIREMENT GUIDANCE (3.4.4.2.6)

Proper coolant flow distribution to all avionic units should be maintained. Avionic equipment can be adversely affected by reduced coolant or loss of coolant when the coolant flow distribution is disturbed by the removal of one or more units from the mounting rack and the coolant lines to and from the equipment are left open. Degraded performance, reduced reliability, and avionic failures can occur.

Shut-off devices in the coolant flow lines or ducts and mounting racks, of all avionic units, that automatically close the coolant flow to and from the unit(s) being removed should be considered. For air cooled equipment, not in a closed system, a shutoff device that automatically closes the flow line with an orifice plates having the same flow-pressure drop characteristics as the units being removed should be strongly considered. Coolant flow lines of liquid cooled units should contain provisions for quick-disconnect and self-sealing automatic shut-off devices to and from the units to eliminate coolant loss. Blind connections should be avoided.

There should be no leakage in coolant distribution ducts and flow lines. The design and compatibility of avionic equipment inlet and exit control of air and liquid coolant flow distribution and shut-off provisions should be coordinated with the air vehicle inlet and exit ducts and flow lines. To achieve this, an early cooperative effort between ECS and avionic equipment engineers, both contractor-furnished equipment and GFE, is required.

Critical to the use of liquids in coolant systems is establishing a means to prevent leaks and determine the quantity of loss that will no longer allow effective performance and maintenance. Based on the maintenance focus on systems being managed using a two level maintenance for line replaceable units, it is recommended that liquid systems consider closed loop operations to minimize the impact of leaks and maximize the opportunity for containment and easy maintenance. This guidance is recommended as a means for highlighting the impact of the distribution system and methodology on the air vehicle’s operations for turning the air vehicle for effective battlefield missions and operations.

REQUIREMENT LESSONS LEARNED (3.4.4.2.6)

The S-3 air vehicle had orifice plates to replace units that were removed from the air vehicle. However, they were kept on the ground and were often lost or hard to find when needed.

The F-18 air vehicle had plates that automatically closed when the box was removed and was pushed out of the way when the box was reinstalled. The F-18 units greatly reduced the overall maintenance time for removing and replacing a box as well as ensuring the proper flow balance was maintained.

D.4.4.4.2.6 Avionic coolant distribution.

Proper avionic coolant distribution shall be verified by __(TBS)__. Ground demonstration on the air vehicle shall verify that one or more pieces of avionic equipment can be removed from their mounting racks without adversely affecting coolant distribution to the other avionics and that liquid cooled boxes can be removed without any leakage of the coolant.

VERIFICATION RATIONALE (4.4.4.2.6)

It is necessary to verify the ability to remove avionics on the ground without adversely affecting flow distribution to the remaining avionics and to remove a liquid cooled box without any leakage of the coolant.

VERIFICATION GUIDANCE (4.4.4.2.6)

TBS: Inspections and tests under actual coolant flow conditions should verify no coolant leakage or loss in the distribution ducts and flow lines.

Coolant shut-off and coolant distribution control devices to and from avionic units that allow the units to be removed from their mounting racks without coolant loss and without adversely affecting coolant distribution to other avionic equipment should be verified. Proper coolant distribution to remaining avionics when one or more avionic units are removed from their mounting racks should be verified. These items should be verified for cockpit and cabin and for each of the different avionics racks or bays in the air vehicle.

VERIFICATION LESSONS LEARNED (4.4.4.2.6)

Air Force experience has noted a loss of valuable turn around time for operations when the origination point of coolant leaks cannot be determined and quickly repaired. The trace of line runs from a physical perspective is often difficult due to packaging constraints and conditions, especially for tactical system air vehicles; therefore, special emphasis is expressed for a more disciplined design pursuit in using liquid-based cooling systems. Thermal packaging of the design is the critical element required for success of this type system. The F-22 radar system is a classic system using Polyalphaolefin (PAO) coolant in a key liquid cooling system that is a lead determinant in the viability of the F-22 air vehicle as an effective weapon system and battlefield operator. Therefore, it is imperative that the design of the liquid distribution system is understood and the rapid turn around of this system under failure conditions is also understood to insure valuable timelines can be retained for a vehicle's return to operations.

D.3.4.4.2.7 Occupied compartment air velocity.

The velocity of air moving past personnel shall be controlled to less than ___(TBS 1)___. Air velocity in the vicinity of litter patients shall not exceed __(TBS 2)__.

REQUIREMENT RATIONALE (3.4.4.2.7)

Air velocity must be limited to ensure a satisfactory environment, prevent blowing of maps, papers, and other loose items at crew stations.

REQUIREMENT GUIDANCE (3.4.4.2.7)

TBS 1: The conditioned air should be properly diffused to limit the velocity in the vicinity of the crew and passengers. Typically, the velocity of air moving past crewmembers is limited to 300 to 500 ft/min, depending upon the crew station and crewmembers' responsibilities. The air velocity in the vicinity of passengers is typically limited to 300 ft/min.

TBS 2: The air velocity in the vicinity of litter patients should not exceed 50 ft/min.

When these requirements are considered, it should be kept in mind that high velocities for extended periods are annoying and fatiguing. High velocity air can also be an acoustical noise problem. Variable and directional flow control is highly desirable at crew stations to allow for individual preference and mission variables (use of maps, as an example).

REQUIREMENT LESSONS LEARNED (3.4.4.2.7)

One of the pilot complaints on the original A-10 distribution system was the high air velocity, which interfered with their maps and knee pads.

D.4.4.4.2.7 Occupied compartment air velocity.

Air velocity requirements shall be verified by analysis and __(TBS)__ testing.

VERIFICATION RATIONALE (4.4.4.2.7)

Verification is necessary to ensure that the air velocity requirements are met.

VERIFICATION GUIDANCE (4.4.4.2.7)

TBS: A cost-effective approach for adequately verifying this requirement should be determined and specified. Typically airflow rates are highest at sea level and can be tested in a mock up or in the air vehicle on the ground. If the system design is such that higher flow rates or variation in the direction of flow rates may result in flight, flight-testing should be required.

VERIFICATION LESSONS LEARNED (4.4.4.2.7)

(TBD)

D.3.4.4.2.8 Occupied compartment flow shutoff.

A method to shut off all air flow to occupied compartments shall be incorporated. At least two means shall be provided to shut off hot air sources to occupied compartments. Accessible means for direct manual operation in flight shall be provided for __(TBS)__.

REQUIREMENT RATIONALE (3.4.4.2.8)

Total flow shutoff capability is required to prevent the introduction of smoke, fumes, toxic gases, or other such contaminants, into the occupied compartments when the source of the contaminants is the ECS and to shut off the system due to a failure (for example, full hot). Dual means to shut off hot air sources are necessary to prevent a single failure from resulting in the inability to shut off hot air to occupied compartments. On cargo, bomber, and other large air vehicles, means for manual operation of certain valves can significantly reduce mission aborts since faulty valves can be manually overridden.

REQUIREMENT GUIDANCE (3.4.4.2.8)

TBS: The manual operation of trim valves, hot air bypass valves, and other such valves, is highly desirable if the valves can be located where they are accessible to the crew. This capability is highly dependent upon the location of the air conditioning package within the air vehicle. In general, this is a "desirable" capability. In some cases, operational needs may dictate a firm requirement; otherwise, the requirement could be specified as, "...should be provided for hot air bypass valves, trim valves, and other such valves, as possible."

REQUIREMENT LESSONS LEARNED (3.4.4.2.8)

The hot air bypass valve on the C-130 has frequently stuck in the open position. This valve is accessible, and the crew has corrected the problem by manually closing the valve. This capability has prevented many mission aborts or degraded missions due to ECS failure.

D.4.4.4.2.8 Occupied compartment flow shutoff.

The ability to shut off all air flow to occupied compartments shall be verified by __(TBS 1)__. The incorporation of at least two means of shutting off hot air sources to occupied compartments shall be verified by __(TBS 2)__. Accessible means for direct manual operation of identified valves shall be verified by __(TBS 3)__.

VERIFICATION RATIONALE (4.4.4.2.8)

Verification is necessary to ensure that the requirements for occupied compartment flow shutoff are met.

VERIFICATION GUIDANCE (4.4.4.2.8)

TBS 1 should be filled in with inspections of drawings and air vehicle demonstrations.

TBS 2 should be filled in with inspections of drawings.

TBS 3 should be filled in with inspections of drawings and air vehicle demonstrations.

VERIFICATION LESSONS LEARNED (4.4.4.2.8)

(TBD)

D.3.4.4.2.9 Transient temperature control

D.4.4.4.2.9 Transient temperature control

D.3.4.4.2.9.1 Transient ground cool-down.

The air conditioning system shall be capable of cooling __(TBS 1)__ to an average temperature of __(TBS 2)__ within a time period of __(TBS 3)__ following a ground heat soak at __(TBS 4)__ conditions.

REQUIREMENT RATIONALE (3.4.4.2.9.1)

Cool-down transient performance requirements are necessary to ensure compartment crew and equipment environmental compatibility with mission requirements.

REQUIREMENT GUIDANCE (3.4.4.2.9.1)

Transient cool-down requirements are mission oriented. Ground maintenance and alert requirements should be addressed when cool-down requirements are developed. Defense customers need to be an integral part of this process to insure customer needs are achieved by this design process and the proper CONOPS are created for proper, integrated operation between man and machine to achieve mission success.

TBS 1 should be filled in with the compartments and equipment requiring transient ground cool down. This may have to generalized, since equipment requirements may not be known when the specification is prepared.

TBS 2 should normally be consistent with the upper level of the temperatures established in, "Occupied compartment ground cooling" in this appendix.

TBS 3 should typically be 15 to 30 min; however, shorter or longer cool-down times may be required as mission requirements dictate.

TBS 4 should use the daily cycle of high temperature and humidity combined with solar radiation called out in the air vehicle specification. The air vehicle specification will normally call out the table in MIL-HDBK-310. This table should be used if it is not referenced in the air vehicle specification and modified to be consistent with the air vehicle specified conditions.

Ambient conditions should be adjusted to account for induced effects such as the increased heating effects from a heat soaked tarmac.

REQUIREMENT LESSONS LEARNED (3.4.4.2.9.1)

(TBD)

D.4.4.4.2.9.1 Transient ground cool-down.

The capability of the ECS to provide the required transient ground cooling shall be verified by (TBS) .

VERIFICATION RATIONALE (4.4.4.2.9.1)

Verification is necessary to ensure that the ECS requirements for transient ground cooling are met.

VERIFICATION GUIDANCE (4.4.4.2.9.1)

TBS should be filled in with the appropriate combination of analysis and testing.

Testing should start no later than three hours prior to sunset to avoid falling temperatures. Note that the time to start the test will vary with the season. The test should proceed until all internal temperatures are varying by less 2°F/hr. The test data should be extrapolated to the conditions specified for the air vehicle.

Testing should be performed with the air vehicle painted as it will be when operational. Extrapolating test data could be performed, but many multi-colored paint schemes such as camouflage are difficult to analyze.

VERIFICATION LESSONS LEARNED (4.4.4.2.9.1)

Often when running cool-down tests, some tests have been run to the specified target temperature rather than to steady state condition. This is useless unless they are running at the specified ambient conditions, which never happens unless the test is conducted in an environmental chamber. In order to extrapolate to specified ambient conditions the steady state temperature must be reached in order to calculate the time constant. Another mistake is starting the test too late and as ambient temperatures fall, the internal temperatures continue to fall never reaching steady state.

Experience has shown that ground cool-down analyses depend a great deal on the skin temperatures utilized in the analysis. The skin temperatures assumed for the air vehicle during these analyses have been frequently too low. This has been particularly true of analyses involving air vehicles with darker paint schemes.

D.3.4.4.2.9.2 Transient ground warm-up.

The heating subsystem shall be capable of heating __(TBS 1)__ to an average temperature of __(TBS 2)__ within a time period of __(TBS 3)__ following a ground cold soak at __(TBS 4)__ conditions.

REQUIREMENT RATIONALE (3.4.4.2.9.2)

Transient ground heat up performance must be specified to define air vehicle cold weather readiness.

REQUIREMENT GUIDANCE (3.4.4.2.9.2)

TBS 1 should be filled in with the compartment(s) to be heated for this requirement.

TBS 2 should be filled in with the temperature value required. Typically 60°F is used as the temperature for the occupied compartments to reach corresponding to the steady state heating guidelines above. Once this is reached, the steady state guidelines then apply. The minimum allowable operating temperature is usually used for equipment and equipment compartments as the temperature goal.

TBS 3 should be filled in with a specified time period to reach the required temperature. Transient ground heat-up times after cold soaking are typically 15 to 30 min. However, shorter or longer warm-up times may be required as mission requirements dictate. Air vehicle scramble, alert time, and ground maintenance requirements should be examined for compatibility with warm-up performance. Trade studies should be performed to determine the specific warm-up times.

TBS 4: Cold soak conditions should use the daily cycle of low temperature called out in the air vehicle specification. The air vehicle specification will normally call out the table in MIL-HDBK-310. This table should be used, if it is not referenced in the air vehicle specification, and modified to be consistent with the air vehicle specified conditions. Nighttime conditions should be used with radiation to a cloudless sky.

REQUIREMENT LESSONS LEARNED (3.4.4.2.9.2)

(TBD)

D.4.4.4.2.9.2 Transient ground warm-up.

The capability of the heating subsystem to provide the required transient ground heating shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.4.2.9.2)

Verification is necessary to ensure that the heating subsystem requirements for transient ground warm-up are met.

VERIFICATION GUIDANCE (4.4.4.2.9.2)

TBS should be filled in with the appropriate combination of analysis and testing.

Testing should be completed before dawn. The test should proceed until all internal temperatures are varying by less 2°F/hr. The test data should be extrapolated to the conditions.

VERIFICATION LESSONS LEARNED (4.4.4.2.9.2.)

Often when running warm-up tests, some tests have been run to the specified target temperature rather than to steady state condition. This has proven to be useless unless the tests were conducted at the specified ambient conditions. Experience has shown that this never happens unless the test was conducted in an environmental chamber. In order to successfully extrapolate to specified ambient conditions, the steady state temperature must be reached in order to calculate the time constant.

D.3.4.4.2.10 Thermal control of other compartments, structure, skin, equipment, and subsystems.

The thermal control of other compartments, structure, skin, equipment, and subsystems shall be as follows: (TBS) .

REQUIREMENT RATIONALE (3.4.4.2.10)

Depending upon the operational needs of the air vehicle, thermal control may be required for weapons bays, wheel wells, structure, skin panels, special purpose compartments or equipment, and other subsystems.

REQUIREMENT GUIDANCE (3.4.4.2.10)

TBS: The other compartments, structure, skin panels, equipment, or subsystems which require thermal control should be defined along with any specific requirements.

REQUIREMENT LESSONS LEARNED (3.4.4.2.10)

Experience has shown that the design of hot air vehicle structures has required the input of three, separate, technical disciplines to be successful. Environmental Control System, structures, and aerodynamics engineers have all needed to be involved. Frequently, only one or two of these disciplines have been involved on past programs. This has led to serious design deficiencies in several, different air vehicle programs. Solution of this problem in the future requires the recognition of the potential problem by the engineers involved and the involvement of all affected disciplines early in the air vehicle design effort.

D.4.4.4.2.10 Thermal control of other compartments, structure, skin, equipment, and subsystems.

Analyses and ground and flight tests shall verify thermal control is provided as follows: __(TBS)__.

VERIFICATION RATIONALE (4.4.4.2.10)

This completed paragraph will provide for verification of the requirements of 3.4.4.2.10.

VERIFICATION GUIDANCE (4.4.4.2.10)

TBS: The other compartments, structure, skin panels, equipment or subsystems which require thermal control should be defined along with any specific requirements. Analytical performance analyses should be conducted early to predict and verify adequacy of thermal control system performance. The performance analyses should then be verified by ground and flight tests.

VERIFICATION LESSONS LEARNED (4.4.4.2.10)

(TBD)

D.3.4.4.3 ECS crew station interface.

The following controls shall be provided: __(TBS 1)__. Controls shall be readily accessible to the appropriate crew member(s). The controls used throughout the ECS shall not cause instability when subjected to any normal operational condition including: __(TBS 2)__. The contractor shall establish minimum dynamic performance requirements, such as settling time, maximum overshoot, and such, consistent with operational requirements and good air vehicle design practice. The following warnings, cautions, and advisories shall be provided: __(TBS 3)__. Controls, sensors and instruments shall be consistent with air vehicle fault isolation requirements.

REQUIREMENT RATIONALE (3.4.4.3)

Appropriate controls, sensors, and instruments are specified (and occasionally, their location) in accordance with the operational needs of the air vehicle to permit the safe operation of the system. Caution indicators, warning lights, and such, are required to alert the crew to problems so corrective action can be taken before personnel injury or physiological deterioration occurs. Appropriate controls, sensors and instruments are required to assist maintenance personnel in fault isolating the ECS.

REQUIREMENT GUIDANCE (3.4.4.3)

The appropriate requirements should be specified based upon the requirements of the system under consideration. Coordination with the crew system engineer should occur when these requirements are established.

TBS 1: The ECS should have a control panel(s) or equivalent (such as a page on a multi-function display) which is (are) accessible by the pilot and co-pilot, or other crew member. The panel(s) should allow all ECS functions to be controlled and all warnings, cautions, and advisories to be displayed. The controls include but are not limited to:

a. bleed air control (on or off) for each source of bleed air, including engine, shaft driven compressor or APU or secondary power unit
b. bleed air temperature out of the engine compartment is too high
c. ECS off and on
d. ram air selection (or other appropriate backup cooling scheme)
e. cockpit temperature control (automatic and manual)
f. cockpit pressure dump as required
g. air flow rate as required
h. individual zone temperature control as required (automatic and manual)
i. NBC system on or off as required
j. defog selection as required
k. windshield anti-ice as required

l. safety critical functions as required

m. mission critical functions as required.

Automatic controls are the most efficient and effective means of controlling modern, complex Environmental Control Systems. Automatic controls can also better maintain the selected cabin temperature and minimize the attention and manipulation required by the pilot (or other crew members). Manual override provisions or degraded mode operation of the control system should be included to permit the crew to position the valves controlling air temperature if the automatic temperature control fails, or for use under special circumstances. Automatic controls may be unnecessary in prototype or special purpose air vehicles.

The controls should be readily accessible to the crew. In large air vehicles where there may be several temperature “zones” or many compartments, individual controls can be provided in each compartment to permit control of the temperature by the occupants. An example would be a separate temperature control in the Aerial Refueling Operator’s Station on tanker air vehicles. On cargo air vehicles, there may be a requirement for a cargo compartment control at the Loadmaster’s Station. In all cases, the pilot or flight engineer should have ultimate control authority over the system, with the capability to disable or override the other individual controls, as necessary.

Response characteristics, such as tolerance, settling time, and maximum overshoot, can be specified, as appropriate. Temperature controls should typically hold the Pilot Envelope or Compartment Ambient Temperature to within ±1.5°F of the setting selected by the occupants. The typical range of temperatures used is 65 to 80°F. If suits are to be used on the air vehicle which require ventilation or pressurization flow from the air vehicle, the temperature control requirements for those suits need to be stated with coordination with the crew system engineer. Suit temperature should normally be maintained within 3°F of the setting selected by the occupants during steady state conditions and 5°F during transient conditions.

TBS 2 should be filled in as appropriate with consideration of the following. Any special conditions for the air vehicle should also be used:

a. All normal flight and ground conditions.

b. All normal vehicle configurations.

c. Any transient induced by changes in air vehicle flight conditions or vehicle configuration.

d. Any manual or automatic changes in ECS control settings.

e. Transients induced by the bleed air source.

f. Changing the bleed air source.

g. Any single failure in any ECS component.

h. If an integrated ECS controller is used, it should not drive the system unstable in the presence of a single internal failure or due to a single sensor failure.

TBS 3: In general, fighter and attack air vehicles have only warning indicators, while large air vehicles with multiple engine bleed, multiple temperature zones, large avionics loads, and such, may require many indicators so the pilot and flight engineer can properly monitor and control the system.

An indication should be provided to the flight crew in the event that coolant supply conditions (temperature and flow rate) do not meet minimum requirements.

An indication of occupied compartment pressurization should be provided in one of the following two ways. If set points are specified for the warning and caution lights, they should be coordinated with 3.4.4.1.6 to ensure adequate time for corrective action or emergency descent.

For combat air vehicles, the following should be considered:

a. Cabin air pressure altitude indicators should be provided.
b. If the air vehicle can fly above 42,000 ft, a warning indication should be provided to warn the crew that compartment pressure has dropped below some predetermined minimum value, usually 3 psia.

For non-combat air vehicles, the following should be considered:

a. Cabin air pressure altitude indicators should be provided.
b. Instruments to show cabin rate of climb and descent in feet per minute and the cabin differential in psi should be provided in the crew compartment.
c. A caution indicator to show loss of compartment pressure below some predetermined minimum value, usually 10 psia, should be provided.
d. A warning indication that compartment pressure has dropped below 8 psia should be provided in all passenger-carrying air vehicles which fly above 25,000 ft.

The following indications should be considered when establishing requirements:

a. Bleed air temperature
b. Bleed air pressure
c. Bleed valve position
d. Refrigeration pack discharge temperature
e. Control valve position
f. Cabin (zone) supply temperature
g. Zone temperatures
h. Turbomachinery overspeed
i. Trim air temperature
j. Turbine inlet temperature
k. Cargo, electronic, other compartment temperatures
l. Unique requirements due to the special mission of the vehicle.

Also, a warning should not be provided if some type of corrective action cannot be taken. To reduce false warnings and system limitations, the same sensor should not be used for both airflow control and warning.

REQUIREMENT LESSONS LEARNED (3.4.4.3)

The USAF has experienced dual failures in cases where single failures (such as a pressure regulator failure) have gone unnoticed until a second failure occurs. These dual failures have resulted in the introduction of high temperature bleed air into the cockpit, with serious consequences. An A-10 experienced an automatic temperature control failure and the backup manual control reacted too slowly to prevent injury to the pilot. A manual control should probably be able to return the inlet temperature to within acceptable limits in less than 5 sec for the worst-case condition.

On the E-4B, the flight engineer could reposition control valves for avionics racks.

Dynamic performance and instability problems have occurred during most recent ECS development programs. The F-4 has always had flow surge problems, and they were aggravated when a water separator and its associated anti-ice control were added. The F-5F had severe pressure surge problems in the cockpit, which were corrected with the addition of a bleed pressure regulator with rate control, and other changes. The AWACS air vehicle experienced bleed system instabilities that could be corrected only through a redesign of the system. The F-15, A-10, and F-111 also had stability problems, which were identified during ground or flight testing.

In the past, dynamic problems generally have been found only after the hardware is built—during ground or flight tests. Problems discovered during flight tests, particularly pressure and surge problems, can be difficult if not impossible to trace and correct because of the many interacting controls in the typical ECS. An excellent example is a pressure surge problem that occurred on the F-111 air vehicle. The pressure surges were causing “overpressure indicators" on pressure regulating valves to indicate a malfunction, but troubleshooting on the ground would never identify any problems or malfunctions. It was necessary to conduct a special laboratory test that identified the cause to be the interaction between two redundant (series) pressure regulators. Once identified, the problem was easily corrected by changing the sensing port locations.

D.4.4.4.3 ECS crew station interface.

Inspection of drawings and the air vehicle shall verify incorporation of the required control, warnings, cautions, and advisories. Analyses, laboratory tests, and air vehicle ground and flight tests shall be conducted to demonstrate satisfactory operation of all control components during: (TBS) .

VERIFICATION RATIONALE (4.4.4.3)

The adequacy of the air conditioning system must be established early in the design of the system to avoid problems and expensive design changes. This is done through review of drawings and qualification tests. Flight testing provides the final verification that the system meets the performance requirements. Flight testing is the only means to verify performance under many conditions, such as transients. Laboratory and flight testing can often be performed in conjunction with other system testing, requiring minimal additional resources. Laboratory testing can identify problems early before costly redesigns are needed and can be used to simulate failure conditions that would be difficult or dangerous to do in flight.

VERIFICATION GUIDANCE (4.4.4.3)

TBS should include the following as applicable and any other special requirements for the specific air vehicle:

a. All normal flight and ground conditions.

b. All normal vehicle configurations.

c. Any transient induced by changes in air vehicle flight conditions or vehicle configuration.

d. Any manual or automatic changes in ECS control settings.

e. Transients induced by the bleed air source.

f. Changing the bleed air source.

g. Any single failure in any ECS component.

h. If an integrated ECS controller is used, the system should demonstrate stable operation during an internal integrated controller failure or a control sensor failure.

Review of drawings and crew station mockups should be used to verify such items as accessibility of controls and as an initial review of provisions for manual or degraded mode operation in the event of automatic mode failure. Laboratory qualification tests provide an inexpensive as well as safe way to test simulated failure modes as well as a preliminary review of control accuracy. Flight testing provides the final verification that the system meets the performance requirements. Flight testing is the only means to verify performance under many conditions, such as transients. Operating the system under “manual full hot” should be a test point to verify the controls properly limit the maximum temperatures entering the occupied areas.

A laboratory system test using the production configuration control software should demonstrate that the ECS control system functions without distracting the crew, displays stable characteristics, and controls all ECS functions safely and as required. Verification should ensure controls and software functionality as well as hardware functionality. This is needed due to the increasing reliance on software in the control of complex systems. The laboratory ECS rig should test all revisions to the ECS software affecting the control functions. The test rig should incorporate interface data buses to simulate control data transfer between systems (or within the ECS) or provide this data to the controller with the specified protocol. For example, a digitized temperature signal from the fuel system may be used by the ECS controller. This feedback information should be provided to the controller at the contractor specified frequency to simulate actual system performance. Air vehicle flight tests should demonstrate that the installed ECS functions as required and that crew compartment control settings vary linearly with the controlled parameter.

With the development and general availability of advanced computer programs such as the Engineering Analysis System (EASY), extensive early evaluation of proposed system dynamic performance is now possible and should be used routinely as a design tool.

VERIFICATION LESSONS LEARNED (4.4.4.3)

(TBD)

D.3.4.4.4 Surface touch temperatures.

Floor areas normally contacted by personnel shall be maintained at or above __(TBS 1)__ for all steady-state flight conditions. All other floor areas shall be maintained at or above __(TBS 2)__. The temperature of all surfaces, except small local areas such as diffusers and circuit breakers, which enter into radiant heat exchange with personnel shall be maintained within the range of (TBS 3)__ for steady-state conditions. All surfaces that can be touched by personnel shall be maintained within upper and lower temperature limits defined by __(TBS 4)__.

REQUIREMENT RATIONALE (3.4.4.4)

Minimum floor temperatures are specified to prevent discomfort or injury. Maximum and minimum surface temperatures are specified to prevent injury to personnel and to control or minimize radiant heat exchange with occupants.

REQUIREMENT GUIDANCE (3.4.4.4)

TBS 1 should be filled in with a minimum temperature value. Generally, the minimum average floor surface temperature should be 60°F or higher at crew stations or passenger seats. For air vehicles such as rotorcraft where 60°F was selected as the minimum average occupied compartment temperature, a lower temperature such as 55°F may have to be selected, since it is impossible to maintain a 60°F floor temperature with a 60°F compartment temperature. A temperature of 40°F is a reasonable lower limit for any other floor areas contacted by personnel.

TBS 2 should be filled in with a minimum temperature value. Temperatures should be above 32°F to prevent the formation of frost or ice, which can cause slippery surfaces. For unoccupied areas, such as some cargo compartments, the surfaces should be maintained above 32°F to prevent the freezing of cargo, formation of frost and ice, and such.

TBS 3 should be filled in with a temperature range. Upper and lower temperature limits for momentary and prolonged contact of different types of materials are defined in MIL-STD-1472. The temperature of all surfaces, except small local areas such as diffusers and circuit breakers, which enter into radiant heat exchange with personnel should be maintained within a specified range for steady-state conditions. Generally, the temperatures of these surfaces should not exceed 105°F under steady-state conditions, since temperatures above 105°F begin to have a noticeable effect on radiant heat transfer with the occupants. For transient periods, typically 30 minutes or less, the requirement can be relaxed to a maximum of 160°F. A value of 160°F will cover ground operation where the air vehicle is heat soaked and high surface temperatures will exist in direct solar radiation. 160°F is also consistent with the high temperature limits usually used for non-operating equipment. A reasonable lower limit is 50°F, as lower temperatures will result in noticeable radiant heat exchange. All surfaces that can be touched by personnel should be maintained within defined upper and lower temperature limits.

TBS 4: The following should be considered when the surface touch temperatures requirement is addressed:

a. Floor temperatures should be kept high enough to prevent cold feet, hazardous conditions, and cargo damage.

b. Unguarded surface temperatures should be kept low enough to prevent personnel injury. See MIL-STD-1472 for guidance on specific temperature values.

c. Heat transfer should be minimized.

REQUIREMENT LESSONS LEARNED (3.4.4.4)

In the past, surface temperature requirements have generally not been enforced or verified, except for floor areas in cargo air vehicle or when pilot comments or complaints indicated an improvement was necessary. However, high surface temperatures are beginning to receive greater attention because of the impact on the crew environment and on instruments and avionics reliability. Very high temperatures have been recorded around and behind the instrument panels and improved instrument panel cooling techniques are in development. It is expected that more stringent instrument panel requirements and verification requirements will be levied in the future. Also, a low temperature requirement should be specified for surfaces that enter into radiant heat exchange with personnel.

Shrouds constructed of phenolic resin with an internal air gap around the pressure carrier have been successfully used on bleed air ducts that pass through occupied areas to provide an insulated surface with safe touch-temperatures.

D.4.4.4.4 Surface touch temperatures.

Proper touch temperature implementation shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.4.4)

Verification is necessary to ensure that proper touch temperatures are maintained.

VERIFICATION GUIDANCE (4.4.4.4)

TBS: Analyses and flight-testing should verify that surface temperatures are adequate for human comfort, floor surfaces are maintained at or above the specified temperature, and surfaces which can be touched meet the specified requirements. Hazard analyses should be performed to ensure no hazards are created by the operation of the ECS and verified in flight test. Instrumentation should generally be required only to verify floor heating systems. Other surface temperatures can be evaluated subjectively by the crew, with measurements required only for questionable areas. Potential temperature hazards should be analyzed. Measurements should be made where the analysis indicates the temperatures are close to their limits to validate the analysis.

VERIFICATION LESSONS LEARNED (4.4.4.4)

Experience has shown that surface temperatures and most other heating and cooling requirements should be tested under all environmental conditions. For example, floor heating systems have been generally tested under cold day conditions, as are the adequacy of floor temperatures and foot warming provisions. As experience on the A-10 showed, the system may appear very adequate during arctic testing when the aircrew is dressed for cold weather. However, under normal operating conditions where the crew is more lightly dressed, they may complain of “cold feet" or other problems. Therefore, test programs should be designed to verify the system with allowance for variation in crew dress.

D.3.4.4.5 Ventilation

D.4.4.4.5 Ventilation

D.3.4.4.5.1 Occupied compartment normal ventilation.

Fresh air ventilation for contaminant and odor removal shall be provided to occupied compartments during all flight and ground conditions. Contamination levels of “Occupied compartment contamination” in this appendix shall be maintained. A minimum of __(TBS 1)__ cubic feet per minute (cfm) shall be provided to each crew member. A minimum of __(TBS 2)__ cfm shall be provided to each passenger. Galley and toilet areas shall be vented and provided with direct overboard exhaust outlets sufficient to eliminate odors.

REQUIREMENT RATIONALE (3.4.4.5.1)

Fresh air ventilation is required to provide the necessary oxygen content, prevent high CO_2 concentrations, and remove moisture and objectionable odors.

REQUIREMENT GUIDANCE (3.4.4.5.1)

Figure D-11 shows ventilation flow requirements as a function of cabin volume.

TBS 1 should be filled in with a minimum flow rate value. Curve D of figure D-11 is recommended for most situations.

TBS 2 should be filled in with a minimum flow rate value. Curve C of figure D-11 is recommended for most situations.

The cooling, heating, or pressurization airflow requirements of an open loop air cycle system generally exceed the minimum ventilation requirements, so this requirement will rarely influence the system design. The possible exception is engine idle descent and ground operation of large-volume, passenger-carrying air vehicles or transport type rotorcraft. Under these conditions, the bleed pressures and flows are low and the requirements frequently relaxed.

The use of vapor cycle and closed loop or partially closed loop air cycles may reduce the amount of fresh air normally used to meet cooling and heating requirements. The ultimate requirement is to maintain the specified contamination levels. Commercial air vehicles currently provide 100 percent (100%) fresh air to the cockpit in air vehicles where re-circulation is used. This requirement should be considered if there is a concern that the specified requirements are not adequate, or that the system design may deteriorate with use and not provide an adequate environment for pilots over the life of the air vehicle.

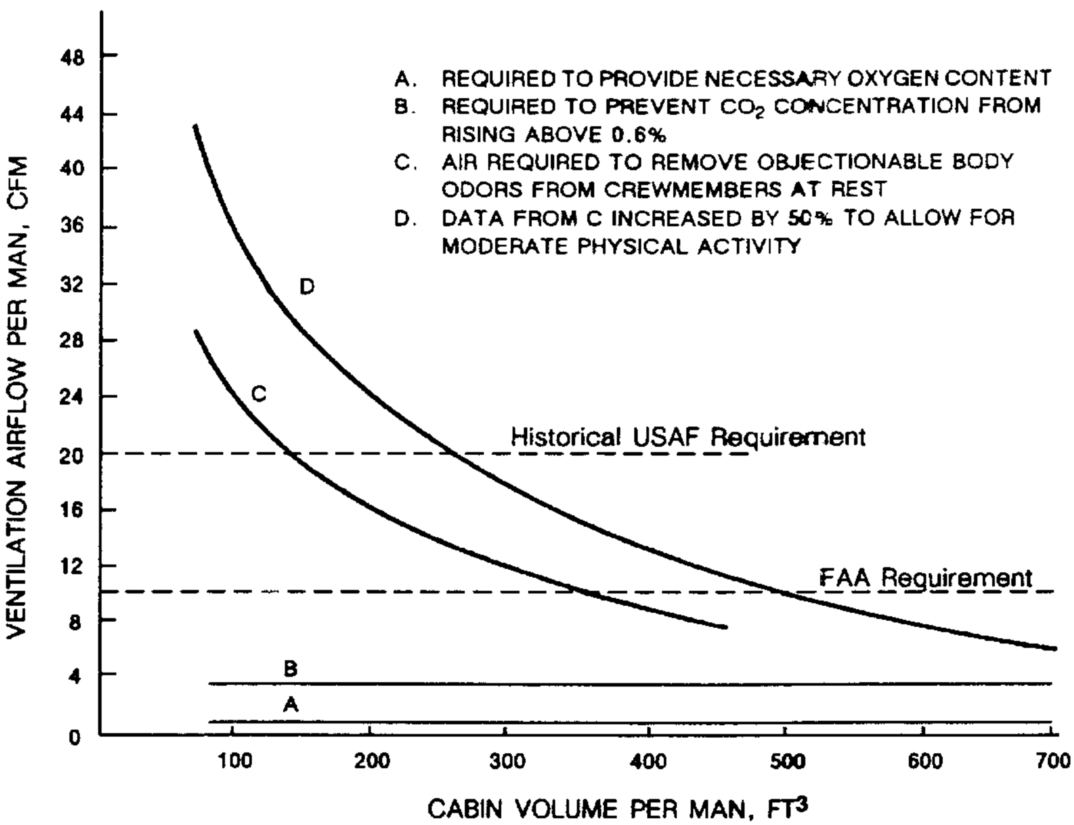

FIGURE D-11. Ventilation flow rate as a function of cabin volume.

REQUIREMENT LESSONS LEARNED (3.4.4.5.1)

For the C-5A air vehicle, the allowable minimum ventilation rate was reduced to 12 cfm per person for the aft troop deck and cargo compartment. This reduced minimum rate has proved acceptable

Experience has shown that several types of failures can cause contamination or overheating of the occupied compartment resulting in the necessity to turn off the ECS. In this event, it is necessary to have an alternate ram air source, especially if the failure has caused smoke or odors in the occupied compartment. Failure of cabin temperature controls can result in overheat and odor and the necessity to shutoff the system and use ram air. Bleed air contamination due to an oil leak can contaminate the bleed system and cause the crew to shut off the ECS and use ram air. Bearing failures of the air cycle machine (ACM) can contaminate air. Combat damage can cause loss of ECS and result in the need for fresh air ventilation. A combat mission may require use of the ram air system when the ECS fails.

During evaluation of generic smoke removal procedures for various air vehicle programs, it became clear that no single procedure was effective for clearing smoke from occupied compartments of all air vehicles. Smoke removal is highly dependent on air vehicle flow patterns and internal compartment design.

D.4.4.4.5.1 Occupied compartment normal ventilation.

The capability of the ECS to provide fresh air ventilation and contamination control shall be verified by (TBS). Galley and toilet areas ventilation shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.4.5.1)

Verification is necessary to ensure that the ECS can provide fresh air ventilation and contamination control as required.

VERIFICATION GUIDANCE (4.4.4.5.1)

TBS should be filled in with the appropriate combination of analysis and testing.

Analysis or testing should show that the required level of fresh air is provided to the cockpit on a continual basis during normal operation.

VERIFICATION LESSONS LEARNED (4.4.4.5.1)

(TBD)

D.3.4.4.5.2 Occupied compartment emergency ventilation and smoke removal.

Emergency fresh air ventilation shall be provided to occupied compartments during periods when the normal air conditioning and ventilation system has failed or is shut off due to contamination of the normal ventilation air supply or temperature control failure. Means shall be incorporated to remove smoke or gases originating in the occupied compartments as a result of fire or smoke.

REQUIREMENT RATIONALE (3.4.4.5.2)

Emergency ventilation provisions are usually required for all air vehicles to provide ventilation when the normal method from the Environmental Control System has failed or is contaminated, or other emergency conditions exist. Also, rapid means for smoke removal from the cockpit and passenger-occupied cargo compartments are required to allow the crew visibility and prevent nausea or asphyxiation.

REQUIREMENT GUIDANCE (3.4.4.5.2)

Ram air is generally used for emergency ventilation. The emergency ventilation air should be supplied to each occupied compartment. It may be desirable to control the volume of ram air entering some compartments. The system should provide the required ventilation under all flight conditions. Icing of ram air scoops is an important consideration. The emergency ram air selector should shutoff the air conditioning system air supply to the occupied compartment when ram air is selected. However, the defrosting air and the electronic equipment cooling should not be automatically shutoff when ram air is selected for occupied compartments. A procedure for smoke removal should be verified early in the flight test program. The procedure should be included in the flight manual.

Consider the effects of the normal air conditioning system, emergency ram air ventilation and pressurization system, and availability of operable doors, hatches, and windows, in establishing the smoke removal procedure. Ensure smoke or gases from the cargo compartment will not enter the cockpit.

REQUIREMENT LESSONS LEARNED (3.4.4.5.2)

(TBD)

D.4.4.4.5.2 Occupied compartment emergency ventilation and smoke removal.

Emergency occupied compartment ventilation shall be verified by __(TBS 1)__. Emergency smoke removal shall be verified by demonstration as specified in __(TBS 2)__.

VERIFICATION RATIONALE (4.4.4.5.2)

The provisions for emergency ventilation and smoke removal can be verified by inspecting drawings, but the performance must be verified by test.

VERIFICATION GUIDANCE (4.4.4.5.2)

TBS 1 should be filled in with inspection of drawings and flight demonstration to verify emergency fresh air ventilation for occupied compartments.

TBS 2 should be filled in with inspection of drawings and flight tests.

A small smoke generator can be used to release smoke in the cabin and the time required to clear the smoke can be measured. This method has been used on many cargo air vehicles. Whether or not an actual flight test is required should be determined based upon the probability of smoke entering the area, possible causes, and the hazard associated with the actual test. For fighter air vehicles, the time could be estimated by analysis. The procedure for removal of smoke should be developed and tested early in the flight test program.

VERIFICATION LESSONS LEARNED (4.4.4.5.2)

Roscoe® Smoke Generators have proven reliable and inexpensive for use in smoke removal tests.

D.3.4.4.5.3 Avionic equipment and equipment compartment emergency cooling.

In the event of failure of the normal mode of avionic cooling, an alternate cooling mode shall be provided for __(TBS)__.

REQUIREMENT RATIONALE (3.4.4.5.3)

An auxiliary means for cooling mission essential or "safe return" to base avionics should be provided for use when the normal air conditioning system is inoperative. This will prevent mission aborts or flight safety hazards due to ECS failure.

REQUIREMENT GUIDANCE (3.4.4.5.3)

TBS: The avionics required to be cooled by the alternate cooling mode should be defined in coordination with the avionics system engineer. This would normally be either mission essential or "safe return" to base avionics.

For Army rotary-wing air vehicles, the backup cooling mode should allow for the mission to be completed. Ram air is usually used as the alternate cooling mode for equipment cooled by ECS air. An acceptable practice is to design emergency ram air cooling to provide sufficient cooling as long as ram air temperature is below 120ºF. For liquid cooled avionics an acceptable practice is to have redundant and independent coolant lines. Another approach is to design the avionics to operate for a specific amount of time without cooling. This approach would need to be coordinated with the avionics system engineer.

REQUIREMENT LESSONS LEARNED (3.4.4.5.3)

(TBD)

D.4.4.4.5.3 Avionic equipment and equipment compartment emergency cooling.

The emergency avionic and equipment cooling provisions shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.4.5.3)

Verification of the existence and adequacy of the emergency cooling provisions is required.

VERIFICATION GUIDANCE (4.4.4.5.3)

TBS should be filled in with inspection of drawings and flight tests.

The avionics required to be cooled by the alternate cooling mode should be defined. The performance of the emergency cooling provisions should be evaluated at several points throughout the flight envelope. Tests should show that enough cooling exists to the avionics and electrical equipment for mission completion or "safe return to base", as specified in the requirement. If there are two modes of emergency cooling, such as a redundant blower and ram air, the performance of each method should be evaluated during flight test.

VERIFICATION LESSONS LEARNED (4.4.4.5.3)

On a new cargo air vehicle program, two methods of emergency avionic cooling were provided. However, the contractor contended it was necessary to conduct verification tests for only one of the methods.

D.3.4.4.5.4 Suit ventilation and pressurization.

If required, an air supply shall be provided to __(TBS)__.

REQUIREMENT RATIONALE (3.4.4.5.4)

Anti-g suits, pressure suits, ventilation suits, NBC suit, anti-exposure suits, and such, may be required to meet the mission requirements of the vehicle. The ECS must supply air at the pressure, flow, temperature, moisture, and contamination levels compatible with the respective suits. The ECS must meet ventilation requirements of capsules or cargo areas if these areas are on the air vehicle.

REQUIREMENT GUIDANCE (3.4.4.5.4)

TBS should identify any suits that require ventilation and pressurization.

Suits such as pressurization, ventilation, anti-g, NBC and anti-exposure suits have specific pressure drop, temperature control flow rate, moisture and contamination requirements which should be maintained. The ECS engineer should coordinate with the crew system engineer to specify the correct requirements for the particular suit or suits to be used on the air vehicle.

These requirements should include such items as shut-off provisions where there needs to be a determination as to whether they will be mounted on the suit or on the air vehicle.

REQUIREMENT LESSONS LEARNED (3.4.4.5.4)

(TBD)

D.4.4.4.5.4 Suit ventilation and pressurization.

If required, suit ventilation requirements shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.4.5.4)

Analysis and laboratory testing should be performed to provide early verification of suit or other ventilation requirements to avoid costly redesigned later. Proper performance can only be completely verified by flight testing.

VERIFICATION GUIDANCE (4.4.4.5.4)

TBS: The performance of ventilation or pressurization provisions for suits such as pressurization, ventilation, anti-g, NBC and anti-exposure suits should be verified first during analysis and then during flight tests. Analysis should be performed to provide early verification that requirements are being met. Pressure, flow and temperature requirements of the suit to be used can be simulated in the ECS laboratory test for additional verification. In flight testing with the actual suit provides the final verification.

VERIFICATION LESSONS LEARNED (4.4.4.5.4)

(TBD)

D.3.4.4.5.5 Capsule pressurization and ventilation.

If an emergency escape capsule is included in the design, the Environmental Control System shall _(TBS)_.

REQUIREMENT RATIONALE (3.4.4.5.5)

Depending upon the operational needs of the air vehicle, emergency escape capsule pressurization and ventilation requirements may need to be specified.

REQUIREMENT GUIDANCE (3.4.4.5.5)

TBS: If any emergency escape capsule system is anticipated or required for the air vehicle under consideration, the following should be considered. The air vehicle pressurization system provides pressurization during normal air vehicle operation. The purpose of the capsule pressurization system is to provide a survivable pressure level during an emergency escape and descent. Since the cabin may be unpressurized (due to damage, system failure, or such) at the start of the escape sequence, the capsule pressurization system should be designed to operate and meet its performance requirements starting with the capsule pressurized or unpressurized. The exact requirements for the capsule pressurization system will depend upon the air vehicle mission, the escape design philosophy, user requirements, among other things. As a minimum, the cabin altitude should never exceed 42,000 ft, as that is the maximum for continuous use of pressure breathing. Altitudes above 42,000 ft require the use of pressure suits. Therefore, minimum requirements would typically be to repressurize the cabin to the equivalent of 42,000 ft and maintain that until the capsule has descended to that altitude.

More stringent requirements may be imposed to improve the crew safety and to reduce the possibility of the crew being disabled during the descent due to decompression sickness, hypoxia, or such. In that case, the requirement should be to repressurize the cabin to a 5 psia differential and prevent the cabin altitude from exceeding 30,000 ft during descent.

The air or gas mixture used to pressurize the capsule should be capable of sustaining life. This is usually accomplished by specifying the minimum partial pressure of oxygen in the air-gas mixture.

The minimum partial pressure of oxygen should be established based upon inspired oxygen pressure requirements. The inspired oxygen pressure P_{IO2} in torr (mm hg) is:

$$P_{IO2} = F_{O2} (P_B - 47)$$

F_{O2} = Fraction of oxygen in ambient air or gas mixture.

P_B = Prevailing barometer pressure in torr.

47 = Vapor pressure of water at body temperature.

The partial pressure of oxygen (P_{O2}) in the cabin air or gas mixture in torr is:

$$P_{O2} = F_{O2}(P_B)$$

The ideal environment for unimpaired performance is as close to sea-level conditions as possible, where the inspired pressure does not fall appreciably below 149 torr. For cases where oxygen is not or may not be available, the inspired oxygen pressure should be no less than the 10,000 ft equivalent of 100 torr. As an example, for an air vehicle at 50,000 ft with a 5 psi differential pressure schedule, the cabin pressure is 7.4 psia or 382.8 torr (1 psi = 51.7 torr).

Combining the above equations:

$$P_{O_2} = \frac{P_{IO_2} \text{ x } P_B}{P_B - 47}$$

For an inspired pressure of 100 torr, the required partial pressure of oxygen is:

$$P_{O_2} = \frac{100 \text{ x } 382.8}{382.8 - 47} = 114 \text{ torr}$$

For the sea level equivalent of 149 torr:

$$P_{O_2} = \frac{149 \text{ x } 382.8}{382.8 - 47} = 170 \text{ torr}$$

For air vehicles where oxygen will always be available and used, this requirement could be based, as a minimum, on the oxygen equivalent required at the altitude where the crew would start breathing cabin air.

Thorough coordination should be used to complete this paragraph, as the requirements are very mission- and user-requirement dependent. For example, the availability and proposed use of a demand oxygen system will influence the specified pressure schedule and oxygen pressure schedule. The engineer should carefully consider the minimum physiological requirements while establishing the capsule pressurization minimum requirements. Because of the unique requirements possible with each capsule application, these requirements may require extensive tailoring.

The capsule system can also be used to provide emergency protection against depressurization due to failure of the normal air vehicle system. This capability can be used for safe descents from high altitudes to permit completion of critical portions of the mission. In this case, the controls for the two systems should be separate and independent so their use is clear to the crew and no single failure (such as a switch) can disable both systems.

This requirement should be carefully considered before being applied, as it can significantly impact the system and air vehicle design. Requiring emergency pressurization for safe descent from high altitude should have little impact on the system design, other than additional controls that could otherwise be part of the automatic ejection sequence. However, requiring the capability to provide emergency pressurization throughout the mission could have a severe impact on the system weight and volume. Therefore, this requirement should be considered only when operational requirements dictate it, and then only the performance conditions should be carefully specified, weighing the operational gains against the impact on the system and air vehicle.

Ventilation provisions should be suitable for landing either on land or water. The system should provide adequate ventilation (adequate oxygen content and minimum CO_2 concentration) without permitting the entrance of water in high sea conditions. Consideration should be given to provisions for automatic actuation of the ventilation device at 15,000 ft. A manual override control should also be provided.

REQUIREMENT LESSONS LEARNED (3.4.4.5.5)

(TBD)

D.4.4.4.5.5 Capsule pressurization and ventilation.

If an emergency escape capsule is included in the design, the ventilation provisions shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.4.5.5)

Verification is necessary to ensure that pressurization and ventilation performance requirements for the emergency escape capsule are met.

VERIFICATION GUIDANCE (4.4.4.5.5)

TBS: This paragraph should be completed as appropriate to assure that the requirements are fully verified by the most cost effective method. In general, pressurization and ventilation system performance can only be verified by flight test. However, some aspects can be verified by analysis and inspection.

VERIFICATION LESSONS LEARNED (4.4.4.5.5)

(TBD)

D.3.4.4.5.6 Cargo and other compartment ventilation.

In cargo compartments there shall be __(TBS)__.

REQUIREMENT RATIONALE (3.4.4.5.6)

Special overboard venting provisions may be necessary for cargo compartments or other compartments so that volatile and hazardous vapors and fumes from cargo or other sources may be vented directly overboard.

Provisions must be incorporated to ensure adequate cargo compartment ventilation during normal loading and offloading of motorized vehicles to ensure crew safety and prevent an explosion hazard.

REQUIREMENT GUIDANCE (3.4.4.5.6)

TBS should be filled in with the ventilation requirements for the cargo compartments. The following should be considered.

Overboard vents can be incorporated for venting volatile cargo. However, even with the vent provisions, cargo compartment ventilation may still be required to ensure dissipation of vapors and fumes to prevent explosive mixtures and hazardous concentrations. The ventilation requirements are usually established for the troop or passenger configuration. If no passenger-carrying requirement exists for the air vehicle, then the ventilation requirement should be established based upon the cargo requirements. An air flow of 15 to 20 cu ft/min per 300 cu ft of cargo volume would be a typical requirement. The air flow rate also depends on the rate of expansion of the material carried in containers. Vents should be the same size as those on previous air vehicles. The ECS vents are part of air vehicle structure. To prevent a possible explosion or fire, it is desirable to have more than one vent onboard a cargo air vehicle. These vents will ensure that oxygen and other possible reactive materials can be vented separately.

The system should provide adequate ventilation for cargo compartments during ground operations to ensure air vehicle exhaust and vehicle exhaust product concentrations will not exceed human tolerance levels during normal loading and offloading operations. This can be accomplished through operation of the normal airborne ventilation system or by separate ground exhaust fans.

Operational requirements may dictate the use of fans so it is not necessary to run the ECS during loading and offloading.

If guns or other weapons or other devices that produce volatile and hazardous vapors and fumes, their compartments should be vented. If used, the air intake should be located away from the gun muzzle to prevent gases from entering the ventilating air. Gun icing by ventilating air should be prevented. This can be accomplished with a ventilating system operating only while the gun is firing. The ventilation airflow rate should be high enough to result in an average concentration of combustibles of 4.5 percent (4.5%) with good mixing, and 2.25 percent (2.25%) with less thorough mixing.

REQUIREMENT LESSONS LEARNED (3.4.4.5.6)

Only one vent existed on the C-130. This vent was used for both liquid oxygen and petroleum products with no instructions to clean the vent between use. If separate vents are not provided, the air vehicle Technical Order (T.O.) should have instructions for cleaning the vent prior to use. If the vent is not cleaned and oxygen is vented overboard, there would be a good possibility of an explosion because of an oxygen and petroleum reaction. The C-141 also contains only one overboard vent.

D.4.4.4.5.6 Cargo and other compartment ventilation.

Cargo and other compartment ventilation shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.4.5.6)

Verification is necessary to ensure that performance requirements are met.

VERIFICATION GUIDANCE (4.4.4.5.6)

TBS should be filled in with analyses, inspection, and tests.

Ventilation for loading and offloading can be verified during loading and offloading tests.

VERIFICATION LESSONS LEARNED (4.4.4.5.6)

(TBD)

D.3.4.4.6 Contamination

D.4.4.4.6 Contamination

D.3.4.4.6.1 Occupied compartment contamination.

During ground and in-flight operation, air within the occupied compartments shall not exceed the permissible exposure limits established in: __(TBS)__. Gaseous concentrations that could create an explosion hazard during pressurized, unpressurized, and depressurized periods shall be prevented.

REQUIREMENT RATIONALE (3.4.4.6.1)

Contamination levels must be limited to ensure the efficiency and safety of the crew, and gaseous concentration must be prevented because of the explosion hazard.

REQUIREMENT GUIDANCE (3.4.4.6.1)

TBS: Contamination of the air in occupied compartments may affect the efficiency and safety of the crew. Three forms of contamination are of concern in the ECS design: gaseous or vapor contamination, liquid contamination, and particulate contamination. High concentrations of contaminants can cause dizziness, headache, nausea, irritation of the eyes and upper respiratory tract, and such. The Surgeon General, USAF, is responsible for the establishment of permissible exposure values within the USAF (basic guidelines for the control of occupational and environmental health exposures are contained in AFMAN 48-155). Contact the 711th Human Performance Wing/Human Effectiveness Directorate, Air Force Research Laboratory, 711HPW/RH, WRIGHT-PATTERSON AFB OH 45433; http://www.wpafb.af.mil/afrl/711HPW/; for further information and detailed bibliographic data on toxic contamination.

Filtration devices such as catalytic filters, activated charcoal and high-energy particulate air (HEPA) filters can be used to remove contaminants from the engine bleed air used to supply the ECS; however, filtration systems like these add weight and maintenance requirements to the aircraft. Whenever possible, the ECS engineer should collaborate with the cognizant engineers (engine project engineer, etc.) to determine what alternatives exist to ensure that appropriate contamination controls are achieved by the systems that supply pressurized air to the ECS. Alternatives to filtration systems include bleed air cleaners, use of erosion resistant turbine materials, use of inlet protection during ground operation, and the use of internal diameter bleed air extraction from the engine which has been shown to greatly reduce the potential for contaminants in the bleed air. Sometimes, however, the engines (or other pressure sources) are government-furnished equipment (GFE) or already designed prior to the air vehicle award; therefore, filtration may be the only viable option. SAE AIR1539 and SAE AIR4766/2 are good references that identify possible sources of contamination, effects contaminants can have on aircraft systems, and how to control/prevent contamination sources.

Wherever possible, vapors resulting from auxiliary engine exhaust systems, air vehicle fuel systems, air vehicle ECSs, gunfire exhausts, combustion heater exhaust, cartridge actuated devices, hydraulic fluid, oil, overheated electrical insulation, coolant fluids, fire extinguisher agents, motor vehicles, fuel tanks, dry ice, electrical equipment cooling air exhaust, and such, should be prevented from entering the occupied compartments. When the entry of the vapors cannot be prevented, sufficient ventilation should be provided to prevent excessive concentrations.

Vapor concentrations that create an explosion hazard during pressurized, unpressurized, and depressurized periods should be prevented. For air vehicles that carry cargo cooled by dry ice, special ventilation rates should be considered because of the sublimation of dry ice into CO_2. If it is assumed the dry ice is stored in an insulated container, the required ventilation rate to preclude a hazardous concentration of CO_2 (0.50 percent) (0.50%) may be estimated as follows:

Air changes/hr = Wt of ice in lbs X 32.2 / compartment vol in ft^3 X 0.47

or

Air changes/hr = Wt of ice in kg X 14.6 / compartment vol in m^3 X 0.0133 .

Additional contaminants in liquid and particulate forms which enter the aircraft through the ECS can cause other damaging effects to the aircraft and the operators. These contamination sources can degrade system performance, increase component removal rate, as well as pollute breathable cabin air essential for pilot performance.

REQUIREMENT LESSONS LEARNED (3.4.4.6.1)

Experience has shown that cadmium dust or vapors are highly toxic. A near accident on a C-130 was attributed to cadmium poisoning of the crew. This resulted from failure of the air conditioning cooling turbine, which had a cadmium-plated turbine nozzle. The turbine failure resulted in the introduction of cadmium dust and vapor into the cockpit. Both pilot and co-pilot became nauseous as a result. The pilot lost consciousness on final approach and was hospitalized for two years.

Incomplete combustion of engine oil has been known to cause odors and increased levels of aldehydes, volatile organic compounds (VOCs), and carboxylic acids in engine bleed air fed systems. These contaminants have led to respiratory irritation and other physiological symptoms when not properly filtered from the air prior to pilot and crew inhalation. Oil vaporization tests have shown that combustion of MIL-PRF-23699 produces higher levels of such contaminants than MIL-PRF-7808.

Noxious odors have resulted when automatic temperature controls fail and the cabin air supply temperature exceeds the normal upper temperature limit. Therefore, the potential for generation of noxious odors at temperatures occurring during failure conditions should be considered in selection of ducting system materials.

Contamination can also affect the onboard oxygen generating system (OBOGS) equipped on some aircraft which is used to supply oxygen to the pilot(s). Such contamination raises the potential for human performance degradation due to physiological symptoms such as hypoxia.

D.4.4.4.6.1 Occupied compartment contamination.

Analyses and tests shall be conducted to verify contaminant levels in occupied compartments are within the maximum allowable levels as follow: __(TBS)__.

VERIFICATION RATIONALE (4.4.4.6.1)

Verification is necessary to ensure that the contamination levels in the occupied compartment(s) do not exceed the allowable limit.

VERIFICATION GUIDANCE (4.4.4.6.1)

TBS: Demonstration of adequate contamination levels is usually a straight-forward, analytical effort. If an existing engine or a derivative of an existing engine is to be used, data should be obtained on the contaminates in the bleed air after the air vehicle has been through its service life. However, special circumstances can arise which require careful consideration and possible testing. These circumstances include possible entry of engine exhaust fumes through open cargo doors or through normal intakes from rotorcraft downwash, off of jet blast deflectors or from lead air vehicles on carrier decks; chemical laser reactants and products, possible noxious odors during high temperature failure conditions, and such. If a re-circulation system is used, testing should be performed to ensure that there is not a build-up of CO_2 or other contaminates. Furthermore, if the ECS contains filter material for NBC purposes or general filtration such as odor removal, a laboratory system test should be conducted to demonstrate that the filter material is not contaminating the ECS air more than the established permissible limit. Since the filtration medium is unknown, limits cannot be established in this document. However, filtration mediums can be hazardous to the crew, and they should also be evaluated for possible maintenance implications if they are released into the ECS. This test should include an air sample taken as close as possible to the bleed air source (for example, upstream of the ECS filter) and a sample downstream of the ECS filter (for example, cockpit supply or avionics supply air). Furthermore, a comparison should be made between the samples taken at the beginning of the system test to samples taken at the conclusion of the system tests or just prior to the rig dissemble. This will help in determining if the filter material is susceptible to breakdown over long periods of time. (This is assuming that the system rig is used for endurance testing. If not, samples from the air vehicle should be taken at the beginning of the flight test program and at the conclusion of the flight test program.) The results of this comparison should be addressed in the System test report.

An investigation of the cleanliness of air supplied to the cabin should be made by collecting air sample in an evacuated container and by analyzing the contents in a laboratory. Samples should be screened for contamination of smoke, oils, water content, biological or chemical agent simulants, and particulates which may be introduced from the outside air via the bleed air source (if used) and by air vehicle specific components such as filters. Samples should be taken in such a manner that the origin of the contamination (outside air infiltration versus contamination from ECS supply air) can be determined. Sufficient samples should be obtained to cover all flight conditions under which contamination may exist. The moisture content of the air in both crew and passenger compartments also should be determined safe and satisfactory. Performance of the system and component equipment should be considered under the following conditions:

a. Climb

b. Descent

c. Level flight

d. Maneuvering flight

e. Hover (in ground and out of ground effects), if applicable.

Testing of Navy air vehicles should be performed in a salt air environment.

VERIFICATION LESSONS LEARNED (4.4.4.6.1)

Past ECS systems have used toxic materials. The intention is to eliminate their use, but this is not always possible. When they are used, a means must be devised to test for the safety of the crew and to ensure that maintainability problems will not be created as a result of their use. Consequently, it may be necessary for the contractor to investigate the physiological effects endemic to the material and also possible maintainability impacts. An example of this is the use of 13x molecular sieve (Sodium Aluminosilicate - Na_2O: Al_2O_3: $2.8SiO_2$: xH_2O - also known as zeolite). This material has been observed to enter the ECS and cause severe erosion to aluminum. It is not expected that this material will cause permanent or serious injury to the crew under normal usage, but its erosive property could release other toxic substances if present. In addition, the long-term effects of this substance on the equipment are unknown. Other unknown filtering agents may be used in the future. These should be evaluated as they are introduced, and conducting tests on the completed system is the only way of determining that permissible limits as established by investigation and study are not exceeded.

D.3.4.4.6.2 Avionic equipment and equipment compartment dust control.

Dust contamination of the avionic equipment by cooling air shall be prevented. Air delivered to the interior portions of internally forced convection air cooled electronic equipment or to avionics cold plates shall not contain more than ___(TBS)___ when air vehicle is operated in dust environment specified in the air vehicle specification.

REQUIREMENT RATIONALE (3.4.4.6.2)

To prevent avionic failures due to dust accumulation within the equipment, it is necessary to specify a requirement to prevent dust contamination.

REQUIREMENT GUIDANCE (3.4.4.6.2)

TBS should be filled in with a maximum concentration level of dust allowable and size distribution. A suggested requirement is, “Air delivered to the interior portions of internally forced convection air cooled electronic equipment shall not contain more that 0.001 grams of solid contaminants per pound of air, and 95 percent (95%) of the particles shall be less than 20 micron in size, and no particle shall be greater than 50 micron."

The dusting environment should be specified in the air vehicle specification. If it is not, see MIL-HDBK-310 for guidance in selecting a dusting requirement. Avionic equipment design configuration and dust control methods and devices should be used to achieve the required dust removal function.

Each piece of avionics may have its own peculiar dust control requirement or different susceptibility to dust contamination depending on the design configuration (for example, compartment ambient air cooled equipment with or without cold plates, and equipment cooled directly by forced air supplied by the ECS). As a result, it is difficult to cite one filtration requirement that will be suitable for all avionics.

Cold plates and finned heat exchangers can be used effectively to prevent contamination of internal avionic compartments, but cold plates and finned heat exchangers can be blocked by dust when avionics are cooled by unfiltered compartment air. In this case the cold plates also need to be protected from dust.

The dust control requirement can be met through use of a single filter in the avionic cooling air supply, individual filters at the inlet to each piece of avionics, or through use of a clean air source. The number of filters should be minimized to reduce the maintenance requirements associated with inspecting, cleaning, and replacing of filters. The filters, if used should be easily accessible without having to remove other components. Generally, avionics cooled by air directly from an air cycle system using engine bleed air will not need a filter except for vertical and short takeoff and landing, helicopter applications, or cases where the engines are located near the ground or at the tail of the air vehicle.

(Refer to MIL-HDBK-454, GUIDELINE 52, for further guidance on filtration for avionic equipment.)

In the future, the more extensive use of COTS equipment may make this requirement more difficult, since COTS equipment typically blows cooling air directly over the electronic components.

REQUIREMENT LESSONS LEARNED (3.4.4.6.2)

Several cases of avionics problems due to dust contamination have occurred. Most dust problems have occurred in cargo air vehicles where the avionics are cooled by compartment exhaust air. Considerable dust and dirt can be present in the compartment exhaust air from cargo air vehicles, which necessitates filtering the air before it passes to avionic equipment.

Avionics equipment cold plate blockage occurred on the S-3 air vehicle due to dust contamination resulting in inadequate cooling of equipment and other equipment problems. Cabin air is used to cool the avionics. Although the cabin is supplied from air cycle system, dust enters the cabin when the doors are opened, and lint enters or the crew's clothing. The problem was corrected by adding filters at the inlets to the cold plates that were readily accessible to maintenance personnel for cleaning.

D.4.4.4.6.2 Avionic equipment and equipment compartment dust control.

Analyses and tests shall be conducted to verify dust levels in avionic equipment and equipment compartment cooling air are within the maximum allowable levels as follow: ___(TBS)___.

Inspection of drawings and air vehicle ground and flight tests shall verify avionics are free from dust contamination by cooling air.

VERIFICATION RATIONALE (4.4.4.6.2)

Inspection of drawings is required to verify provisions are incorporated to prevent the entrance of dust into the avionics. Air vehicle ground and flight tests will then be used to show freedom from dust problems under operational conditions.

VERIFICATION GUIDANCE (4.4.4.6.2)

TBS: An analysis should be conducted to determine the quantity and type of dust that can enter the ECS during periods when backup or emergency cooling is selected. This analysis should show that the contamination levels due to dust has no effect on the avionics, that it does not degrade the cooling capability of heat exchangers, and that it does not adversely affect any other component in the ECS. If this cannot be demonstrated, then the analysis should describe the maintenance actions required to restore avionics operation, the cooling capacity, or restore the other ECS components to their normal operating condition; the frequency with which said action is to be done; and that this condition is allocated in the flowdown requirements for air vehicle maintainability. Early in the program, system drawings should be inspected to ascertain incorporation of filters or determine they are unnecessary due to air source.

VERIFICATION LESSONS LEARNED (4.4.4.6.2)

(TBD)

D.3.4.4.6.3 Nuclear, biological, and chemical contamination.

The ECS shall have the following provisions to counter nuclear, biological, and chemical (NBC) threats __(TBS)__.

REQUIREMENT RATIONALE (3.4.4.6.3)

Depending upon the mission of the air vehicle and the expected threats, nuclear, biological, and chemical protection provisions may be required to remove deadly or incapacitating agents from the ECS air to provide for the safety of the crew and to improve the survivability of the air vehicle.

REQUIREMENT GUIDANCE (3.4.4.6.3)

TBS: NBC protection should be provided as required. Much of the NBC material and data are classified. Therefore, these requirements should be established in cooperation with the program office, survivability and command personnel. The NBC protection should not be a cause for reduced reliability of the other ECS components either in the normal operating mode or in the backup mode. Since outside, contaminated air can traverse the engine or APU, ECS bleed air components, air cycle machine, and distribution ducting rapidly, the NBC protection equipment should be operational full time in an NBC threat area, or should be able to activate rapidly enough in order to provide the necessary protection. If the NBC device is used for additional purposes other than NBC protection (for example, water vapor removal), all functions and required performance should be achieved simultaneously.

Generally, one of two possible approaches should be selected for providing NBC protection for the crew and passengers requiring different requirements from the ECS:

a. Individual protection. Under this option only the crew and passengers are protected from NBC agents. The occupied compartment may become contaminated and will need to be cleaned after an encounter. Individual protection interfaces with the ECS may include such items as suit hook-ups and control of the pressure, temperature and humidity of the suit supply air. If the suits selected do not have ventilation, additional cooling of the compartment may be necessary to compensate for the added heat stress on the individuals. OBOGS air supply may need to be filtered, if the masks being used do not have filtration. If the masks do have filtration, the added pressure drop will need to be compensated for in the OBOGS supply requirement. Crew system engineers should be consulted to obtain appropriate interface requirements.

b. Collective protection. Under this option selected occupied and other compartments are protected from NBC agents to avoid costly, difficult and potentially damaging clean up following encounters. Usually individual protection should also be provided as a backup to the collective system and in case ingress or egress has to be accomplished in a contaminated area. For collective protection, the air vehicle needs to be pressurized to at least the level of the dynamic head of the air vehicle at maximum speed to preclude contaminant entry from an airborne cloud. Generally an NBC filter should be used to filter the air entering the protected compartments. The temperature and humidity of the air delivered to the NBC filter should be in accordance with the filter specification. Single failures in the ECS that allow contaminated air to enter the clean air source should be avoided. If avionics compartments are selected for collective protection, only particulate and liquid filtration of avionics supply air may need to be provided, unless temperatures within the avionics are expected to cause condensation of liquid (aerosol) agents.

REQUIREMENT LESSONS LEARNED (3.4.4.6.3)

(TBD)

D.4.4.4.6.3 Nuclear, biological, and chemical contamination.

The ability of the ECS to provide protection against nuclear, biological, chemical contamination shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.4.6.3)

Verification is necessary to ensure that the ECS is able to meet the requirements of providing protection against NBC contamination.

VERIFICATION GUIDANCE (4.4.4.6.3)

TBS: Much of the material and data involving chemical, biological, and radiological contamination are classified. Coordination with survivability personnel to establish the proper method for verification is recommended. Live agent testing is the only way to prove that NBC equipment can work as required, but it is difficult to conduct because of the sheer size of an ECS (laboratory availability) and the need to take extraordinary safety precautions. Therefore, exhaustive laboratory testing with simulants should be followed by smaller scale live agent testing that combines the proof of the concept (live agent testing) with the practicalities and limitations of real system operation. Both type tests should be considered to conclude that the NBC system will perform as required.

The performance of this system should be demonstrated by testing in the laboratory and during flight tests. If the system provides dual functions such as water or water vapor filtration in addition to NBC materials, each function should be tested individually and combined. For example, the NBC system should be tested for its water removal capability without NBC contaminants present. The system should also be tested with water and NBC contaminants present at the required challenge levels. Furthermore, ambient temperatures (for example, bay temperatures where the equipment is located) should be simulated during the testing if it is known that the filter medium performance or system performance is dependent upon temperature. For chemical challenges the system test rig should be used to demonstrate compliance to the performance requirement. While other ECS performance testing is being conducted (for example, heating, cooling, pressurization, or ventilation), the test rig should be used to test NBC characteristics with a suitable chemical simulant(s) that does not require extraordinary safety precautions to be taken. If simulant testing cannot be done in conjunction with the other ECS performance testing, chemical simulant testing should be scheduled towards the end of the system testing to ensure ample time for discovery of malfunctioning equipment, component infant mortality, or such, which may adversely affect the chemical protection performance outcome. The simulant should be introduced at the simulated bleed air source (for example, APU or engine bleed port). The rig should be instrumented to take samples or record the simulant concentration at the source, before and after heat exchangers, before and after the air cycle machine, the cockpit inlet concentration, and sources of air that may be possible to bypass the filtration equipment, such as cooling air for air cycle machine bearings. Reductions in the concentration of the simulant as it traverses the ECS should be recorded as a function of time (for example, concentration as a function of location and time). If a heat exchanger or other component failure can cause contamination of the cockpit, the rig should be instrumented to detect contamination due to a failure of these components. Filter medium integrity should also be demonstrated with laboratory testing. Air samples downstream of the filter should be taken at the onset of the system testing and be examined for filter medium material such as Sodium Aluminosilicate. Samples should be taken throughout the test program to determine if the rate of output of filter medium is changing. These samples should show that filter medium contamination does not increase with usage. Live agent testing should also be considered. Preferably, where the ECS equipment is an integral part of the NBC system, such as with a pressure-swing absorption system, this should be done in the system rig. If this is not feasible, a pseudo-ECS test rig should be constructed which encompasses as much of the ECS as practicable. For passive filtration systems such as charcoal filters, testing the filter alone with live agent testing may be sufficient. The pseudo-ECS rig should be able to provide the interface parameters and boundary conditions of the absent ECS components (for example, flow rate, pressure, temperature, liquid water content, humidity, and other persistent contaminants such as engine oil vapors) which represents the most severe operating condition for the filtration equipment. Engine or APU oil vapors at concentrations allowed by the respective specifications should be imposed simultaneously with water and chemicals for the duration of live agent testing. Challenge levels and time duration of the chemical agents should be as established by the system specification. If the specification does not distinguish between ambient challenge level(s) and the challenge level(s) that would exist at the interface of the NBC equipment, then the specification requirement (both chemical concentration and time) should be introduced at the bleed air source. The flight test should be conducted with a suitable detectable simulant. The purpose of this test is not to show that the ECS-NBC system components work and perform as required, but rather it is to show that chemical infiltration to the occupied compartments does not occur under field operating conditions. However, if laboratory testing has not been conducted to demonstrate performance of the NBC equipment, then the flight test should be used as the platform to demonstrate it as well as stopping infiltration. As such, instrumentation described for the laboratory testing should be included for the flight test air vehicle, and this instrumentation should be able to show that the ECS supply air is free from contamination and that infiltration does not occur.

VERIFICATION LESSONS LEARNED (4.4.4.6.3)

Work to date on a pressure swing system has illustrated problems with water and dusting. Therefore, testing methods and objectives should be used which can demonstrate satisfactory operation with respect to these type problems.

D.3.4.4.7 Moisture and humidity control

D.4.4.4.7 Moisture and humidity control

D.3.4.4.7.1 Occupied compartment moisture control.

All air delivered to all compartments shall be free of entrained liquid water.

REQUIREMENT RATIONALE (3.4.4.7.1)

Entrained moisture needs to be eliminated from air delivered to occupied compartments to prevent:

a. Fogging
b. Water spray from outlets, diffusers, gaspers, and such obscuring crew visibility.
c. Shorting of electrical equipment.

REQUIREMENT GUIDANCE (3.4.4.7.1)

Entrained moisture is defined as the moisture carried in the air as free water. It should not be confused with water vapor in the air, or “humidity”. This requirement can be met by proper design practices. Water separators, heat exchanger drains, and such, can eliminate most of the entrained moisture from the air. Any entrained moisture not removed in the air conditioning packages or evaporated in the downstream distribution ducting can be trapped and drained overboard before it reaches the outlets. (See SAE AIR1204 for more guidance.)

REQUIREMENT LESSONS LEARNED (3.4.4.7.1)

Experience shows state-of-the-art, low-pressure water separators located downstream from the turbine remove approximately 85 percent (85%) of the entrained moisture. More effective moisture removal can be accomplished through use of high-pressure water removal; that is, remove the entrained water before air passes through the expansion turbine. Also, it has been learned that system penalty can be reduced through use of the removed water as a system heat sink. The F-15 experienced an early problem with water from the water separators being sprayed over the secondary heat exchanger and collecting on the back side of the cabin ram air valve. Over time, the water entered the cabin distribution system as a fine spray and as a drenching spray when ram air was selected. Drain holes were added to correct the problem. Several earlier designs of fighter air vehicles, such as F-4 and F-105 air vehicles, did not have water separators in the air cycle air conditioning system. This proved a serious deficiency when operated in a hot, humid environment, such as Southeast Asia.

D.4.4.4.7.1 Occupied compartment moisture control.

All ground and flight tests shall verify the air delivered to occupied compartments is free of entrained moisture. During ground and flight test the ambient conditions shall be __(TBS)__.

VERIFICATION RATIONALE (4.4.4.7.1)

Actual testing is the only way to verify that entrained moisture is being prevented, due to the many phenomena involved. For example, how much reheating takes place in the distribution ducting; actual effectiveness of water separator, traps, and such, during air vehicle maneuvers. Testing is only valid if conditions exist which normally cause moisture problems.

VERIFICATION GUIDANCE (4.4.4.7.1)

TBS: Ambient conditions for the ground and flight testing of moisture control need to be carefully selected. If the requirement is too rigid, it will be costly and time consuming to perform the test. If the requirements are not rigid enough, the test will not adequately reflect how the system will work when the specification conditions do exist. Test should be run at the highest absolute humidity as possible and the highest relative humidity conditions at moderate dry bulb temperatures. A near 100 percent (100%) relative humidity case at 70 to 80°F dry bulb is desirable for the high relative humidity case.

VERIFICATION LESSONS LEARNED (4.4.4.7.1)

The V-22 air vehicle used 95°F dry bulb and 80°F as the high absolute case.

D.3.4.4.7.2 Occupied compartment humidity control.

The humidity in occupied compartments shall __(TBS)__.

REQUIREMENT RATIONALE (3.4.4.7.2)

At altitudes above 30,000 ft, the absolute humidity of the ambient air becomes very low, which results in crew compartment relative humidities of only a few percent on air vehicles with conventional, open-loop air cycle systems. Prolonged human exposure to low humidity results in nasal problems, dry skin, dehydration, and fatigue. Breathing 100 percent (100%) oxygen further aggravates the problem.

Humidification may also be required for the cabin of aeromedical evacuation air vehicles to provide a safe, controllable, and stable environment for aeromedical patients.

REQUIREMENT GUIDANCE (3.4.4.7.2)

TBS: General humidification of the entire occupied compartment is usually not considered practical because of the weight penalty of the water required for the humidification and because of the problem of condensation on the walls, floors, and other areas due to low outside ambient temperatures. Humidification provisions are available for and used by some airlines on Boeing 747 and Lockheed L-1011 air vehicles. On Boeing 747 air vehicles, water from the potable water supply is sprayed into recirculated cabin air. On Lockheed L-1011 air vehicles, potable water is evaporated into hot engine bleed air. With the increased acceptance and use of various “closed loop" air conditioning concepts, humidification may become more easily accomplished, and with much lower air vehicle penalties. (See SAE AIR1609 for additional guidelines.)

For air vehicles that have mission times in excess of 12 hr at high altitudes (above 30,000 ft), consideration should be given to maintaining a minimum ambient relative humidity of 30 percent (30%) for the crew and passengers.

For aeromedical evacuation air vehicles, the possibility of providing general humidification of 30-to-50-percent (30-50%) relative humidity should be considered and incorporated as state-of-the-art permits. Provision for humidity control to an isolated portion of an aeromedical evacuation air vehicles is also a possibility.

High humidity levels in air vehicle occupied compartments should be prevented because high humidity has a detrimental effect on the sweat evaporation from crew members and passengers. Since sweat evaporation is the primary mechanism for body thermoregulation in hot environments, the pilot's body will tend to overheat and become fatigued. Normally, properly designed temperature control provisions will prevent excessively high humidity levels in air vehicle compartments.

REQUIREMENT LESSONS LEARNED (3.4.4.7.2)

United States Air Force experience gained from extended duration missions has shown a definite need to provide humidification of the crew compartment at high altitudes. The Strategic Air Command Flight Surgeon has recorded pilot weight losses of 10-15 lb as a result of flights of approximately 24 hr.

D.4.4.4.7.2 Occupied compartment humidity control.

Verification of humidity control shall __(TBS)__.

VERIFICATION RATIONALE (4.4.4.7.2)

Verification is necessary to ensure that performance requirements are met.

VERIFICATION GUIDANCE (4.4.4.7.2)

TBS should be filled in with a combination of laboratory and flight tests to verify the humidity control provisions. Laboratory tests should demonstrate the capability of the system to add water to the ECS air without creating problems with entrained moisture. Flight testing should verify the adequacy of the humidity levels.

VERIFICATION LESSONS LEARNED (4.4.4.7.2)

(TBD)

D.3.4.4.7.3 Avionic equipment and equipment compartment moisture control.

Moisture contamination of avionic compartments, avionic equipment cooling air, and fluid coolants during ground and flight operation shall be prevented.

REQUIREMENT RATIONALE (3.4.4.7.3)

To prevent avionic failures due to free water, it is necessary to specify a requirement that prohibits the introduction of moisture into the avionic equipment by the cooling air or liquid coolant.

REQUIREMENT GUIDANCE (3.4.4.7.3)

When using an open looped air cycle system, the use of high-pressure condensing type and centrifugal type water separators in the ECS should be considered for the removal of entrained moisture in avionic cooling air. Efficiencies in most low-pressure air cycle systems are not adequate to remove enough water from the avionic cooling air to disregard water as a problem for the avionics. Entrained water may still be present during some modes of operation and in some environments.

The requirement for controlling avionic equipment moisture contamination can be met through the use of cold plates or heat exchangers. The use of cold plates or heat exchangers is an effective means of reducing moisture problems since the cooling air does not enter or come into direct contact with the internal portions of the equipment containing electronic parts and circuitry. If this approach is used the distribution system should be designed to be tolerant of moisture. Also, long-term corrosion of the cold plates should be considered, especially in Navy applications. Note that condensation could still occur on the inside of the cold plate if the coolant temperate was low enough. This approach requires that the avionics engineer specify that the equipment be designed with cold plates. If the equipment is already designed and retrofit of cold plates may not be feasible. (Refer to MIL-HDBK-454, GUIDELINE 52; and MIL-STD-2218.)

The use of closed-looped air cycle simplifies this problem. Surface temperatures should still be maintained above the dew point to prevent condensation within the equipment.

The requirement for controlling moisture contamination of coolant fluids can be met by suitable efficient filtration of the inlet pressurization air flow used for pressurizing coolant fluid reservoirs. Since moisture can come into contact with coolant fluids when fluid reservoirs are being serviced, refilled, or when fluid is being replaced or added, methods of eliminating moisture contamination in these situations should be considered. The design of the equipment to which the fluid will come in contact should assume, however, that some moisture will be present in the fluid.

In the future, the more extensive use of COTS equipment may make this requirement more difficult, since COTS equipment typically blows cooling air directly over the electronic components.

REQUIREMENT LESSONS LEARNED (3.4.4.7.3)

Past experience has shown a number of cases of avionics failures due to free water being delivered to internal portions of the equipment. One such case was failure of the AGM-69A (SRAM) INU due to free water collected inside the INS outer case from the ECS air during captive flight on FB-111 air vehicles.

A problem has been identified with equipment that incorporate chemical dryers for humidity control when the pressurization system is operated on the ground with one or more of the units that require pressurization removed for maintenance.

The system that normally does not flow significant quantities of air can flow large quantities of humid air through the system and quickly saturate the drier. This is also the case when a unit is replaced and the pressurization system is not reconnected.

Although not due to moisture in the cooling air itself, the F-15 air vehicle experienced a problem associated with using cold air out of a ground cooling cart which caused moisture to condense and collect on the external surface of the distribution ducts and run to a low point where it would drip. This problem also existed as a result of rainwater entering the air vehicle. In at least one case, the water dripped onto an avionics box with louvers on top. This problem can be eliminated if considered in the early design phase of the system. The F-15 air vehicle required the addition of deflectors over certain avionics boxes and drain holes in some of the avionics shelves.

The A-5 air vehicle experienced Verdan computer failures, less than an hour in flight, during operations in hot humid climates due to internal accumulation of moisture that was entrained in the cooling air. These failures resulted in frequent mission abortions.

Silicate ester fluid was used to cool the radar and missile on the F-14 air vehicle and the radar on F-18 air vehicles. It was assumed the fluid when purchased to proper specifications would stay free of moisture, and there were no filtration devices used on these air vehicles. Due to the hygroscopic nature of the fluid the fluid easily entrained water when stored in open containers or reservoirs. Water was also added to the fluid in leaky heat exchangers in the ground support equipment. The water attacked the bonding material in the missile cold plates, whose design also falsely assumed there would be no water present, which resulting in their failure and major damage to the missile. Also, the fluid and water when subjected to high voltage in the radars chemically reacted to form alcohol and an ionized gel. The alcohol resulted in a few cases in fires. The gel attached itself to the interior of the radars resulting in significant maintenance activity to clean it out.

D.4.4.4.7.3 Avionic equipment and equipment compartment moisture control.

All ground and flight tests shall verify that air delivered to avionic equipment and equipment compartments is free of entrained moisture. During ground and flight test the ambient conditions shall be __(TBS)__.

VERIFICATION RATIONALE (4.4.4.7.3)

Analyses of cooling system performance and avionic configuration are required to ascertain that free water will not be delivered to or formed in the internal portions of avionics. Flight testing is required to verify the analyses.

VERIFICATION GUIDANCE (4.4.4.7.3)

TBS: Ambient conditions need to be carefully selected. If the requirement is too rigid, it will be costly and time consuming to perform the test. If the requirements are not rigid enough, the test will not adequately reflect how the system will work when the specification conditions do exist. Tests should be run at the highest absolute humidity as possible and the highest relative humidity conditions at moderate dry bulb temperatures. A near 100 percent (100%) relative humidity case at 70 to 80°F dry bulb is desirable for the high relative humidity case.

Analyses of cooling performance during high humidity conditions and avionic configuration should be done early in the development program to ensure that free water will not be delivered to or formed in the internal portions of avionics . Flight testing should be conducted in a hot, humid environment to demonstrate that free water will not be delivered to internal portions of avionics.

VERIFICATION LESSONS LEARNED (4.4.4.7.3)

The V-22 air vehicle used 95°F dry bulb and 80°F wet bulb as the high absolute case.

D.3.4.4.7.4 Moisture control of other compartments, structure, skin, equipment, and subsystems.

Means shall be incorporated to prevent moisture contamination of other compartments, structure, skin, equipment, and subsystems as defined __(TBS)__.

REQUIREMENT RATIONALE (3.4.4.7.4)

Depending upon the operational needs of the air vehicle, moisture control may be required for weapons bays, wheel wells, air vehicle structure, skin panels, special purpose compartments or equipment, and other subsystems.

REQUIREMENT GUIDANCE (3.4.4.7.4)

TBS: The other compartments, structure, skin panels, equipment, or subsystems which require moisture control should be defined along with any specific requirements.

REQUIREMENT LESSONS LEARNED (3.4.4.7.4)

(TBD)

D.4.4.4.7.4 Moisture control of other compartments, structure, skin, equipment, and subsystems.

Moisture control of other compartments, structure, skin, equipment, and subsystems shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.4.7.4)

Verification is necessary to ensure the moisture control requirements are met.

VERIFICATION GUIDANCE (4.4.4.7.4)

TBS should be filled in with analyses, inspection, and tests.

VERIFICATION LESSONS LEARNED (4.4.4.7.4)

(TBD)

D.3.4.4.8 Transparent area fog and frost protection.

Critical viewing area interior surfaces of these transparencies shall be maintained free of fog and frost for all steady-state ground and flight operating conditions. The critical viewing areas are __(TBS 1)__. Critical viewing areas shall also be maintained free of fog and frost during maximum rate descent from the operational ceiling of the air vehicle in the ambient environment of __(TBS 2)__. Preheating of the critical viewing areas by increasing occupied compartment air temperature above normal limits prior to descent shall not be required to maintain fog-free surfaces.

REQUIREMENT RATIONALE (3.4.4.8)

Fog and frost protection is required to ensure adequate crew visibility. Fog and frost protection may also be required for other transparent areas such as sensor windows. Preheating the compartments to accomplish the fog and frost protection function is prohibited for two reasons:

a. It unnecessarily heats the cabin above the specified limits.

b. It adversely affects the transient capability. If a sudden dive is required due to loss of cabin pressurization or combat maneuvers, the crew will not have the time to preheat the cabin.

In-flight failure of an ACM or other component may necessitate turning off the air conditioning system. However, fog and frost protection is still required to permit the safe completion of the mission or return of the air vehicle.

REQUIREMENT GUIDANCE (3.4.4.8)

Protection from fog and frost is achieved by raising the temperature of the transparency interior surface above the compartment dew point temperature.

TBS 1 is to define the transparency areas which are critical viewing areas and for which the transient fog protection requirements must be met. The critical viewing areas of the windshield and canopy are determined by crew station performance considerations. Critical viewing areas of camera and sensor windows are determined by the operational requirements for these pieces of equipment. The critical viewing areas of the canopy and windshield should be obtained from the crew station engineer. Camera windows, sensor windows, and other special fog and frost protection requirements should also be specified. Close coordination with the engineers responsible for the special equipment is necessary to ensure these requirements are accurately and completely specified.

TBS 2 should be filled in with consideration of the following. The ambient conditions for the maximum rate of descent requirement are to be specified. The historical requirement in MIL-T-5842 was unrealistically severe, requiring the system to function from near MIL-STD-210A cold day conditions at altitudes of 25,000 feet and above to tropical day conditions at sea level. The USAF Environmental Technical Applications Center was requested to investigate the occurrence of cold temperatures aloft with high humidities below. The results of their analysis are shown on figure D-12. The air should be assumed saturated all along the profile (temperatures are dew point temperatures). The sea-level dew point temperature of 88°F corresponds to the MIL-HDBK-310 high humidity 1 percent (1%) extreme. This curve is recommended for specifying the environmental interface under which the performance requirements must be met. This curve may need to be tailored to be consistent with the environmental requirements specified in the air vehicle specification.

Consideration should also be given to emergency fog and frost protection. In the event of failure of the fog protection system, some other means should be available to meet the steady-state fog protection performance requirements for the critical viewing areas. For example, analysis may show that the transparency anti-icing system is capable of supplying enough heat to the transparency interior surface to meet the steady-state fog protection requirements. Another alternative for lower speed air vehicles is a clear vision panel that can be opened in flight.

The normal fog and frost protection provisions should not be disabled by closure of an air conditioning package shutoff valve.

REQUIREMENT LESSONS LEARNED (3.4.4.8)

Experience has shown that the use of an anti-fogging approach is very effective for fog protection. Also, the use of effective water removal in the air conditioning system aids in minimizing fogging problems.

The F-15 approach of blowing 88º F air over the transparency interior surfaces has proved an effective means of fog protection. The only drawback has been the complaint by some pilots of a warm head on hot, sunny days.

Use of a high-pressure water separator in air cycle systems greatly minimizes the possibility of fogging as shown by the Advanced Environmental Control System (AECS) advanced development program.

Lack of water removal in air cycle systems greatly aggravates cockpit fogging problems, as experienced by F-4's in Southeast Asia operations.

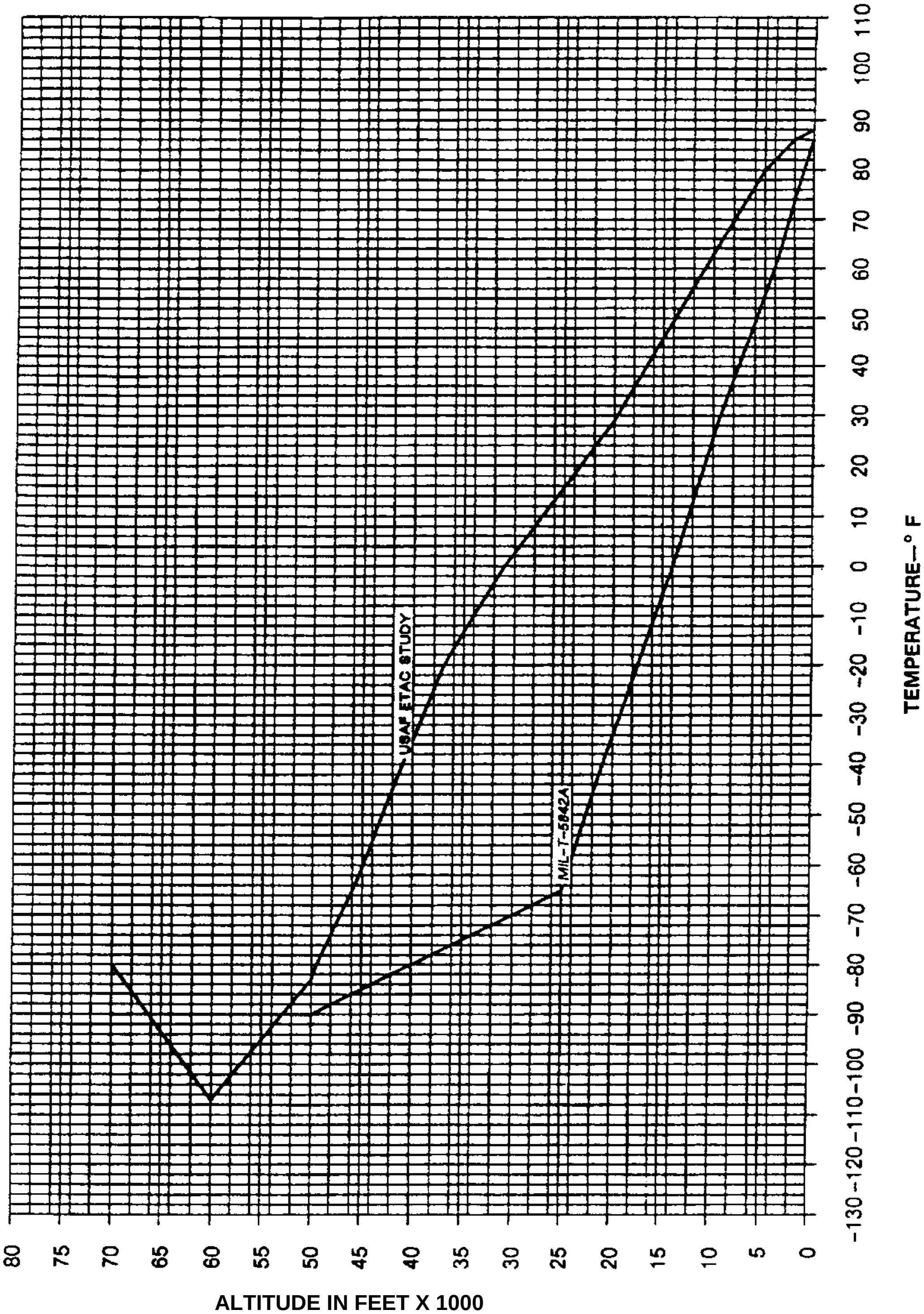

FIGURE D-12. Upper air temperature profiles for design of windshield defogging system.

D.4.4.4.8 Transparent area fog and frost protection.

The capability of the ECS to provide fog and frost protection

to the defined critical view areas shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.4.8)

Verification is necessary to ensure the ECS meets the fog and frost protection requirements.

VERIFICATION GUIDANCE (4.4.4.8)

TBS should be filled in with analyses, laboratory testing, and ground and flight tests. Analyses and flight tests should demonstrate that preheating of critical viewing areas by increasing occupied compartment air temperature above normal limits is not required to maintain the critical viewing areas clear of fog during rapid descent. Inspection of drawings and flight demonstration should show that normal fog protection provisions are not disabled by closure of air conditioning package shutoff valves.

The steady-state analysis should show that the fog and frost protection system can supply enough heat to the transparency to raise the interior surface above the dew point. For this analysis, the outside ambient air temperature and the heat transfer properties of the transparency will determine how much heat flow is required. The cabin dew point should be determined from the outside ambient humidity plus the moisture given up by the crew. An allowance of 0.25 to 0.50 lb/hr for each crewmember should be made. It should be noted that no allowance is made for water removed from the cabin air by the water separator. This practice prevents a water separator malfunction from being a critical single point failure. Another important parameter in this analysis is the temperature of cabin air in close proximity to the transparency.

The analysis for transient system performance is more complicated than for the steady-state condition. The transient performance requirements are generally more severe than the steady-state requirement. However, for the transient performance case, water removed by the water separator should be considered since the probability of performing a maximum rate of descent dive with a failed water separator is low. Also, for this analysis, the transparency is assumed to be at its normal steady-state temperature when the dive is initiated. If a system is used that requires activation by the crew, the analysis should not take advantage of system activation prior to initiation of the descent. The cabin dew point will change instantaneously during the descent as the outside ambient dew point changes.

Analyses, laboratory testing, and ground and flight tests should verify that thermal protection for all critical viewing areas prevents overheating for normal and backup cooling modes.

Final verification should be by a flight test where the sea level dry bulb temperatures and dew point temperatures are within a specified differential from the required temperatures. A 5 to 10^{o}F differential is recommended. The following flight test procedure is recommended for all but rotorcraft, but it is especially applicable to combat air vehicles.

The flights should be made during early morning or late evening when the dry bulb and dew point temperatures are the closest. Climb the air vehicle to the lowest altitude at which a true atmospheric temperature of -65°F exists. The air vehicle should loiter at this altitude, at the minimum engine power setting required to maintain level flight, for a period of 30 minutes. A maximum rate of descent dive with the lowest practicable engine power setting should be performed too the safe minimum altitude. The air vehicle should descend through as much cloud as possible particularly at low altitude. The test should be repeated with the dive being made at the maximum allowable speed. The following test data should be recorded as a minimum:

a. Sea-level dew point and dry bulb temperatures during test flights.

b. Cockpit temperatures at head and foot level taken at regular intervals during the flight. These temperatures should be recorded immediately before and after the descent.

c. Defogging air temperature and temperature at various locations on the inner surface of the transparencies.

d. The condition of all transparencies during the flight. The condition should be described in detail and illustrated by sketches.

e. The cloud conditions encountered during flight.

f. Speed, altitude, and duration of any extra flying required to clear the transparencies at the end of the dive.

VERIFICATION LESSONS LEARNED (4.4.4.8)

(TBD)

D.3.4.4.9 Rain removal.

The rain removal subsystem shall maintain the visibility required through critical viewing areas for mission completion under the precipitation rate of “Design environment at installed locations” of the Air Vehicle System Specification. The critical viewing areas for rain removal are __(TBS 1)__. The system shall maintain the required visibility during operation in rain for the following conditions: __(TBS 2)__. The rain removal system shall not be damaged by flight at the maximum air vehicle speed. A single failure shall not result in depriving the crew of the minimum critical viewing area.

REQUIREMENT RATIONALE (3.4.4.9)

Viewing area rain removal is required to ensure adequate visibility for crew, camera, and sensors.

REQUIREMENT GUIDANCE (3.4.4.9)

TBS 1: The critical viewing areas are determined by crew station performance considerations. The critical viewing areas of the windshield should be obtained from the crew station engineer. Critical viewing area for camera windows, sensor windows, and such, should be obtained from the engineers responsible for those pieces of equipment.

TBS 2 is used to list the specific flight and ground conditions that will require rain removal. The factors discussed above should be used in determining this requirement. Sensor requirements may differ significantly from crew station transparencies requirements, and the operational needs of the air vehicle should be considered when establishing this requirement.

Different air vehicles have different rain removal requirements. All air vehicles require adequate rain removal during landing approach and ground operations. In addition, rotorcraft require rain removal throughout their flight envelope. Fighters also require sound rain removal throughout the low altitude portion of their flight envelope, especially if they have a terrain-following capability, such as the F-111. Most transports only require rain removal during landing approach, landing, and ground operations. Bombers, such as the B-52 and the B-1, which have a terrain-following capability, need rain clearance at this flight condition. In addition to any mission requirements, Navy carrier based air vehicles must be able to see the carrier deck and signaling equipment when landing in the rain and must be able to see personnel and equipment on the crowded flight deck when taxiing into position for launch in the rain.

The design of the air vehicle has an even greater effect on the type of rain removal required than does the mission. The size and shape of the windshield is very important. It is usually much easier to clear the rain off the relatively small, flat windshields of most transports than it is the large, bubble canopies on combat air vehicles, rotorcraft or observation air vehicle. The availability of bleed air from the air vehicle engines, the slope of the windshield, and the material from which the windshield is made all affect the design of the rain removal system.

Types of rain removal systems:

a. Windshield wipers. Windshield wipers are the oldest method in existence to remove rain from windshields. Built with arms and blades in the shape of inverted airfoils, they work satisfactorily at air vehicle speeds up to approximately 150 knots, true airspeed (TAS). The aerodynamic shape of the arms and blades cause the blades to press harder against the windshield surface rather than blowing from the surface as airspeed increases. Tests of this concept by Lockheed in 1965 demonstrated that a windshield wiper could satisfactorily clear a rainfall of 2.8 in/hr from a windshield at an airspeed of 115 knots, TAS. The same test showed a 2.0 in/hr rainfall could be cleared at 150 knots, TAS with only a slight decrease in visibility.

   The wiper was operating at 340 strokes/min. This is state-of-the-art for windshield wipers and may remain as an upper limit of their performance. At higher airspeed and rainfalls, the speed of the wiper should be increased to provide the same amount of clearance. In addition to the mechanical and power consumption problems involved in faster wiper speeds, the wiper itself begins to become a serious obstruction to good vision. Many pilots find the flickering effect of the windshield wiper moving back and forth through their line of sight to be very distracting when the wiper speed exceeds 350 strokes/min.

   There are other problems with windshield wipers that have not been solved. Wipers work very well on flat surfaces. The more pronounced the curve of a windshield the less effective wipers become. Wipers are all but useless on modern fighter air vehicles with single-piece, bubble canopies. There is also a serious problem when windshield wipers are used on materials other than glass. Polycarbonate and stretched acrylic both scratch easily. The continuous rubbing of windshield wipers combined with the dust in the air will rapidly wear a pattern of fine scratches into the surface of the windshield. In bright sunlight the scratches cause a severe glare. As nothing can be done about dust in the air, the only apparent solution to this problem seems to lie in making non-glass transparencies more scratch resistant. This problem is particularly bothersome on rotorcraft, as these air vehicles most often combine windshield wipers and non-glass windshields. This results in a very high replacement rate of windshields.

   Overall, windshield wipers are an acceptable means of rain removal for helicopter, transport, and utility-class air vehicles, which usually do not fly at high speed at low altitude and tend to have reasonably flat windshields. Windshield wipers are low cost, reliable, and lightweight. They are also readily available.

b. Jet blast rain removal systems. This method was developed from the chance observation that the high-pressure, high-temperature air used to de-ice the windshield of the F-86 air vehicle also did a good job of preventing rain from striking the windshield. These systems have evolved as follows. High-pressure, high-temperature engine bleed air is ducted to the base of the windshield. The bleed air is controlled by a shutoff and pressure regulator valve. When the valve is opened, the bleed air is directed over the windshield by a series of nozzles or by one slot-type nozzle at the upstream edge of the windshield. If a series of nozzles are used, they should be spaced closely together or water streaks will result on the windshield. Experience has shown the slot nozzle to be the better choice in this application. The nozzles should be a convergent type and should direct air parallel to or slightly away from the windshield. Tests have shown that a slight angle away from the windshield of the jet blast nozzles, which provides a small component of jet blast air velocity normal and away from the transparency, gives the best performance. The nozzle exit air should be at sonic velocity. Since the sonic velocity is proportional to the square root of the temperature, the jet blast air should be as hot as other systems requirements will permit. The jet blast air typically requires a pressure of at least 60 psig. These systems also require between 4.5 and 7 lbm/min of bleed air for each inch of width of cleared windshield. Experiments have repeatedly shown the above requirements to be the minimum for acceptable jet blast system performance. Unfortunately, this system has two very serious disadvantages. The greater of these is the amount of bleed air required. As stated above, the system needs 4.5 to 7 lbm/min of bleed air for each inch width of clear windshield. This means that a 1 ft-wide, clear section of windshield would cost from 54 to 84 lbm/min of bleed air. Also, the engines should be able to supply these quantities of bleed air at idle power at sufficient pressure to produce sonic flow at the jet blast nozzle exit. These conditions should be the design point because idle descent to land is the time most critical to good visibility.

A second, serious problem with this system is its potential for damaging or failing the windshield by overheating its surface. Experiences on the F-4, F-15, and other air vehicles have shown the importance of using means to protect against overheating the transparencies. Overheating can result in cracking, internal delamination, or discoloration.

Windshield over-temperature protection may be provided by limiting the jet blast temperature or by allowing the jet blast to mix with some of the slipstream air before it reaches the windshield so an insulating layer is formed between the windshield and the jet blast air or by a combination of both.

There are several ways to provide the desired mix of slipstream and jet blast air. The jet blast nozzles can be raised somewhat above the plane of the windshield outer surface. The jet blast nozzles may be rotated slightly away from the plane of the windshield. The nozzles may also be located a few inches forward of the leading edge of the windshield. In addition, there should always be a cockpit signal to warn the pilot of an eminent overheat of the windshield.

The F-18 air vehicle reduces the temperature of the air used for rain removal and other warm air uses by separating the bleed air coming through the primary heat exchanger into two air streams, diverting the cooler air closest to the ram air inlet to the warm air manifold that supplies the rain removal system.

One other problem with jet blast systems is that they cannot be designed totally analytically. Wind tunnel testing of cockpit mock-ups complete with simulated rain to size and position the jet blast nozzles properly relative to the windshield is required to refine the system design.

c. Rain repellents. All rain repellents, whether “in-flight” or “ground applied”, work in the same manner. A thin film, usually one molecule thick, of rain-repellent material is deposited on the windshield. Water does not adhere to or wet the repellent. As a result, the water will remain in the form of spherical droplets rather than spreading into the non-uniform film it normally forms. These droplets will then rapidly roll off the windshield due to gravity and the slipstream. Both types of rain repellent have two common problems:

1. Glare. At night, in rain under overhead lighting, there is a very distracting glare from light being diffracted into the pilot's eyes by the droplets on the windshield. This effect will occur with any rain repellent. This glare is not noticed in daylight and does not occur at night with any lights other than overhead lights. This glare could be a problem near hangers and other facilities with overhead lights.
2. Static and taxi. During slow taxi and static operations, rain repellents are sometimes unsatisfactory because there is insufficient wind to blow the droplets off the windshield. The droplets should become quite large before they roll off due to gravity. This will result in a high percentage of the windshield covered with water droplets and the associated impaired visibility. This problem becomes even worse when the slant angle of the windshield is low. Thus, even with a good ground-applied rain repellent, windshield wipers or jet blast may still be needed for low-speed taxi and static operation.

Ground-applied rain repellents should be reapplied every 30 to 50 flight hr, or after each encounter with rain. In the Air Force, requirements for applying rain repellents are provided in TO 42D4-1-4. All ground-applied rain repellents suffer in some degree from additional problems. These problems are discussed below.

1. Limited life. The ideal, ground-applied rain repellent would be applied during manufacture of the windshield and would last the life of the windshield. To date, this goal has not been approached and there is no reason to believe it can ever be reached. Failure to solve this problem leads to the next—maintainability.
2. Maintainability. The fact that current, ground-applied rain repellents are periodically reapplied leads to several problems. First, the pilot has no way of knowing if the proper reapplication of rain repellent has indeed been accomplished. Reapplication requires manpower. The effectiveness of all current, ground-applied rain repellents is heavily dependent on the skill and dedication of the people applying them and the weather conditions in which they are applied. Finally, once the repellency is gone in flight, it cannot be replaced in flight.

Rain repellents applied in flight are sprayed onto the transparency from nozzles located upstream of the windshield. The air and rain impinging on the windshield then distribute the repellent material evenly over the windshield's surface. This results in a rain repellent film being formed on the windshield, which will last for several minutes. When the film loses its repellency another may be applied.

In principle, the designs of in-flight, repellent-dispensing systems are quite simple. There are two basic types. The first type, or Type 1, system has an unpressurized reservoir. The reservoir is pressurized during flight by compressed air either from a small compressor or from the air vehicle service air system. When the pilot activates the system, the compressed air forces the repellent through the system plumbing to the distribution nozzles and out onto the windshield. The system has a timed solenoid valve in the plumbing so that a fixed amount of repellent is applied to the windshield on each command from the pilot.

The second type, or Type 2, rain-repellent dispensing system has a pre-pressurized bottle of repellent. This type of system eliminates the need for an active rain repellent pressurization system in the air vehicle. If this type is used, the materials used as the charge for the bottles must meet current hazmat requirements established in the air vehicle specification.

In-flight-applied systems also have some inherent problems, as follow:

1. In-flight systems do not work adequately on the ground because the repellent is not distributed properly, so windshield wipers or jet blast are still required for ground operations.
2. In-flight systems also require maintenance to fill or replace the reservoir. If the reservoir (bottle) has to be replaced after it is empty, the storage and replenishment for replacement bottles may be a problem, particularly for carrier-based air vehicles.
3. Because it is a fluid system, In-flight-applied systems are subject to corrosion and clogging problems, adding additional maintenance hours. This does vary with the system design and the type of fluid being used.
4. The in-flight system does add weight to the air vehicle compared to ground-applied rain repellent. This needs to be considered particularly for high performance (combat) air vehicles and rotorcraft.

There are also many advantages to the in-flight-applied repellent. Although not true of all current, in-flight-applied rain repellent systems, this system can be very simple and reliable. Its cost can also be competitive with windshield wipers and jet blast systems. The system is very effective in flight, assuming proper design. Unlike ground-applied repellents, this system gives the pilot complete control over the repellency of his windshield. To date, this system has been largely restricted to transport-type air vehicles. However, with the exception of rotorcraft, this system could be applied to all air vehicles. Rotorcraft, when hovering or flying at very low airspeeds, lack the necessary airflow to distribute the repellent.

Consult SAE AS6882 for further guidelines if ground-applied repellent is to be used.

Various types of air vehicles lend themselves to different types of rain removal systems:

a. Rotorcraft (helicopters) are probably the most difficult type of air vehicle for which to provide a rain removal system. In-flight-applied repellent systems do not work at the very slow speeds at which rotorcraft sometimes operate. Windshield wipers tend to scratch the polycarbonate used almost exclusively for helicopter transparencies. Ground-applied repellent should be considered as a prime candidate for a helicopter rain removal system. The only alternatives would be a windshield wiper—thus a high replacement rate of polycarbonate windshields or the large weight penalty of glass windshields.
b. Utility air vehicles are compatible with wiper use. Glass transparencies do not cause a very serious weight penalty to this type of air vehicle and the performance of these air vehicles is well within the capability of wipers. Utility air vehicles also tend to have flat windshields. These utility vehicles are referring to historically cargo-oriented or large

payload-carrying vehicles that have multi-functional and utility-oriented performance capabilities.

c. Combat air vehicles would be prime candidates for in-flight-applied systems when jet blast is not practical and where static and taxi visibility is not critical. Wipers are not usable at the speeds at which these air vehicles operate. The performance requirements of such air vehicles would justify the development of an in-flight-applied rain repellent system. Current ground-applied rain repellents are only of limited value in the environments where these air vehicles must operate. Where static and taxi visibility is critical, such as on an air vehicle carrier, a combination of a jet blast system supplemented by a ground applied system would be the prime candidate. The jet blast provides the needed clearance during taxi, static and low speed. The ground applied rain repellent provides additional capability to meet heavy rain conditions without requiring excessive bleed air flows, but limited capability is there if the repellent has worn off. The jet blast may also be used for anti-icing.

d. No particular type of rain removal system is more beneficial for transport-class air vehicles. All types of rain removal systems could work on this type air vehicle. In fact, current transports use all types of rain removal systems in many different combinations.

e. Bombers have characteristics of both combat and transport air vehicles when all aspects of their missions are examined. The systems most likely to satisfy the requirements of bombers would be in-flight-applied rain repellent and jet blast.

The items above are guidelines only. It is often necessary in practice to combine two and even three different rain removal systems to achieve desired performance under all conditions. A trade study that considers all possible rain removal methods should be conducted for each new air vehicle early in the program to select the best rain removal system.

REQUIREMENT LESSONS LEARNED (3.4.4.9)

(TBD)

D.4.4.4.9 Rain removal.

The capability of the rain removal subsystem to provide the required rain removal functions and performance shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.4.9)

Verification is necessary to ensure proper rain removal performance is met. Verification needs to ensure the clearance area of the rain removal provides for safe operations of the air vehicle where the system operates.

VERIFICATION GUIDANCE (4.4.4.9)

TBS should be filled in with the appropriate combination of laboratory tests, failure mode and effects analyses, and air vehicle ground and flight tests to verify adequate rain removal through critical viewing areas.

Flight tests should demonstrate the rain removal system is not damaged by flight at maximum speed.

A failure mode and effects analyses (FMEA) should verify that no single failure results in failure of rain removal for two windshields.

Laboratory tests in “rain tunnels" are very effective in the design and evaluation of rain removal systems. Rain tunnels permit test of the system under carefully controlled conditions that are difficult or impossible to encounter during flight testing. Flight tests, in natural rain or behind a spray tanker, permit evaluation of the rain removal system installed on the air vehicle in the flight environment.

VERIFICATION LESSONS LEARNED (4.4.4.9)

The A-10 program made very effective use of a rain tunnel in the development of the rain removal system. The tests demonstrated that a ground-applied rain repellent would work very well. However, as a result of these tests it was learned that a small jet blast system was also required to help clean the windshield under “mist” rain conditions at low speeds of 40 knots and under.

D.3.4.4.10 Transparency cleaning.

A cleaning system shall be provided for the following transparencies: __(TBS 1)__ . The cleaning system shall be designed to remove __(TBS 2)__ and shall have sufficient capacity to provide necessary cleaning of critical viewing areas throughout any single mission. The critical viewing areas for cleaning are __(TBS 3)__. There shall be no loss of fluid during flight maneuvers of the air vehicle.

REQUIREMENT RATIONALE (3.4.4.10)

Air vehicles with low altitude missions, vertical takeoff and landing capability, and similar missions or those required to operate on an air vehicle carrier may require a transparency cleaning capability to ensure adequate crew visibility. Camera windows, sensor windows, and such, may require cleaning system to ensure proper performance of the device. Cleaning systems must be able to remove salt, dust, insects, gun gas residue, and such, depending upon the environment in which the air vehicle is to operate.

REQUIREMENT GUIDANCE (3.4.4.10)

TBS 1 should designate the transparency surfaces that require a cleaning system. This may include a windshield, a canopy, sensor window, or such.

TBS 2 should define the substances that the cleaning system must be able to remove.

TBS 3 should define the critical viewing areas for which the cleaning system must meet performance requirements. The critical viewing areas are determined by performance consideration and the requirements of special sensors. The critical viewing area of the areas to be cleaned should be obtained from the appropriate cognizant engineer.

The system should be required to remove dried salt fog from the transparencies when the air vehicle is expected to operate over or near saltwater. Insect and dust removal is required for operation over land. Another application for a transparency cleaning system is on air vehicles subjected to large quantities of smoke from air vehicle armament. In these applications, the system should be able to remove smoke or residue from transparencies.

The capacity required for salt removal is a function of the expected mission altitude and duration. The system capacity should be adequate for a complete mission.

For dust and insect removal systems, the design and capacity should be determined by the insect removal case, as that is more difficult to achieve than dust removal. The insect removal system capacity is determined by mission duration and washing frequency.

A common design criteria for insect removal is that one honeybee-sized insect (120 mg) can be expected to impact each square foot of windshield frontal area for each 20,000 ft of horizontal extent. A common design criteria for vertical takeoff and landing air vehicles is for the washing system to maintain the pilot and co-pilot's windshield free of dust based on a dust density of 0.1 gram per cubic foot of commercial 140 mesh silica flour.

Since smoke and armament residue may be unique to each air vehicle, wind tunnel and perhaps flight test experience should be conducted to determine smoke and residue cleaning requirements.

Typical wash system operation is usually initiated by spraying a washing fluid on the transparency exterior surface. Then a jet blast or windshield wipers are used to provide scrubbing action, if necessary, to loosen the foreign substance from the transparency surface. The system controls can either automatically sequence the wash duration and jet blast initiation or the control can be completely manual.

Normally, the wash fluid will be contained in a reservoir pressurized by bleed air. Since maintenance may be required on the system after each flight for reservoir filling, it is important for the reservoir to be located in an accessible location and fill and drain ports should be easy to use. If the washing fluid has a freezing point that may be reached while the air vehicle is operative or inoperative, heating provisions should be required for the reservoirs. Reservoir heating can be accomplished either electrically or by the use of bleed air.

The wash fluid is to be non-corrosive and non-toxic, meet current hazmat requirements established in the air vehicle specification and should be in no way detrimental to the transparency surface. Also, the system design can usually be simplified if a fluid is used that will not freeze at temperatures encountered in the air vehicle, thus alleviating the fluid heating requirement. The use of detergents should be avoided since corrosion problems can result for the air vehicle, and system maintenance and reliability will be adversely affected due to line clogging problems and the necessity to purge fluid lines with bleed air after washing.

(See SAE AIR1102 for additional guidance.)

REQUIREMENT LESSONS LEARNED (3.4.4.10)

Solutions of 60 percent (60%) water and 40 percent (40%) ethylene glycol and some commercially-prepared fluids have proved to be satisfactory washing fluids.

D.4.4.4.10 Transparency cleaning.

Inspection of drawings and the air vehicle shall verify incorporation of cleaning provisions for (TBS 1) and that fluid cannot be lost during flight maneuvers. Laboratory and flight tests shall verify the capability of the system to remove from (TBS 2) critical viewing areas throughout any single mission.

VERIFICATION RATIONALE (4.4.4.10)

Laboratory tests are essential in the design, development, and test of cleaning systems. Design conditions are difficult to encounter and measure during flight testing, so laboratory testing is required. Flight tests are required to evaluate the system installed on the air vehicle and in the flight environments.

VERIFICATION GUIDANCE (4.4.4.10)

TBS 1 is used to define the transparencies with cleaning provisions.

TBS 2 is completed by defining the substances that must be removed by the cleaning system. Laboratory wind tunnel tests are usually necessary to finalize system detain design (nozzle sizing, wash duration, or system geometry). These tests can also serve to verify the performance of the system.

VERIFICATION LESSONS LEARNED (4.4.4.10)

Cleaning systems are difficult to design and it should be verified that the contractor makes sufficient provisions for system testing.

D.3.4.4.11 Ice protection.

The air vehicle and its subsystems shall maintain full flight critical operation in the icing environment defined in the air vehicle specification. Except for an air vehicle required to perform its typical mission while under icing conditions, the air vehicle and its subsystems shall recover a “full mission capability” within the (TBS 1) time period after exiting icing conditions. When an air vehicle is required to perform its typical mission while under icing conditions, mission capability shall be maintained as defined in the air vehicle specification. An Ice Protection System (IPS) shall be provided as required to meet these requirements.

a. Unprotected components. Ice accretion on components that cannot or will not be protected shall present _(TBS 2)_ degradation to mission capability and maneuvering performance parameters and shall not present unacceptable safety risk to flight crew or ship-or-ground personnel in all operational phases.

b. Protected components. The IPS designs shall adhere to the _(TBS 3)_ documents for the IPS technology implemented for a particular subsystem or component.

c. IPS detection and controls. If an IPS is required, a manual or automatic (or both) detection system for sensing incipient ice accretion shall be provided and shall enunciate (TBS 4)_ information to the pilot. A _(TBS 5)_ method for reporting surface ice control performance shall be provided for flight critical and safety-of-flight components.

REQUIREMENT RATIONALE (3.4.4.11)

A properly designed IPS provides operational safety, strategic, and tactical advantages for a given air system. The natural environment cannot be controlled, nor can it be reliably predicted on small to intermediate spatial and temporal scales in which most weapon systems operate, such that safety-of-flight risk due to inadvertent entry is a common event. Tactical advantages include mission planning efficiency, mission readiness, mission timeliness, and success rate, which all increase with an IPS, since operations can be executed during known or predicted icing environments of certain severities. Strategic advantages include utilizing adverse weather conditions such as icing as a cover to capitalize on the element of surprise during offensive operations and to protect air vehicles in transit or on special missions.

Commonly, the decisions regarding the components protected by an IPS on a given air system are made during contract negotiations, such that the detail specification should be descriptive to the component level to ensure an adequately balanced system is developed during acquisition. The cost of designing, testing, manufacturing, operating, and maintaining an IPS has been historically very high and may consequently result in under-designed systems being introduced to the fleet. However, there are many exposed air vehicle components on which ice accretion has a neutral effect beyond drag increase, and should not be protected. The determination of protection requirements for a given component should not be done via contract negotiation or cost tradeoffs, but by engineering evaluation of system or mission impact. There are a wide range of IPS technologies available with different levels of maturity, levels of electrical power requirements, weight impacts, reliability and maintainability characteristics, as well as functionality (ice control performance).

As the complexity of air vehicle weapon systems has increased, so have the IPS technologies to protect them, causing an increased need for autonomous control, monitoring, and performance reporting of the IPS, to reduce crew workload. An automatic system can provide IPS activation upon entering into an icing environment without flight crew action. A manual IPS can allow the flight crew to prioritize air vehicle resources during normal and emergency operations. The performance adequacy of an IPS to control ice accretion or removal is generally provided by monitoring air data and propulsion instruments, visible external cues, and airframe vibrations and air vehicle handling qualities. The design of an IPS is most always a compromise of cost, weight and power for a specified icing severity protection level, such that there will be environments that exceed this level, and the flight crew should not discover these limits by exceedance before exiting the environment. Failure reporting in the cockpit will provide the flight crew with information that will allow flight, safety, and mission critical decisions to be made during system malfunction.

REQUIREMENT GUIDANCE (3.4.4.11)

The air vehicle specification should specify which components are to be protected or unprotected, what portion of the each surface will be protected, and the type of protection required (deice active shedding, deice passive shedding, anti-ice running wet, anti-ice evaporative).

TBS 1: If not defined in the air vehicle specification, the “time period” should be based on mission requirements as well as expected performance of available technology and is typically 5-30 minutes. The term “full mission capability” should be well defined based on intended system reliability and robustness during normal and instrument meteorological conditions (IMC) operations. The IPS should provide protection for all components exposed to in-flight, ship, and ground icing conditions as given in “Operational environment” of this document’s handbook that present unacceptable operational safety risks to personnel or materiel, prevent or delay mission completion, or degrade mission readiness or success. The best commercial design practices should be used in the IPS design process (guidance information is provided in the "Aircraft Icing Handbook," FAA Report DOT/FAA/CT-88/8, which is the most up-to-date, central source of icing design data to date (beyond the Aeronautical Design Standard ADS-4 available from the US Army Materiel Command at www.redstone.army.mil). The handbook is updated on a regular basis by the FAA and the SAE AC-9C Aircraft Icing Technology Subcommittee. The determination of icing effects, appropriate protection techniques, and which components can be unprotected should be resolved by technology trade studies, accepted and validated ice accretion computer simulation, and documented experience. Component and material testing using artificial, simulated, or natural testing should also be used. Protection technologies including Type I & II Freezing Point Depressant (FPD) deicing fluid categories require appropriate levels of airframe watertightness to prevent intrusion and degradation of subsystem components and have an environmental impact that should be addressed.

TBS 2: The limits of degradation should be specified. For example, maximum engine inlet distortion (engine qualification limits should be used), a maximum shed ice size for engine foreign object damage (FOD) potential (determined from distortion energy criteria or ice ingestion testing), a maximum airframe parasitic drag delta (5 percent (5%) is recommended), a maximum air vehicle lift to drag ratio delta (5% is recommended), a minimum transparency critical visible area (70% of total viewing area is recommended), or a maximum radome signal attenuation to dispersion (10% is recommended). Consideration should be given to preventing excessive ice accretions on the fuselage and exposed subsystems and components during all conditions of flight and ground-or-ship operations. The determination of whether a particular component does not require protection should consider the potential aerodynamic degradation, the ice elimination process (sublimation, shedding, melting, manual removal) and its operational phase impact, and the component functionality and criticality contribution to mission success.

TBS 3: No components should deice or self-shed accreting ice into air induction inlets or exhausts (engine inlets), transparencies, or rotating components (main or tail rotors) and fixed surfaces should be protected from excessive ice impact forces. No IPS component should cause compromising emanations (electrical or acoustic), behave abnormally in electromagnetic or acoustic environments, or excessively degrade system reliability or maintainability. All IPS components exposed to the ambient environment should be resistant to solar radiation; salt spray; and hydrometeor, sand, dust erosion. New technology IPS systems are permitted with DOD concurrence concerning operational characteristics, reliability, maintainability, cost effectiveness, design risk, test evaluation, and technical maturity. IPS component, electrical, pneumatic controller failure modes should be addressed to maximize survivability and mission capability. When GFE components are used, the airframe contractor should provide all necessary electrical, control, pneumatic, and hydraulic utility service connections located at the component mounting interface in an accessible manner. When a component IPS requirement must be assessed during flight testing, there should be utility service, structural, and spatial provisions provided for that IPS subsystem if it must be installed.

Protection should be provided for all flight critical surfaces (such as the wing or empennage) and optionally for other aerodynamic surfaces degraded by ice accretion. The operation of any surface contraction or folding design and locking indicators should not be degraded by ice accretion. Design considerations should include degradation of lift, performance, range, endurance, handling qualities, stall angle-of-attack (AOA), control effectiveness, and sink rate and increase of drag, stall speed, takeoff speed, and control forces. Components should be resistant to impact and accretion from residual ground or ship ice accretion during flight platform operations.

Engine and Engine Air Induction Inlet IPS considerations are also given in JSSG-2007, Engines Joint Services Specification Guide, and should be considered such that a balanced Airframe and Engine Integrated IPS is developed. The engine inlet, inlet duct, components, inlet auxiliary inlets, and the engine front frame should be protected to < +40°F by an anti-ice or deice IPS system. High flow rate (> 80 lbm/min) propulsion systems with long ducting, prone to condensation or vortex icing, should be protected to < +60°F. If a particle separator is required the design separating efficiency should include removal of natural-shed, passive-shed, and active-shed ice from engine-face-forward components such that particle sizes entering the engine do not affect the fatigue limits of the fan or compressor design and the separated particle sizes do not damage or obstruct auxiliary blowers or ducts. If the IPS is an active-shed or passive-shed deice design then engine FOD-threatening shed ice shards should not be generated in any phase of operation. If the engine IPS subsystem is a "running wet" design the runback of liquid water should not refreeze and shed into the engine in any icing environment or phase of operation. Consideration should be given to condensation icing; vortex icing; ice crystal and snow accumulation; water plug or slush formation; airflow spillover characteristics; and ramp, guide vane, and boundary layer suction and bleed design. If shielding screens are installed over or in front of any inlet consideration should be given for protecting the screen, determining exposure duration limits before functional and total obstruction, and assessing shedding characteristics and FOD potential. Ram air inlets are to be protected, or sized appropriately for partial obstruction if not protected.

Drains and vents should not be placed inside nor forward of engine inlets and should not shed damaging accumulated ice into air induction inlets or exhaust, rotating components, or transparencies. These ports should not incorporate a design that will cause ice to accrete and should resist subsequent obstruction.

Electromagnetic components susceptible to degradation due to ice accretion should be protected. Consideration should be given to the dielectric, reflective, and refractive properties and the electro-static space charge accumulation and retention of the ice accretions and the associated component functional degradation.

Neither the operation nor failure of transparency IPS should cause structural damage or degradation of clarity in any icing environments or any other environment or phase of operation. A transparency overheat control device should be required. Alcohol or other corrosive materials should not be used on acrylic panels.

Consideration should be given to the fuel tankage design within flight surfaces (wing, sponson, and fuselage) for external surface sub-freezing cooling (due to internal vaporization of fuel) causing clear ice to form. Fuel additive behavior for preventing system obstruction due to freezing of dissolved water or other fuel components should be considered.

Provision for an anti-icing and deicing IPS for rotor blades or propellers should be provided. The direct use of exhaust gases for anti-icing or deicing of rotor blades or propellers should not be permitted, unless all materials in contact with the exhaust gases have adequate corrosion, oxidation, and elevated temperature resistance properties and component leakage poses a minimal threat to affected subsystems and personnel. Fluid-type systems should not eject FPD fluids into air induction inlets or exhausts; vents or drains; antennas or radomes; or windshields, canopies, or transparencies. When the rotor head is exposed to icing conditions the various components (droop stop, articulation joints) should be insensitive to icing or be protected from accreted ice restriction or malfunction. Spinners should be designed with considerations for attachment point and bracket cold spots. The blade-fold system should be insensitive to icing or shielded from direct exposure to icing conditions.

All exposed sensors should be assessed for ice accretion degradation.

Air data systems such as pitot-static and AOA sensors should be protected by an anti-ice "evaporative" IPS.

The IPS subsystem components should withstand lightning strikes in accordance with MIL-STD-464. The IPS electrical components should not be directly used to transmit lightning currents and should be designed to prevent inadvertent transmission damage.

Electrostatic discharge systems should be designed to function during and after exposure to icing conditions.

Landing gear systems and wheel well sub-systems should be designed to be resistant to accumulation of freezing precipitation and ground accretion residual and should not be functionally degraded or damaged.

Lighting systems should be positioned such that ice accretions will not cause total functional degradation and should be resistant to ground de-icing fluids.

Function of externally-mounted armament should not be degraded by ice accretion. The appropriate exposed subsystem components should be protected when a weapon must be guided by laser or video. Consideration should be given to ice accretion on armament or drone surfaces where aerodynamic performance and impact accuracy are important.

Federal Aviation Administration Report DOT/FAA/CT-88/8 provides excellent guidance on the design of IPS. SAE AIR1667 provides guidance on rotor blade electothermal IPS.

TBS 4: Enunciation or activation should be initiated by a detector subsystem that senses either accreting ice or outside air temperature and liquid water content. All IPS subsystems should have a manual deselect or reselect capability with sustained re-inunciation and respective failure modes should be indicated in the cockpit.

TBS 5: The decision to provide manual or automatic icing environment detection (or both) should be made upon evaluation of cost limits of the particular program, the expected operational icing environments, and the workload and experience of the flight crew. IPS surface ice control performance should be monitored and reported when failure or capability exceedance can result in a flight critical or safety-of-flight risk. It is recommended that mission critical component IPS provide a monitoring function as well. Built-in-test capabilities are critical for acquiring high levels of reliability and maintainability for an IPS, as well as mission readiness and system robustness. There are three basic types of ice detectors: probe (extends out into the local flowfield and droplet dispersion field), surface (mounted on an exposed component between impingement limits), and remote (detects ice on an exposed surface from another air vehicle location). A desirable feature of an ice detector is that it can sense incipient ice accretion in the four air vehicle local environments (fuselage, flight surface, air induction inlet, and rotational component) and that it can sense ice on an area of a surface and not just a point indication. The ice detectors should be provided in accordance with SAE AS5498. Controls for operating the IPS should be readily accessible to the pilot and co-pilot. An ice-detected indicator should exist as a separate enunciation readily viewable by the pilot and copilot. The IPS subsystems that have potential for causing engine FOD, or rotating or fixed system impact damage should be activated automatically and all other IPS subsystems may be activated automatically or manually.

REQUIREMENT LESSONS LEARNED (3.4.4.11)

On the V-22, the IPS design was considered in the ‘conceptual’ stage prior to production, allowing for minimum cost-to-benefit on a very complex system. The initial rotor IPS on the SH-60B was a kit based on the UH-60A kit. The SH-60B evaluation tests behind a spray tanker revealed that the UH-60A droop stop heaters, not included on the initial SH-60B configuration, had to be added prior to further testing. The Navy limited the air vehicle icing envelope to an icing envelope that was qualified by Army tests. Several years late, the SH-60B rotor IPS became a production line installation. Kit methods for IPS design were found not to be a viable option for the complex tilt-rotor V-22 air vehicle. Both the propulsion system, air induction system, and airframe system should have complementary and matched IPS capabilities. This was not the case on the F-18 air vehicle such that a considerable portion of F-18 engine FOD events have occurred, and the large portion of unknown FOD sources are suspected to consist of a comparable ratio of icing-related sources.

On various programs, certain components that were initially left unprotected or partially protected required add-on protection or extension of coverage to be installed on the air vehicle.

For example, on the P-3 air vehicle the UHF antenna was not protected (actually, not connected) and was believed to result in excessive p-static noise on communications equipment when used in light rime icing conditions. The V-22 air vehicle has many unprotected exposed components that have the potential to shed ice during the landing or hover flight phase that can be recirculated in the external flowfield and be ingested by the engines or threaten ground or ship personnel.

Few mishaps or safety of flight threatening events have occurred related to the operation of an IPS installed on an air vehicle while in icing conditions. Protection systems have failed in and out of icing conditions causing some structural damage, but the majority of adverse experience has been inadvertent entry into icing conditions causing degradation to unprotected flight or mission critical components. This experience is understandable, since IMC flight is typically avoided when possible, and even more so for potential icing conditions, as well as the fact that the majority of military operations occur in warmer climates and seasons.

Flight critical surfaces, such as the V-22 wing, did not initially have adequate upper and lower surface chordwise coverage, allowing residual ice to form aft of the protected leading edge. This was realized using computer simulation for the lower surface early in the program, but it was later realized that the upper surface coverage could not protect for Supercooled Large Droplet (SLD) that runback and ice past the protected area on the upper surface (SLD icing was outside FAA and DOD icing envelopes when the V-22 air vehicle was developed). Empennage protection was designed for the P-3 vertical stabilizer, but later on it was disabled. On the V-22 air vehicle, empennage protection was planned, but then canceled with provisions. The lack of empennage protection on fixed wing air vehicles is dangerous because its sensitivity to icing depends upon the design margins (rudder or elevator effectiveness), the allowable c.g. limits of the air vehicle, and the severity of the icing encounter. Tailplane icing is a threat to fixed wing air vehicles since the more slender leading edges accrete ice at a much faster rate than the blunter wing and fuselage leading edges.

A large majority of icing incidents have involved the propulsion system, mainly from FOD-producing, ingested ice originating from internal engine inlet components, inlet lips, or external components forward of the inlet. The F-14 inlet design has sectioned ramps, one of which under certain flight conditions would adjust to create a forward facing step that would allow ice to accrete, subsequently shed, and be captured inside the ramp area. Upon carrier landing this ice would be dislodged and ejected forward, and upon going full throttle (standard procedure), the ice would then be subsequently ingested by the engine. The ramp scheduling was adjusted to prevent the undesired ramp position. The F-18 air vehicle had an inlet drain installed in the port ducting that would seep water, which under flight conditions would freeze upon exiting the drain, accreting large ice chunks that would eventually shed and cause engine FOD. This behavior was extensively experienced by the Canadian Air Force, who operated the F-18 air vehicle in predominately colder weather. The drain was rerouted so that it would exit external and aft of the engine inlet.

An icing event during takeoff of an A-6 resulted in a canopy ice-over causing total visual obstruction as well as air data instruments becoming obstructed (loss of airspeed indication). This was an inadvertent encounter, where other air vehicles previously passing through that airspace 15-20 minutes before had not noticed any icing conditions. Avoidance was stressed in this case and no redesign was attempted. An F-14 icing event caused a canopy to be impacted by ice, and in combination with the rain, reduced forward visibility to a one inch strip and also resulted in catastrophic dual engine FOD upon arrestment. This was also an inadvertent encounter during a marshal flight pattern placed inside a thunderstorm cell pattern. This air vehicle did not have the updated ramp schedule for the engine inlet.

The SH-60B air vehicle has an exposed rotor head, and it was realized that the droop stops were being frozen in the retracted position by accreted ice allowing the rotor blades to droop to a dangerous position on deck. A redesign was instituted that placed the existing UH-60A resistive heater in the droop stop fastener. The SH-60B and V-22 rotor systems wiring harness or clamps, that bring control and power signals from the rotor head to the blades, were failing due to the extreme rotational force and vibration environment. Stronger connectors, clamp materials or positioning, and specialized wiring were used to prevent these problems.

A UH-1 rotor IPS was developed during which it was found that runback icing on the blades was occurring due to overheating of the electrothermal blankets. This behavior caused ice to form aft of the protected leading edge, which resulted in considerable torque rise and also asymmetrical shedding or vibration. Better tailoring of power densities along the blade prevented this problem.

On the V-22 pitot-static airflow distortion can occur when ice builds up on unprotected antennae placed in front of those components. Ice accretion on the base of the pitot-static probes was found to grow outward and forward of the base thereby affecting the air flow around the probes. Air data instruments should be placed on the airframe in a manner that will ensure unobstructed airflow from freestream early in the program.

On the P-3 air vehicle, which has a manually activated IPS, there have been a few instances of inlet snow or ice FOD or obstruction. The obstruction occurred when an engine was shut down to conserve fuel, during which time the air vehicle was in air induction icing or snow or ice crystal IMC flight, causing the engine inlet to become packed with snow and ice, preventing an engine restart when needed. Other cases of engine FOD occurred when icing conditions were perceived some time after entrance, resulting in a delayed manual activation of the inlet and engine IPS. This resulted in FOD-capable ice accreting in the inlet that subsequently was shed when the IPS was activated. Even though a probe-type ice detector is installed on the P-3 fuselage and Naval Air Training Operating Procedures Standardization guidance is provided, the flight crew cannot perceive all possible accreting environments.

D.4.4.4.11 Ice protection.

The Ice Protection System (IPS) shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.4.11)

The phenomena of ice accretion is very complex and current modeling capabilities still necessitate extensive ground and flight testing periods to validate IPS design capabilities at the component and subsystem level. Artificial icing testing on the ground and in-flight are also of significant value, primarily due to the ability of these facilities to produce a controlled, repeatable icing cloud over a greater range of conditions than may be found during a natural ice flight test program. Natural icing surveys provide the final validation of the design on the air vehicle system level.

VERIFICATION GUIDANCE (4.4.4.11)

TBS: The verification of the IPS should be determined by artificial, simulated, or natural testing, by accepted ice accretion computer codes or by a combination of the above. Qualification by similarity should only be exercised on non-flight critical components and should consider surface ice control performance. The capabilities of the air vehicle should be demonstrated on the component level, subsystem level, and on the air vehicle level. Mission completion potential should be demonstrated. The following methods should be considered:

a. empirical correlation of experimental data or historical design data
b. computer simulations using flow field, trajectory, heat transfer, accretion and performance codes
c. ground-based icing facility testing on the component and subsystem levels
d. ground-based component and subsystem functional, reliability, and fit evaluations
e. ground-based, full-system mockup functional testing
f. ground-based climatic lab testing
g. simulated ice testing (icing tunnel)
h. in-flight artificial spray tanker testing
i. natural icing survey flight testing
j. cold weather ground and flight operations evaluations

The engine should be evaluated ultimately in an installed airframe in a natural or artificial (or both) in-flight or ground environment.

Federal Aviation Administration Report DOT/FAA/CT-88/8 provides excellent guidance to establish a test and certification program for an IPS and unprotected surfaces.

VERIFICATION LESSONS LEARNED (4.4.4.11)

Component level demonstration has included computational analysis with approved software and icing test facilities (ground-based or flight-based) as a combined effort on the V-22 air vehicle. Air vehicle level demonstration involved flight-based testing (either artificial spray tanker or natural icing conditions) efforts. Mission completion demonstration was accomplished by using the resulting above data and computer simulation with validated software.

On one aircraft program that went through extensive analysis and ground-based testing, ice buildup on a small surface not considered in the analysis and testing resulted in shedding causing significant damage to the aircraft. There is no substitution for full aircraft testing in icing. Natural icing testing should be performed on larger aircraft where the tanker cannot totally cover the aircraft.

D.3.4.4.12 Bleed air

D.4.4.4.12 Bleed air

D.3.4.4.12.1 Overbleed protection.

Protection against overbleeding of the bleed sources shall be incorporated.

REQUIREMENT RATIONALE (3.4.4.12.1)

One intent of this requirement is to ensure that any failure of the ECS will not result in overbleeding of the bleed source(s). Overbleeding can be detrimental to the bleed air source and result in a hazardous condition.

REQUIREMENT GUIDANCE (3.4.4.12.1)

A flow limiting device is required to protect the bleed source from overbleeding in the event of a duct failure or control component failure in the bleed air system. Frequently, the bleed air source may contain its own flow limiting device, in which case such a device (such as a flow orifice) can be deleted in the bleed air system. The flow limiting device should satisfy maximum system demand, which should not exceed the maximum allowable flow from the source(s). On multiple engine air vehicles, the engines may require flow sharing limitations.

On multiple engine air vehicles, certain engines require that a balanced flow be maintained between the engines. If excess flow is taken from one engine it may have a detrimental effect on its reliability. The air vehicle engineer in coordination with the propulsion engineer should provide the maximum imbalance in the flow allowed for the engines.

REQUIREMENT LESSONS LEARNED (3.4.4.12.1)

The UH-60 winterized heater subsystem uses engine bleed air. Since the engine anti-ice also uses engine bleed air, the heater includes an interlock that reduces engine bleed air to the heater when the engine anti-ice switch is on. This prevents overbleeding of the engines when both the heater and engine anti-ice are in use.

D.4.4.4.12.1 Overbleed protection.

Analyses, inspection of drawings, and laboratory, ground, and flight tests shall verify the protection against overbleeding the bleed sources.

VERIFICATION RATIONALE (4.4.4.12.1)

Analyses provide preliminary verification of maximum flow control requirements. Laboratory testing of the flow control component(s) is required to verify their safety. Final verification can only be done when combined with actual engines in ground and flight test.

VERIFICATION GUIDANCE (4.4.4.12.1)

Usually, flow control performance is strictly a function of a flow control component, unless certain system or engine interfaces have been overlooked. Laboratory testing should verify that the design meets its requirements and is safe. Final verification in ground and flight test should require minimal instrumentation and can be accomplished in conjunction with other tests.

VERIFICATION LESSONS LEARNED (4.4.4.12.1)

(TBD)

D.3.4.4.12.2 Bleed air source shut off.

An independent means shall be provided for shutting off the bleed air flow from each bleed air source. These shutoff provisions shall be controllable from the air vehicle crew station. The shut-off provision shall be located __(TBS)__. A second means of shutting off the bleed air flow from each bleed source shall be provided for rotary-wing air vehicles.

REQUIREMENT RATIONALE (3.4.4.12.2)

Provisions for shutting off bleed air are required to enable the flight crew to stop flow from the bleed source(s) in case of bleed air contamination. Also, bleed air duct rupture or excessive leakage downstream of the source can be isolated through bleed shutoff provisions used in conjunction with isolation valves. The shutoff provisions are often required for maintenance or other operational requirements. Dual means for shutting off hot air sources are necessary to prevent a single failure from resulting in the inability to shut off hot air to occupied compartments.

REQUIREMENT GUIDANCE (3.4.4.12.2)

The intent of this requirement is to provide shutoff provisions for the onboard high pressure bleed air sources, such as the engines, APU and auxiliary compressors. The ability to control these valves from the crew station is important since they can be used to isolate a contaminated bleed source or a leaking duct section from the rest of the bleed air system. Bleed shutoff valves are also used to eliminate engine bleed during engine maintenance trim runs. Most modern air vehicles have a leak detection system that automatically shuts off the source from the leaking system.

TBS: The shutoff valves should be located as near as practicable to the bleed air source in order to isolate as much of the bleed ducting as possible in the event of a leak or rupture. The ECS engineer should coordinate with the cognizant engineers for each of the pressurized air sources to determine the closest practical location for the shutoff valves. Careful selection of mounting methods is desired in high vibration areas such as the engine compartment. Shutoff valves for ground pneumatic power sources are not required on the air vehicle. Bleed air shutoff provisions should comply with fire safety requirements.

Shutting down the normal mode of ECS cooling should be allowed to count as a second means of shutting off bleed air into the cockpit. (See SAE ARP1796 for more guidance.)

REQUIREMENT LESSONS LEARNED (3.4.4.12.2)

Serious damage from high temperature bleed air leakage or duct rupture has occurred in a number of cases due to the lack of bleed air shutoff provisions at the source. Experience shows it is best to locate these provisions as close to the bleed port of the engine as possible

D.4.4.4.12.2 Bleed air source shut off.

Inspection of drawings and air vehicle demonstrations shall be used to verify that independent means are incorporated for shutting off the bleed air flow from each bleed air source that these provisions are controllable from the air vehicle crew station. Inspection of drawings shall verify that shutoff provisions are within the required distance from the bleed source.

VERIFICATION RATIONALE (4.4.4.12.2)

Bleed air source shutoff provisions require verification through air vehicle demonstration to ensure proper installation and functional interface. Drawings and schematics must be examined to verify that shutoff control features are independent and within the required distance of the source.

VERIFICATION GUIDANCE (4.4.4.12.2)

Verification of proper utilization of shutoff features requires a systems operational analysis. A functional demonstration of these features is easily performed on the air vehicle and is usually included in air vehicle acceptance procedures and during flight-testing. A drawing review is all that is required to verify that the shutoff provisions are within the required distance of the source.

VERIFICATION LESSONS LEARNED (4.4.4.12.2)

(TBD)

D.3.4.4.12.3 Bleed air distribution control.

An independent means shall be provided for shutting off the bleed air flow to each subsystem using bleed air source. These shutoff provisions shall be controllable from the air vehicle crew station. The shutoff provisions shall be located __(TBS)__.

REQUIREMENT RATIONALE (3.4.4.12.3)

Subsystem shutoff provisions are required to enable the flight crew to eliminate airflow to a failed subsystem without deactivating other subsystems. Distribution shutoff valves can also be used for leakage isolation.

REQUIREMENT GUIDANCE (3.4.4.12.3)

Distribution shutoff valves, in addition to controlling the function of a subsystem, also provide a means of isolating a failed subsystem or air leakage source without deactivating other subsystems. Most new air vehicles have a leak detection system that automatically shuts off the source from the leaking system.

TBS: Location of the shutoff provisions at the inlet to the using subsystems improves reliability, safety and reduces cost and weight.

REQUIREMENT LESSONS LEARNED (3.4.4.12.3)

Experience has shown it is best to locate the shutoff valve at the subsystem inlet rather than the outlet, as has been done in the past on some hot air rain removal and nacelle vent systems. The inlet location allows the ducting to be unpressurized when the subsystem is not being used, and if a leak develops during system operation, the leak can be stopped by closing the shutoff valve.

D.4.4.4.12.3 Bleed air distribution control.

Inspection of drawings and air vehicle demonstrations shall be used to verify that independent means are incorporated for shutting off the bleed air flow to each subsystem which uses bleed air and that these provisions are controllable from the air vehicle crew station. Inspection of drawings shall verify shutoff provisions are at required locations.

VERIFICATION RATIONALE (4.4.4.12.3)

Distribution shutoff provisions require verification through air vehicle demonstration to ensure proper installation and functional interface. Drawings and schematics must be examined to determine that shutoff provisions are independent and at proper location.

VERIFICATION GUIDANCE (4.4.4.12.3)

Verification of distribution shutoff features can usually be accomplished through a single air vehicle demonstration. This demonstration is usually included as part of the air vehicle acceptance test procedures.

VERIFICATION LESSONS LEARNED (4.4.4.12.3)

Individual switches are provided in the AH-1 cockpit for shutting off bleed air to the rain removal system and the environmental control unit.

D.3.4.4.12.4 Isolation and crossover control.

On air vehicles with multiple bleed sources, or where multiple subsystems are supplied, isolation and crossover shutoff valves shall be provided.

REQUIREMENT RATIONALE (3.4.4.12.4)

Incorporating isolation and crossover shutoff valves permits alternate bleed source utilization for multiple subsystem, multiple engine air vehicles, often eliminating the need for mission abort in the event of a bleed supply duct failure.

REQUIREMENT GUIDANCE (3.4.4.12.4)

Figure D-13 illustrates the typical use of isolation and crossover valves in a multi-engine, multi-subsystem air vehicle. Isolation and crossover systems are normally limited to multi-engine air vehicles with large bleed air systems. During normal operation, the crossover valve will be closed with left-hand engines supplying air to the left-hand system and right-hand engines supplying air to the right-hand system. If a duct failure occurs in the left-hand system, the leak detection system or a bleed air hot light should alert the crew to close the left engine bleed source shutoff valves, close the left-side isolation valve, and open the crossover valve so the right-hand engines will be able to supply air to the left-hand system in addition to the right-hand system. Also, if an engine is shut down for emergency or economy reasons, the same procedure allows bleed air to be supplied to the opposite side. In either of the above situations, the cross bleeding allows continuation of the mission and eliminates a potential hazard. The crossover valve can also be opened to allow cross starting of engines.

REQUIREMENT LESSONS LEARNED (3.4.4.12.4)

Experience has shown it is advantageous to locate isolation and crossover valves so they are readily accessible in flight and have provisions for manual and automatic operation.

D.4.4.4.12.4 Isolation and crossover control.

The bleed air system design shall be analyzed and functionally demonstrated to verify proper use of isolation and crossover shutoff provisions.

VERIFICATION RATIONALE (4.4.4.12.4)

Analyses of the bleed air system design and air vehicle functional demonstration are required to verify proper use of isolation and crossover shutoff provisions.

VERIFICATION GUIDANCE (4.4.4.12.4)

Inclusion of bleed source isolation should be verified by inspection of drawings and an analysis of the bleed air system design. Functionality of the bleed source isolation should be demonstrated with air vehicle testing, and it should include all applicable combinations of normally operating valve positions and with valve failures.

VERIFICATION LESSONS LEARNED (4.4.4.12.4)

(TBD)

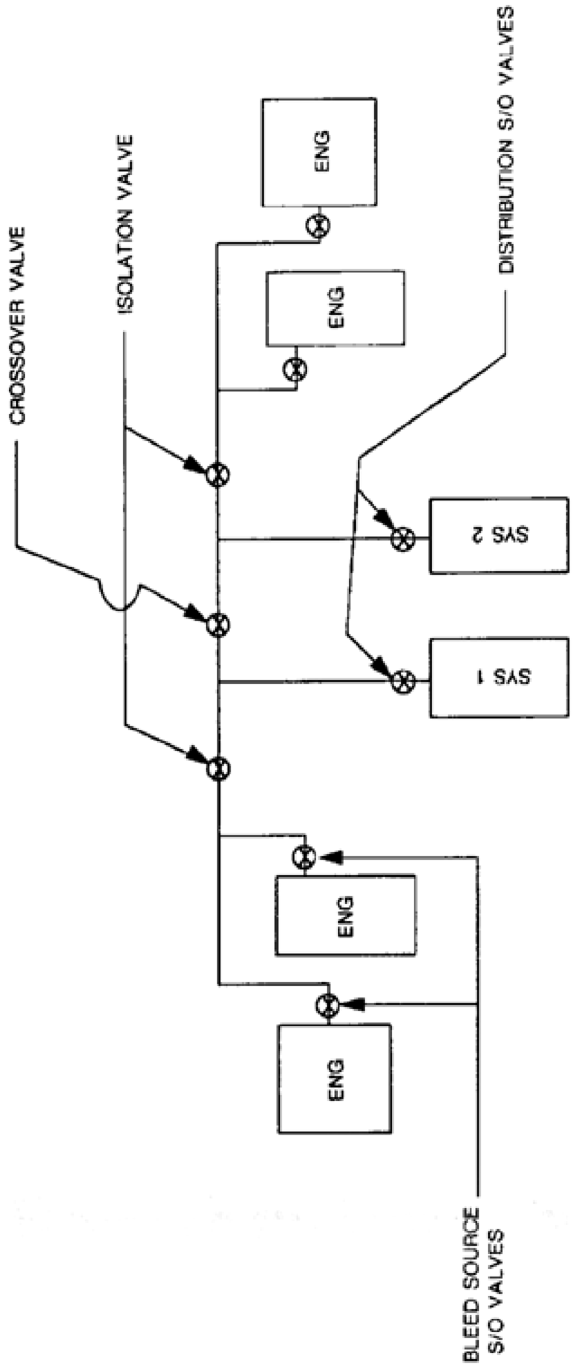

FIGURE D-13. Typical isolation and crossover valve installation.

D.3.4.4.12.5 Reverse flow prevention.

There shall be provisions to automatically prevent reverse flow of bleed air from any source into any other source. This protection shall include conditions where one failure is present.

REQUIREMENT RATIONALE (3.4.4.12.5)

Provisions are required to prevent reverse flow into a bleed source to eliminate the potential for engine performance degradation or damage and to ensure proper air flow control in the event of a failure of a single bleed source.

REQUIREMENT GUIDANCE (3.4.4.12.5)

Reverse flow into failed bleed sources is to be prevented. Failure to stop flow could prevent cross engine bleed start and may prevent operation of critical systems such as OBOGS. Pressurizing the outlet port of some bleed sources prior to their achieving full operational speed may be detrimental to operation and cause failure. In some cases, typically check valves are used to prevent reverse flow. Check valve failures can go undetected for several flights if they do not cause problems with other components, but could result in a hazardous condition if a failure occurs that they are designed to protect against. As a result, means should be incorporated to allow for periodic inspection of bleed air system check valves. Borescope provisions have been used for this purpose. Dual check valves have been used to provide the insurance that a single check valve failure will not cause engine malfunction in applications where both low and high stage bleed are used. High quality check valves that minimize loss of flappers also have been used. (See SAE ARP1796 for additional guidance.)

REQUIREMENT LESSONS LEARNED (3.4.4.12.5)

Many problems have resulted on air vehicles due to failure of check valves in the engine bleed air system. Careful attention to their design is required, especially the flapper design. There have been instances where the flappers have become disengaged and then lodged in downstream components causing them to malfunction. Serious incidents have occurred from shutoff valves being held in the open position by failed check valve parts. Such an incident resulted in an engine starter going into an uncontained turbine wheel failure with a part of the wheel striking and killing a B-58 crewmember during takeoff.

Reverse flow protection in the AH-64A pressurized air system is provided by a check valve and an engine compressor bleed air selector valve to prevent shaft driven compressor air from feeding into the No. 1 engine bleed air output.

D.4.4.4.12.5 Reverse flow prevention.

Inspection of drawings, engineering analysis, laboratory tests and air vehicle demonstrations shall be used to verify that there is no reverse flow of bleed air into a source under any operating conditions. These shall include conditions where one failure is present.

VERIFICATION RATIONALE (4.4.4.12.5)

Verification that reverse flow provisions are utilized can be obtained by inspection of the system configuration.

VERIFICATION GUIDANCE (4.4.4.12.5)

Reverse flow control features usually result in check valves being employed on the system at appropriate locations. Inspection of the locations in which these provisions are incorporated usually provides sufficient assurance of reverse flow protection for the system. Rigorous qualification testing of bleed air check valves under realistic conditions, such as air flowing at pressure and temperatures to be experienced in operation, should be performed. A safety analysis of the bleed air system should be conducted assuming a bleed air check valve fails. This analysis should indicate whether or not additional design effort is needed for the bleed air system. This feature may be safety critical, and the assessment is necessary because of the difficulty of knowing when a bleed air check valve failure has occurred.

VERIFICATION LESSONS LEARNED (4.4.4.12.5)

(TBD)

D.3.4.4.12.6 Bleed air pressure regulation.

The pressure of engine bleed air shall be regulated to that pressure level determined to be the minimum necessary for all recipient subsystems to meet operational performance requirements. Proper pressure regulation shall be maintained with one failure present.

REQUIREMENT RATIONALE (3.4.4.12.6)

The requirement for pressure regulation to the lowest acceptable level ensures that any damage experienced by the air vehicle as a result of a bleed system failure will be minimized. This requirement also allows for lower system cost and higher reliability by providing a less severe component design and operating environment. In addition, pressure regulation aids in eliminating problems due to pressure surge.

REQUIREMENT GUIDANCE (3.4.4.12.6)

The intent of this requirement is to ensure bleed air used within the air vehicle is controlled to the lowest possible pressure.

An immediate advantage to pressure regulation is that it lessens the hazard potential and the potential for secondary damage in the event of a bleed system failure. Lower air pressure also allows for the utilization of lower cost components, less rigorous testing, and simplified system design. Pressure regulation is often accomplished in stages. The first stage of pressure regulation is the regulation of the bleed air system pressure. Further reduction in pressure can sometimes be accomplished for other subsystems. This is especially useful if the using subsystems are remotely located from the bleed air system. This provides a design where two failures are required in order for full bleed pressure from the pressure source to travel downstream to the using subsystems. Since single failures are normally assumed for designing bleed system ducting and components, this results in further savings in cost and weight of the downstream components as well as providing a safer system.

The regulator schedule for the bleed air system should be set to accommodate the highest pressure and flow rate demands for the air vehicle plus distribution duct losses. To illustrate, the highest pressures required for subsystem operation may be for an ejector designed to utilize 65 psig. The ducting to the ejector may create a 5-psi pressure drop at the design flow rate. Therefore, the first stage regulator should be scheduled for 70 psig. Pressure regulation should occur as near the bleed source as possible.

REQUIREMENT LESSONS LEARNED (3.4.4.12.6)

A severe cockpit pressure surge problem existed on early F-5F air vehicles due to the lack of bleed air pressure regulation.

The AH-64A shaft driven compressor provides its own pressure regulation, and if the pressure output falls below 10 psi, a valve on the No. 1 engine bleed air output opens to allow continued operation of the pressurized air system on engine bleed air.

D.4.4.4.12.6 Bleed air pressure regulation.

The proper pressure regulation of bleed air shall be verified by engineering analysis, laboratory tests and air vehicle demonstrations. These shall include conditions where one failure is present.

VERIFICATION RATIONALE (4.4.4.12.6)

The critical nature of the bleed air pressure requirement necessitates interim verification by analysis during the initial system design phase and final verification by laboratory and air vehicle tests.

VERIFICATION GUIDANCE (4.4.4.12.6)

Proper system pressure control requires verification of system components in laboratory tests as well as system tests performed on the air vehicle. The air vehicle testing is required to ensure compatibility between control components and the rest of the system.

For pressure measurement, all pressure taps should be located to minimize the effect of turbulence caused by valves, elbows, or orifices in the system, and to determine all pressure required for a complete evaluation of system operation.

Probable single failures should be simulated in laboratory tests.

VERIFICATION LESSONS LEARNED (4.4.4.12.6)

(TBD)

D.3.4.4.12.7 Bleed air temperature control.

The ability of the ECS to maintain the temperature of bleed air ducted out of an engine, APU, or auxiliary compressor at or below the maximum allowable shall be __(TBS)__. A crew station indicator shall be activated in the event that bleed air temperature leaving an engine compartment exceeds the normal maximum value.

REQUIREMENT RATIONALE (3.4.4.12.7)

The requirement for maximum temperature control ensures that any damage experienced by the air vehicle as a result of a bleed system failure will be minimized. This requirement also allows for lower system cost and higher reliability by providing a less severe component design environment. The crew should be alerted to failure of the bleed air temperature control provisions since a safety hazard could exist.

REQUIREMENT GUIDANCE (3.4.4.12.7)

TBS should be filled in with a maximum temperature value. There are several important advantages to limiting the maximum temperature of the bleed air ducted out of the engine, APU, or auxiliary compartment. Lower air temperatures will result in less air vehicle damage from bleed air system failures. Safe bleed air system surface temperatures can be more easily obtained with lower internal air temperatures. Also, less costly materials can often be utilized in the system. The maximum temperature of bleed air ducted from the engine, APU, or auxiliary compartment should be limited to the autogenous ignition temperature of combustible fluids that, through a fluid system failure, could contact the bleed air system. By this criterion, fuels, oils, and hydraulic fluids usually limit bleed air temperatures to 450°F outside the engine, APU, or auxiliary compartment. Space and weight limitations on fighter and attack air vehicles may make this a difficult requirement to meet. Also, improved leak detection systems have reduced the consequences of failure. A trade-off should be performed to review cost, weight, and safety issues. Modern air vehicles typically have the over-temperature indication automatically shut off the bleed air supply, with a crew reset available. This reduces crew workload and reduces the potential damage from the overheat condition.

Requirements of this paragraph should be coordinated with those in "Hot surface temperature." Also see MIL-HDBK-221 for further guidance.

REQUIREMENT LESSONS LEARNED (3.4.4.12.7)

(TBD)

D.4.4.4.12.7 Bleed air temperature control.

The ability of the ECS to maintain the temperature of bleed air ducted out of an engine, APU, or auxiliary compressor at or below the maximum allowable shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.4.12.7)

Bleed air temperature control is a critical design feature and final verification that the system meets this requirement must be through air vehicle test. Over temperature indication must be demonstrated in a laboratory to preclude possible air vehicle damage.

VERIFICATION GUIDANCE (4.4.4.12.7)

TBS: Analyses and air vehicle ground and flight tests should be conducted to verify that the maximum temperature of bleed air ducted out of the engine, APU or auxiliary compartment does not exceed the maximum allowable value under normal conditions.

The ability of the ECS to indicate to the crew that an over temperature condition exists should be verified by inspection of drawings, engineering analyses, laboratory tests and air vehicle demonstrations.

Bleed air temperature should be monitored during air vehicle flight and ground testing. Normally, extrapolation of this data will be required to predict worst-case extremes.

VERIFICATION LESSONS LEARNED (4.4.4.12.7)

(TBD)

D.3.4.4.12.8 Bleed air leak detection.

When bleed air ducting is routed in areas where leakage could cause damage to the structure or nearby components, or could cause surface limits to exceed the autogenous ignition temperature of any substance contained in that compartment, a means for leak detection shall be incorporated. Automatic shutdown with a crew station advisory or a crew station warning shall be provided when a potentially damaging or fire-producing leak occurs. The sensors for the leak detection system shall recover their required leak detection temperature range following exposure to a leak.

REQUIREMENT RATIONALE (3.4.4.12.8)

The requirement for a leak detection system is necessary to protect against air vehicle damage or fire due to high temperature bleed air.

REQUIREMENT GUIDANCE (3.4.4.12.8)

The sections of the bleed air system that can contain air at temperatures that could damage surrounding components in the event of excessive leakage, or could cause surface limits to exceed the autogenous ignition temperature of any substance contained in that compartment should be defined. The air vehicle engineer should be consulted to obtain information on what structure, wiring or combustible substances are present in compartments where high temperature air will be ducted. Emphasis should be placed on assuring adequate detection in the engine nacelle, pylon, wing, wheel well, and ECS equipment compartment when high temperature ducting is present in these areas. The insulation on electrical wire is often the least temperature-tolerant material commonly used in air vehicle equipment bays. Usually, 350°F is accepted as an upper temperature limit in these areas and ducts which carry air at or above this temperature should have a leak detection system. A system safety hazard analysis should be conducted to determine the appropriate course of action upon detection of a bleed air leak. Compartments containing fuel, hydraulics or liquid coolant should also be reviewed. In many cases positioning of the leak detecting elements are critical. Unless the ducting will be required to divert leaks away from critical surfaces, the leak detector should be placed such that it detects a leak aimed in the direction of the critical surfaces. Careful selection of the type of leak detection system is important: some measure an average compartment temperature; others measure discreet temperature; and some do both. The accuracy and reliability vary with the type of technology. The discreet provides the best measure of the hazard if the element is between the bleed duct and the critical surface. If it is not in the right location, it may not detect at all; therefore, the selection of the detection technology should be considered carefully and in conjunction with the bleed air duct design.

Continuous length-sensing elements placed along the entire length of the high temperature ducting have proved to be a satisfactory approach for detecting hazardous leaks. Satisfactory bleed air leak detectors should meet the following requirements:

a. The detectors indicate a bleed air leak within 5 seconds when a 1-inch length of the detector element is subjected to a hot air blast 100°F above the nominal detector setting (with the entire element stabilized 100°F below its nominal setting).

b. The detectors have the nominal detector setting 100°F above the maximum local ambient.

c. The detectors maintain a warning signal for the duration of the overheat condition and automatically clear the signal following the removal of the overheat condition.

To save precious time, most modern air vehicles require that the bleed system be automatically shutdown when a potentially damaging or fire producing leak is detected.

For an effective design, the leak detection system should consider the entire bleed air system, not just the sensors used for detection. Bleed air duct, including insulation covers are an integral part of leak detection. The ducting and covers can be used to divert most leaks away from critical areas and toward the leak detector sensors.

REQUIREMENT LESSONS LEARNED (3.4.4.12.8)

The lack of a bleed air leak detection system has been a contributing factor to the loss of a significant number of air vehicles and has resulted in serious damage to numerous air vehicles. Both the F-4 and F-105 fighter air vehicles have long runs of high temperature ducting from the last stage engine compressor section in the aft portion of the air vehicle to the ECS equipment bay in the forward part of the air vehicle. Numerous leaks, of which the crew was unaware, occurred in this ducting on F-4 and F-105 air vehicles and were of sufficient magnitude to cause either serious damage or loss of air vehicles. The F-105 air vehicles were eventually retrofitted with a bleed air leak detection system.

D.4.4.4.12.8 Bleed air leak detection.

Bleed air leak detection shall be by __(TBS)__.

VERIFICATION RATIONALE (4.4.4.12.8)

The potential for air vehicle damage precludes the use of air vehicle testing to verify leak detection system operation. Therefore, system operation must be verified under laboratory conditions.

VERIFICATION GUIDANCE (4.4.4.12.8)

TBS: Analyses should be conducted to verify the areas of the air vehicle that require or do not require leak detection. Laboratory tests should be conducted to verify the ability of the leak sensors in conjunction with the bleed air system to detect potentially damaging bleed air leaks. Detectors should be tested to verify that they recover their required detection range following a detection. Inspections of drawings and air vehicles should verify installation of leak detection system and indicator for leaks in the crew station.

Since limited testing can be conducted of leak detection system effectiveness, inspection of system installation drawings requires careful attention to verify that typical leakage paths would be detected by the system. The leak detector sensors should be laboratory tested to verify they operate within the proper operating range and that they recover that range after exposure to a leak. Following these tests the leak detection system should be laboratory tested in conjunction with the bleed air system to verify minimum required leaks from the bleed system are detected.

This joint testing is required since the bleed air system design can greatly influence the leak path and thus its potential for detection.

VERIFICATION LESSONS LEARNED (4.4.4.12.8)

(TBD)

D.3.4.4.12.9 Bleed air pressure relief.

Air vehicle compartments containing bleed air ducting shall be protected against detrimental compartment over pressurization in the event of duct failure. Ducting and other components shall be protected from detrimental positive and negative pressure following single failures.

REQUIREMENT RATIONALE (3.4.4.12.9)

Pressure relief provisions are required to protect the air vehicle and subsystem components from damage in the event of a bleed air system failure.

REQUIREMENT GUIDANCE (3.4.4.12.9)

If a bleed duct located in a sealed compartment ruptures, the compartment could become pressurized to the same pressure as the duct air pressure. The pressures used in the bleed air system are often greater than the air vehicle compartment structure can withstand. Therefore, to prevent air vehicle damage in the event of a duct failure, provisions for compartment overpressure relief should be incorporated. Overpressure relief provisions may be required for ventilated compartments when it can be shown the compartments' ventilation flow areas (inlet and exhaust areas) could provide adequate pressure relief. Overpressure relief provisions typically utilize a “pop-out"-type panel in the compartment, which may be spring loaded and hinged. Implementation of overpressure relief features and specification of pressure relief settings may require familiarity with air vehicle structural requirements.

Secondary failure of bleed air system ducting or components due to excessive positive or negative pressure should not be caused by a single failure. This should also apply to the using systems being supplied by the bleed air system. Component overpressure (internal or external) protection is a function of the components' design and structural integrity. This requirement should be reviewed for the complete flight envelope of the air vehicle. High altitude may result in lower than expected ambient (ram) pressure. Pressure recovery at high Mach numbers may result in higher than expected ambient (ram) pressures. This requirement may be met by installing protection devices or by designing and qualifying the components to possible single failure condition.

REQUIREMENT LESSONS LEARNED (3.4.4.12.9)

The F-111 air vehicles were plagued with numerous cases of extensive damage within the engine compartment due to rupture of the nacelle vent duct. Failures of this duct were generally undetected but occasionally indicated by a fire warning light. Continuous length-sensing elements placed along the entire length of the high temperature ducting have proved to be a satisfactory approach for detecting hazardous leaks.

A duct rupture on the C-141 caused pylon damage due to the lack of pressure relief provisions.

D.4.4.4.12.9 Bleed air pressure relief.

Bleed air pressure relief shall be verified by _(TBS)_ .

VERIFICATION RATIONALE (4.4.4.12.9)

Verification of compartment and component pressure protection is left to analysis and laboratory testing, since air vehicle demonstrations are not feasible.

VERIFICATION GUIDANCE (4.4.4.12.9)

TBS: Failure modes and effects analyses should verify which compartments need or do not need protection from over pressure and which bleed air ducting and components require protection from excessive positive and negative pressure. Analyses should be conducted to verify the size of pressure relief areas and pressure relief settings. Installation of pressure relief devices should be verified by drawing and air vehicle inspection. The performance of pressure relief devices should be verified in laboratory tests.

Structural design factors should be considered during verification of these requirements. Analysis should consider entire flight envelop to ensure there are no higher or lower pressures.

VERIFICATION LESSONS LEARNED (4.4.4.12.9)

(TBD)

D.3.4.4.12.10 Uncontrolled bleed air.

Uncontrolled bleed air shall be prevented from entering the cabin after any failure of the system.

REQUIREMENT RATIONALE (3.4.4.12.10)

The position of bleed air system valves after failure or loss of the actuation signal is critical to system safety. The valve normal (no actuation signal) position and the failure position must be determined from an analysis of the most acceptable and least hazardous failure modes. If control ranges of bleed air valves in series over lap, the resulting control instability will result in performance degradation, poor valve life and possibly harmful or annoying pressure transients in occupied compartments.

REQUIREMENT GUIDANCE (3.4.4.12.10)

Uncontrolled hot air should be prevented from entering the cabin after any failure. For most air vehicles, maintaining cabin pressurization airflow and engine starting airflow capability following any bleed air valve failure is highly desirable. In the case where the bleed air is supplying an OBOGS, maintaining pressurized flow may be mission essential. Redundant bleed air shut-off valves are often used to be able to maintain bleed flow with a failure and without an over temperature hazard. If bleed air valves are used in series, their control operating range should not overlap. This will cause control instability affecting performance, valve life and possibly harmful or annoying pressure transients in occupied compartments.

Normal and failure mode positions of valves refer to the position (open or closed) to which a valve returns when no actuation signal is supplied to it (normal position), and the position to which a valve returns when experiencing loss of power (failure position). This terminology applies to valves operated electrically and pneumatically. For pneumatically-actuated valves, the actuation signal is the sense pressure or control pressure and the valve power is the upstream air pressure. The modes for electrically-actuated valves and electrical-pneumatic combination valves refer to valve positions with upstream pressure applied to the valve. These modes are critical because they determine air distribution in the event valve control is lost.

REQUIREMENT LESSONS LEARNED (3.4.4.12.10)

(TBD)

D.4.4.4.12.10 Uncontrolled bleed air.

Uncontrolled bleed air shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.4.12.10)

Valve normal and failed positions and series valve stability can be adequately determined from laboratory testing.

VERIFICATION GUIDANCE (4.4.4.12.10)

TBS: Laboratory tests readily reveal valve normal positions and typical failure mode positions. In this area, emphasis should be placed on verification of proper valve modes for respective valve applications.

VERIFICATION LESSONS LEARNED (4.4.4.12.10)

(TBD)

D.3.4.4.13 Thermal system protection.

Ducting and components shall be insulated or shrouded as required to prevent overheating of surrounding structure, wiring, plumbing or other equipment; eliminate personnel hazard; or eliminate potential fire hazard. Entry and retention of fluids including water under or within insulation or shroud shall be prevented. All insulation and shrouds shall be flame resistant. Insulation shall not be damaged by normal handling by and contact with maintenance personnel. The contractor shall perform a trade-off study to determine what additional ducting, component and compartment thermal insulation is required to meet thermal requirements of this specification. The trade-off study shall include __(TBS)__ comparison of the overall Thermal Management System with and without the additional insulation. Acoustical insulation shall be provided as required to meet the air vehicle acoustical requirements.

REQUIREMENT RATIONALE (3.4.4.13)

Hot surfaces must be insulated or otherwise protected to prevent damage, fire hazard, personnel hazard, and such. Flammable fluid soaked insulation is a serious fire hazard. Insulation soaked with any fluid degrades insulation performance, causes corrosion and other maintenance problems. The weight penalty of adding insulation to meet thermal performance requirements must be compared to a true penalty of meeting those requirements without the insulation.

REQUIREMENT GUIDANCE (3.4.4.13)

Care should be taken in the selection and application of insulation materials to ensure they are impermeable to fluids. The outer surface should be durable enough to resist damage due to handling and normal maintenance actions. Air blast is also a major consideration when the duct or component is located in a weapons bay, wheel well, or such. Insulation exposed in cargo compartments and other exposed areas should be designed to withstand the environment and handling it will experience.

Insulation made of neoprene should not be used in areas where the temperature will exceed 250°F because of the likelihood of corrosion problems.

Sandwich-type insulation blankets, where used, should be vented, and drained at their lowest point. The vent and drain holes should be shielded if required to prevent entrance of fluid. The insulation material should be “nonpacking” under service conditions. Insulation should be attached to ducts and components so that a single failure cannot cause ignition.

SAE AMS-I-7171 is recommended for use as a detail specification for a thermal-acoustical insulation blanket.

TBS: Adding insulation to meet thermal performance requirements is often rejected based on its fixed weight penalty. The fact that the refrigeration system will have to become larger and extracted more power is overlooked. The system with and without insulation should be compared based on the overall impact on the air vehicle. Take-off-gross-weight is often the best comparison for new air vehicles required to meet a fixed mission.

Impact on range or performance may be more appropriate for existing air vehicles or air vehicles with other limitations. Life-cycle cost might be another important factor. The air vehicle engineer should be consulted to determine the best measure.

REQUIREMENT LESSONS LEARNED (3.4.4.13)

Damage due to air blast when the weapons bay doors were opened resulted in engineering changes to strengthen the insulation in the weapons bay and ECS bay in the F-111 and F-105 air vehicles. Fuel-soaked insulation was a problem on F-111 air vehicle. This occurred when the surface was punctured during maintenance actions. On B-52A through B-52E air vehicles, the pneumatic ducts were covered with a neoprene insulation. It was discovered that neoprene heated above 250°F deteriorates and in the presence of moisture forms an acid that is highly corrosive. This necessitated an extensive duct rehabilitation program for B-52 air vehicle.

KC-130 bleed air ducts failed due to corrosion. The ducts are made of stainless steel. Water held against the duct by cotton insulation, which had become wet and stayed saturated, caused the corrosion. The duct failure resulted in hot bleed air impinging on the wing spar, wiring that controls the bleed air valves, and fuel tanks whose sealant degrades at a temperature that are very close to that of the bleed lines. In at least one case, an Air Force air vehicle was lost due to bleed duct failure. This failure, and others that caused substantial damage, has occurred on the ground. Failures in-flight have been identified by pilots and procedures taken (bleed air shut off) to avert substantial damage. Twice, wing leading edge panels were blown off at take-off due to bleed duct failure.

The bleed air system is comprised of 40 duct sections. The inspection process is very costly, approximately 850 man-hours for entire system. The insulation is fiberglass over cotton, which tends to trap water. The Navy depot must have the duct insulation re-installed by a vendor after it has been unwrapped for inspection, adding to the cost and time it takes to inspect ducts. After going to the expense and time to conduct the inspection, it makes most sense to replace corroded ducts with new Inconel duct sections at that time.

D.4.4.4.13 Thermal system protection.

Analyses, inspections, and tests shall be used to verify ducting and components are insulated or shrouded to eliminate potential fire or personnel hazard and prevent overheating of the wiring, structure, or other components. Water absorption characteristics shall be verified by laboratory test. Maintenance handling provisions shall be verified by demonstration. A tradeoff study shall verify that the correct amount of additional insulation has been added to meet thermal performance requirements. Analysis and air vehicle test shall verify the correct amount of acoustical insulation has been added.

VERIFICATION RATIONALE (4.4.4.13)

Verification of this requirement can be accomplished by analysis, inspection, and tests, as appropriate.

VERIFICATION GUIDANCE (4.4.4.13)

The required air vehicle testing should normally be accomplished in the course of doing other ECS test.

VERIFICATION LESSONS LEARNED (4.4.4.13)

(TBD)

D.3.4.4.14 Structural integrity

D.4.4.4.14 Structural integrity

D.3.4.4.14.1 Proof pressure.

All system components exposed to positive or negative pressure shall withstand, without permanent deformation at associated component temperature and pressure, each of the following proof pressures:

a. __(TBS 1)___ times the gauge pressure at associated temperature that occurs during normal operation, without malfunction, that would have the most adverse effect upon the component's structural integrity.

b. __(TBS 2)__ times the gauge pressure at associated temperature that occurs in the event of failure of an upstream pressure or temperature control device that would have the most adverse effect upon the component's structural integrity.

Additionally, the ducts that are susceptible to excessive handling and maintenance loads shall be identified and either (1) designed to withstand these loads, or (2) be clearly and appropriately marked to warn maintenance workers not to use excessive force on these items. No permanent deformation is permitted when designing to identified installation or maintenance loads.

REQUIREMENT RATIONALE (3.4.4.14.1)

The intent of this requirement is to ensure all pressurized components are adequately designed for structural integrity under both normal operating conditions and upstream pressure or temperature control device failures.

REQUIREMENT GUIDANCE (3.4.4.14.1)

Proof pressure is that pressure which a duct or component must sustain without permanent deformation.

TBS 1 should be filled in with a number to serve as a multiplier for the gauge pressure. A value typically used is “1.5.”

TBS 2 should be filled in with a number to serve as a multiplier for the gauge pressure. A value typically used is “1.1.”

These values are accepted industry standards and are based on previous USAF experience that has shown that components designed and tested to these criteria have proved to be durable and reliable. The Navy historically used “2” for bleed air systems. Although somewhat on the conservative side, it had the advantage of providing a growth capability when higher pressures resulted from increasing ECS capacity or engine upgrades. For new air vehicles using a “2” value should be considered. Requalifying and retrofitting bleed ducting can be expensive. Other less stringent requirements should be specified only after very careful consideration of the application.

Consideration in design and installation should also be given to maintenance related issues.

Furthermore, if column action, torsional, or bending loads exist in the ducting, the duct’s strength should be adequate to adsorb these and the internal pressure loads simultaneously. The most critical operating condition is that combination of operating pressure and temperature which results in the lowest yield strength of the duct material.

REQUIREMENT LESSONS LEARNED (3.4.4.14.1)

(TBD)

D.4.4.4.14.1 Proof pressure.

All proof pressure requirements on ECS systems and components shall be verified by component tests and ECS laboratory tests.

VERIFICATION RATIONALE (4.4.4.14.1)

This requirement can be demonstrated only by actual tests on each component and tests conducted on air vehicle installed systems.

VERIFICATION GUIDANCE (4.4.4.14.1)

Ducting may be proof pressure tested while assembled as a system or as individual components. All components should be supported for the test as they will be in the actual air vehicle installation.

Proof pressure tests should be conducted on the air vehicle-installed engine bleed air system and warm air ducting systems prior to first flight. The objective of proof pressure testing-installed systems is to verify the system is properly assembled. For this test as well as acceptance testing of components, the test may be performed at room temperature with the pressure elevated to correct for the temperature. For the laboratory qualification test, however, the actual operating temperature should be used.

VERIFICATION LESSONS LEARNED (4.4.4.14.1)

Excessive ducting misalignment resulted in a dramatic failure on the first air vehicles of a new bomber program when the air vehicle-installed warm air ducting system was subjected to proof pressure. No problem was evident when the ducting was subjected to normal, maximum operating pressure prior to the proof pressure test. As a result, the improperly aligned ducting would have gone unnoticed if the proof pressure test had not been conducted, creating the possibility for a later, serious, in-flight failure.

D.3.4.4.14.2 Burst pressure.

All system components exposed to positive or negative pressure shall withstand, without rupture at associated component temperature and pressure, each of the following burst pressures:

a. __(TBS 1)___ times the gauge pressure at associated temperature that occurs during normal operation, without malfunction, that would have the most adverse effect upon the component's structural integrity.

b. __(TBS 2)__ times the gauge pressure at associated temperature that occurs in the event of failure of an upstream pressure or temperature control device that would have the most adverse effect upon the component's structural integrity.

REQUIREMENT RATIONALE (3.4.4.14.2)

The intent of this requirement is to ensure all pressurized components are adequately designed and tested for structural integrity under both normal operating conditions and upstream pressure or temperature control device failures.

REQUIREMENT GUIDANCE (3.4.4.14.2)

Burst pressure is the pressure the component must withstand without rupture. Deformation resulting from the test is acceptable and the part need not be functional after the test.

TBS 1 should be filled in with a number to serve as a multiplier for the gauge pressure. A value typically used is 2.5, which is based on previous USAF experience that has shown components designed and tested to these criteria have proved to be durable and reliable (SAE ARP1796 recommends “3”). This should be considered to maintain consistency with commercial standards. The Navy historically used “4” for bleed air systems. Although somewhat on the conservative side, it had the advantage of providing a growth capability when higher pressures resulted from increasing ECS capacity or engine upgrades. For new air vehicles using a “4” value should be considered. Requalifying and retrofitting bleed ducting cant be expensive.

TBS 2 should be filled in with a number to serve as a multiplier for the gauge pressure. A value typically used is “1.5,” which is accepted industry standard and based on previous USAF experience that has shown components designed and tested to these criteria and have proved to be durable and reliable.

Other less stringent requirements should be specified only after very careful consideration of the application.

REQUIREMENT LESSONS LEARNED (3.4.4.14.2)

(TBD)

D.4.4.4.14.2 Burst pressure.

All burst pressure requirements on ECS systems and components shall be verified by component tests and ECS laboratory tests.

VERIFICATION RATIONALE (4.4.4.14.2)

This requirement can be verified only by test.

VERIFICATION GUIDANCE (4.4.4.14.2)

Since the burst test is a destructive test (even if no deformation occurred at the burst level, the component is still considered not to have any useful life), continuing to test to failure after reaching the specified burst limit is highly recommended. If future growth or engine upgrade results in higher operating pressures, an additional, expensive destructive test may not be required if the components already exceeded the required burst level in this test to failure.

VERIFICATION LESSONS LEARNED (4.4.4.14.2)

(TBD)

D.3.4.4.14.3 Rotating equipment structural integrity.

The housing and scrolls of all rotating machinery of the Environmental Control System shall completely contain all fragments from:

a. Fused drive rotor failures (including tri-hub burst) at the maximum fuse speed and at the pressure and temperature associated with this speed.

b. Non-fused drive rotor failures (including tri-hub burst) at the maximum speed that can result from any failure-inducing condition or __(TBS 1)__ percent of the maximum normal speed, whichever is greater, at the pressure and temperature associated with the speed.

c. Driven rotor failures (including tri-hub burst) at the maximum speed that can result from “a.” or “b.”, above, at the pressure and temperature associated with this speed. Driven rotors shall not burst at speeds lower than the drive rotors burst.

d. Driven rotor failures when powered by electric or hydraulic motors at the maximum speed that can result from any failure including condition or 135 percent (135%) of the maximum normal speed, whichever is greater.

“Contain” means fragments may penetrate the housing, scroll or shroud but should not pass through the housing. Particles or parts resulting from a rotor burst and passing through the inlet or outlet port of the rotating component must be contained by the adjoining ducting.

All rotating equipment shall be designed so that operation at the speed resulting from the worst case single failure or up to __(TBS 2)__ percent of normal maximum operating speed for a period of __(TBS 3)__ minutes is possible without rubbing or other adverse effect upon the equipment. There shall be provisions to prevent or limit the "windmilling" or "freewheeling" of all rotating ECS equipment. Fans, such as ground cooling fans, shall not "windmill" in a ram air flow. If a fan is protected from "windmilling" in a ram air flow by a check valve, a failure of that check valve shall not constitute a flight safety hazard.

REQUIREMENT RATIONALE (3.4.4.14.3)

To prevent further damage to the air vehicle or injury to crewmembers, the housing and scrolls of all rotating machinery should completely contain all fragments from blade failures or wheel bursts.

Rotating equipment should be designed to operate satisfactorily under certain failure conditions without adverse effect, such as pressure regulator malfunctions, short-term ram air circuit blockage, or starvation. Freewheeling of rotating equipment should be limited or prevented because of the hazards associated with failure of the equipment under these conditions.

REQUIREMENT GUIDANCE (3.4.4.14.3)

Analysis shows the three-section hub burst is the highest energy-level failure and, therefore, is usually the primary containment design criteria. To limit the speed at which containment must be demonstrated, the drive rotor can be "fused" so it will fail at the desired maximum overspeed condition. For these cases, containment is demonstrated at the maximum speed.

TBS 1: If the drive rotor is not fused, then containment is to be demonstrated at the maximum overspeed condition that could occur as a result of any failure-inducing conditions (pressure regulator malfunction, ram air circuit blockage, or such). The "single failure" criteria may not result in a speed much higher than the normal, maximum operating speed. In that case, a minimum percent of overspeed is usually specified to ensure adequate structural integrity and a safety factor. This value has been 35 percent (35%) in the past; however, 35 percent (35%) may be excessive in some cases, especially in the case of bootstrap ACMs. Air bearing ACMs sometimes have difficulty in achieving 35 percent (35%). Therefore, care should be exercised in completing the requirement. A value of 35 percent (35%) is appropriate for fans, simple cycle ACMs, and such. Lesser values are appropriate for the bootstrap or air bearing machines.

Driven rotors should be tested at the maximum speed that occurs as determined from "a." and "b." above. The object is to have the drive rotor fail first so there will be no sudden increase in rotating speed because of load loss. Speeds used for containment tests should also be selected with consideration to the speeds that result from freewheeling.

TBS 2 should be filled in with a percentage value. Air cycle machine rotors are usually spin tested to 120-percent (120%) overspeed during manufacture to ensure their structural integrity. This has proved an excellent design criterion, as there have been few cases of wheel failures on operational equipment.

TBS 3 should be filled in with a time value. The overspeed spin and containment requirements should be consistent. Overspeeds of 120 percent (120%) for 5 minutes have been the typical requirement.

When this paragraph is completed, the overspeed requirement should be consistent with (lower than) the containment requirement.

REQUIREMENT LESSONS LEARNED (3.4.4.14.3)

Control of freewheeling is very important. On the F-111 air vehicle, hydraulically-driven fans are used for ground cooling. In flight, check valves prevent the flow of ram air through the fans. However, the check valves failed and the reverse flow caused freewheeling of the fans, which ultimately failed. The failures caused extensive damage when blade fragments were thrown through the wheel well. Fan failure also occurred on the first F-15 flight due to check valve failure and freewheeling. These experiences emphasize the need for freewheeling protection.

Lack of containment capability is unacceptable, as evidenced by several instances of uncontained wheel failures that resulted in the loss of life and air vehicle. An air turbine starter failed on a B-58 and killed a crewmember. A B-52 sustained extensive damage when an air turbine failed.

D.4.4.4.14.3 Rotating equipment structural integrity.

The capability of the housing and scrolls of the rotating machinery of the ECS to completely contain all fragments from the failures and the conditions described in "Rotating equipment structural integrity" in this appendix shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.4.14.3)

Verification is necessary to ensure that the containment requirements imposed on the housings and scrolls are met.

VERIFICATION GUIDANCE (4.4.4.14.3)

TBS: When using fused rotors, several tests should be conducted to determine the consistency of the fuse failure speed and to determine the maximum fuse failure speed for containment purposes. If the adjoining ducting or other hardware is part of the containment feature, it should be included in the containment test and installed using the air vehicle configuration. Testing and analyses should be performed to determine the speed of the fan during freewheeling. If the testing and analyses show the freewheeling speed exceeds the maximum overspeed during normal operation, the fan should be designed for the overspeed condition.

VERIFICATION LESSONS LEARNED (4.4.4.14.3)

(TBD)

D.3.4.4.15 Ground interfaces

D.4.4.4.15 Ground interfaces

D.3.4.4.15.1 Ground test provisions.

Provisions shall be incorporated for:

a. Ground pressure leakage testing of the (TBS 1) . Means to prevent controls left in the closed position shall be incorporated.

b. Functional checkout of the (TBS 2) on the ground using a ground pneumatic cart as the air source.

c. Cooling, heating, and ventilation of (TBS 3) by an external ground air conditioning cart.

d. Ground proof pressure testing of the (TBS 4) . These provisions shall facilitate performance of the proof pressure test without having to remove or cap duct sections.

REQUIREMENT RATIONALE (3.4.4.15.1)

Ground test provisions are required to perform maintenance on the ECS, avionics, and other equipment dependent on the ECS.

REQUIREMENT GUIDANCE (3.4.4.15.1)

TBS 1: Provisions for ground pressure leakage testing of duct systems, pressurized compartments, and such, should be provided for troubleshooting and integrity checks following maintenance. Typically, compartments utilize two control devices that ensure proper pressurization. The compartment pressure level is maintained by a device that either controls to a constant absolute pressure or a constant differential to the ambient pressure. Additionally, a safety device should be utilized to ensure that the crew and air vehicle structure will be protected, in the event of a system failure. It is necessary that these pressurization control devices have provisions for frequent testing. All required test functions, such as cabin leakage testing or safety valve testing, should be able to be accomplished as required by the operational needs of the air vehicle. Additionally, all compartments which are pressurized to a prescribed schedule should have a means to manually close the automatic pressure regulating device in order that the structure may be pressurized and leak checked and for air vehicle disinsectization.

TBS 2: Provisions for functional checkout of the ECS on the ground are also necessary for proper maintenance of the system. Bleed air can be provided by the air vehicle engine, APU, or ground support equipment for functional checkout. Ground pneumatic connections and the use of ground support equipment is preferred, as this minimizes the use of onboard air vehicle equipment.

TBS 3: Provisions should be incorporated for cooling, heating, and ventilating occupied areas and avionics equipment, for ground operation, maintenance, checkout, and such. This requirement should be consistent with those in “Occupied compartment ground cooling”, “Occupied compartment ground heating”, and “Avionic ground operation” in this appendix.

TBS 4: Provisions that enable personnel to conduct ground proof-pressure testing of high-pressure and high-temperature ducting systems quickly and safely should be incorporated to verify proper installation of the systems. The requirement to pressure test the bleed air system is obvious because of the hazards and potential structural damage associated with high-temperature and high-pressure bleed air leaks. Provisions for pressure testing the conditioned air distribution ducting are also necessary because leakage in that system, although not hazardous, can significantly impact system performance.

When this paragraph is completed, the project engineer should establish the ground provisions required for the system under consideration. For a prototype or one-of-a-kind system, minimal provisions may be required. However, for full-scale development and production systems, provisions should be required for complete test of the entire system. Serious consideration should always be given to ground pneumatic connections, as ground support equipment is the most efficient source of bleed air for ground servicing and reduces the use of onboard equipment.

REQUIREMENT LESSONS LEARNED (3.4.4.15.1)

The need for ground checkout capability is demonstrated by the F-111 forward bay cooling system. Many “forward" equipment “hot" warnings were being experienced on operational air vehicles which could not be resolved by normal maintenance procedures. When pressure leakage tests were accomplished on several air vehicles during an investigation into the problem, it was discovered that leakage in the distribution system was a major contributor to the malfunction.

Therefore, complete ground test provisions should be provided, along with comprehensive TO procedures on troubleshooting and testing of the system.

The requirement to provide means to prevent the regulator left inoperative is based on USAF experience.

D.4.4.4.15.1 Ground test provisions.

Ground test provisions shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.4.15.1)

Incorporation of provisions can be verified by inspection. However, the adequacy can be verified only by demonstration or test.

VERIFICATION GUIDANCE (4.4.4.15.1)

TBS: Verification should be accomplished by inspection and test.

Ensure adequate pressure data are provided in conjunction with cooling capacity (flow and temperature) when potential ground cooling carts are evaluated. In addition, air vehicle distribution system back pressure should be evaluated and tested to confirm compatibility with the advertised maximum cooling capacity of the cart.

The adequacy of ground checkout provisions and ground cooling and heating provisions is very important. High pressure drops in distribution ducting frequently restrict the ground heating and cooling capability. Accessible and adequate test provisions are not always provided and should be carefully evaluated.

VERIFICATION LESSONS LEARNED (4.4.4.15.1)

The pressure drops in the distribution ducting should be carefully determined to ensure the specified performance will be achieved using the proposed ground support equipment. During evaluation of potential alternative ground carts for Special Operations Forces air vehicles, inadequate back pressure data were available for the air vehicle distribution system. Although overall capacity of the MA-3 cooling cart should have been sufficient to cool the required avionics, the overall distribution system back pressure reduced flow in some parts of the system to insufficient levels.

Ducting failure occurred during proof pressure testing of a new bomber air vehicle due to incorrect test procedures. The procedures failed to account properly for the impact of disconnecting ducting to provide isolation between sections.

D.3.4.4.15.2 Ground connections.

Air inlet connections for the external ground air conditioning source shall conform to (TBS 1) . Ground pneumatic cart connections shall be in accordance with (TBS 2) . Ground leakage connections shall be in accordance with (TBS 3) . Ground connections shall be located so they are accessible for use during all ground maintenance activities.

REQUIREMENT RATIONALE (3.4.4.15.2)

United States Defense Standardization and International Standardization Agreements require specific interfaces with ground support equipment.

REQUIREMENT GUIDANCE (3.4.4.15.2)

TBS 1: There are Defense Standards that address most ground connections: MS33561 and MS33562 address 5-in. and 8-in., respectively, ground air conditioning connections for air vehicles.

TBS 2: The 3-in. pneumatic starting nipple is addressed by MS33740.

TBS 3: Air vehicle pressurized cabin ground leakage test connections and canopy seal inflation and test pressure gauge connections are addressed by STANAG 3315.

Defense Standards MS33740, MS33561, and MS33562 are consistent with North Atlantic Treaty Organization Standardization Agreements (NATO STANAGs), as shown below.

MS	STANAG
33561	3208
33562	3208
	3315
33740	3372

When the engineer completes this paragraph, he should consider the operational requirements of the vehicle. For prototype air vehicles or special purpose air vehicles, it may not be necessary to use the standard connections. However, for operational air vehicles, the standard connections are to be used. In general, it is necessary only to specify the connection be “compatible with" the appropriate standard connector.

REQUIREMENT LESSONS LEARNED (3.4.4.15.2)

Use of non-standard connections results in operational problems which require the use of special adapters to make them compatible with standard USAF ground equipment. Provisions should be made to apply cooling air to the air vehicle during all types of ground maintenance activity, including gear swings.

D.4.4.4.15.2 Ground connections.

Inspection of drawings and air vehicle ground demonstrations shall be used to verify the requirements in “Ground connections” in this appendix.

VERIFICATION RATIONALE (4.4.4.15.2)

This requirement can usually be verified by inspection.

VERIFICATION GUIDANCE (4.4.4.15.2)

Where questions arise over the conformity of a connection, it should be verified by demonstration(by making actual connection to the appropriate ground equipment).

VERIFICATION LESSONS LEARNED (4.4.4.15.2)

(TBD)

D.3.4.4.15.3 Ground servicing.

The minimum diameter of air vehicle gravity filling orifices shall be as follow: __(TBS)__.

REQUIREMENT RATIONALE (3.4.4.15.3)

International standardization agreements require a minimum diameter for air vehicle gravity filling orifices.

REQUIREMENT GUIDANCE (3.4.4.15.3)

TBS should be filled in with the appropriate diameter(s) with consideration of the following:

a. Deicing fluids 1.75 in.

b. Coolant fluids 1.50 in.

c. Methanol water 1.50 in.

d. Demineralized water 1.50 in.

The STANAG 3212 specifies the minimum diameters listed above.

It may be possible to delete this requirement for prototype and some special-purpose air vehicles; however, this requirement should be met for operational air vehicles.

REQUIREMENT LESSONS LEARNED (3.4.4.15.3)

(TBD)

D.4.4.4.15.3 Ground servicing.

Inspection of drawings shall verify gravity filling orifices conform to the requirements of “Ground servicing” in this appendix.

VERIFICATION RATIONALE (4.4.4.15.3)

Verification of ground servicing provisions are required to ensure that the air vehicle will be compatible with ground support equipment.

VERIFICATION GUIDANCE (4.4.4.15.3)

Demonstration and Inspection are the most common methods for compliance of this requirement.

VERIFICATION LESSONS LEARNED (4.4.4.15.3)

The combination of inspection and demonstration has been an extremely effective approach for Air Force programs.

D.3.4.4.16 Hot surface temperature.

The operation of the ECS, including the bleed air system and any auxiliary heaters shall not cause any exposed surface to be raised above __(TBS 1)__ of any fluid that might be present in that compartment due to normal operation or leakage. Ducts with a maximum surface temperature above __(TBS 1)__ shall be either insulated so that the maximum surface temperature is less than __(TBS 1)__ or the following measures shall be taken to avoid a fire hazard:

a. Provide an air flow velocity of at least __(TBS 2)__ in the areas immediately surrounding the external duct surface.

b. Prevent direct impingement of combustible fluids on the duct.

All air distribution ducting shall be flame resistant.

REQUIREMENT RATIONALE (3.4.4.16)

When bleed air system components or auxiliary heaters are located near combustible fluids, maximum surface temperatures must be controlled as a fire protection measure. Non-metallic materials are frequently used for cold air distribution ducting. Since this ducting runs through the occupied cabins and avionics bays, it can serve as a path for fire.

REQUIREMENT GUIDANCE (3.4.4.16)

High temperature surfaces can provide an ignition source when in contact with combustible fluids. For this reason, the use of high temperature equipment in compartments with combustible fluids should be avoided. Where for justifiable reasons, high temperature equipment must be in such compartments, the maximum component surface temperatures are to be limited when the possibility of contact with a combustible fluid exists under any condition including normal, emergency, or failure conditions.

TBS 1 should be filled in with a temperature value. A temperature of 50°F below the minimum hot gas ignition temperature is recommended to provide a margin of safety. The temperature should be assessed at all altitudes and all operating conditions. Autogenous ignition temperature is less at latitude. Bleed air temperatures may be higher on cold days.

TBS 2 should be filled in with an air flow velocity. A recommended value is "2 feet/second."

High temperature surfaces radiate heat to surrounding components. To improve the thermal environment of nearby equipment, it is desirable to minimize hot component surface temperatures. (See "Thermal system protection" in this appendix.)

For safety reasons, all duct materials should be flame resistant.

REQUIREMENT LESSONS LEARNED (3.4.4.16)

Non-metallic, flexible hoses were used on the RC-135C air vehicle to duct cooling air to the avionics equipment. A fire occurred in one of the avionics boxes and was carried to other avionics equipment by the flammable air hoses.

Usage of flame resistant materials such as Kevlar® for ducting, as is used in the AH-64A, ensures the flame resistance requirement will be met, while also providing a strength-to-weight advantage over other materials.

D.4.4.4.16 Hot surface temperature.

Hot surface temperature requirements shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.4.16)

To ensure safe component surface temperatures, air vehicle test data must be obtained. Normal analytical methods are not accurate enough to adequately predict component surface temperatures. Only actual test data can verify flame resistance of given materials.

VERIFICATION GUIDANCE (4.4.4.16)

TBS should be filled in with inspection of drawings and the air vehicle, and analysis of ground and flight test data.

Component surface temperature below levels that could cause auto-ignition of flammable fluids or below other critical levels should be demonstrated by heat transfer analyses. At locations where surface temperatures are allowed to be above critical levels, it should be demonstrated via inspection of drawings and a safety hazard analysis that such conditions pose insignificant probability of a safety hazard. During testing, component surfaces should be provided with temperature instrumentation so temperatures can be monitored for ground and flight test conditions. Extrapolation of this data will probably be required to predict worst-cases results.

Instrumentation should be installed to determine the quantity and temperature of air from each source and the temperature and quantity of airflow in all main distribution ducts. Appropriate surfaces should be instrumented to provide a chordwise profile of exterior and interior skin temperatures as well as temperature drop and airflow through the double skin passages. The surface to be instrumented should be subject to approval of the procuring activity. Critical structures should be instrumented with sufficient thermocouples to insure that overheating does not occur. Shielded thermocouples should be used to measure air temperatures at locations where there is a substantial difference between air temperature and the surrounding metal. If there are discontinuities in the heated areas, sufficient temperature measurements should be made to determine the effect of the heat flow from the heated to the unheated areas.

If ventilation is necessary to meet the requirements, the flow should be measured.

Laboratory tests should be conducted to verify all non-metallic air distribution ducting is flame resistant. Previous tests that demonstrate this requirement for the material used or contractor assessments that demonstrate fires cannot originate at the equipment source may negate the need for this test

VERIFICATION LESSONS LEARNED (4.4.4.16)

(TBD)

D.3.4.4.17 Growth.

The ECS shall have sufficient capacity to allow for an increase of __(TBS)__.

REQUIREMENT RATIONALE (3.4.4.17)

The purpose of growth capacity is to provide for those avionic equipment changes and additions that normally occur during the service life of an air vehicle. Growth assessment is also a critical design parameter to insure field balance and flexibility for integrity of performance and life.

REQUIREMENT GUIDANCE (3.4.4.17)

TBS: The ECS should have sufficient capacity to allow for growth. Most DoD air vehicles designed in recent years have been designed with a 25-percent (25%) excess or "growth" capacity for the ECS based upon the initial production avionics cooling load. However, experience shows a 25-percent (25%) growth capacity is not necessarily enough to cover all future changes in avionics, especially on fighter, bomber, and electronic air vehicles. It is difficult to suggest a single value for excess growth capability that will be adequate for all types of air vehicles. For each particular new program, the project engineer should base the value of growth capacity on the best available estimate of likely increase in avionics load of the particular weapon system, although experience has shown that most of the increases in avionic heat load are unanticipated during the initial design. Since the original excess capacity is often exceeded, experience has shown the need for the ECS to be a flexible design with the capability to increase system capacity easily. This flexibility should consider space allocation for growth beyond the original built-in growth, especially for key, space dependent components such as heat exchangers. Strong consideration should also be given to over sizing hard to retrofit items such as ducting and coolant lines. Consideration should also be given to using flexibility as one of items considered in the trade-off to be performed. Provisions for an additional 25-percent (25%) growth beyond an initial 25-percent (25%) growth was required by the former Navy ECS specification.

Another consideration in determining the growth requirement is possible envelope expansion in the future. Frequently new engines can be foreseen during the initial air vehicle development. These new engines could allow the expansion of the envelope, increasing aerodynamic heat loads significantly, especially to the cockpit in manned air vehicles. Some temperature limits might be established because of material or aerodynamic limitations. However, even if a maximum temperature can be determined, heat loads could be much higher due to greatly increased duration at specific Mach number.

REQUIREMENT LESSONS LEARNED (3.4.4.17)

Experience has shown it is definitely necessary to have excess cooling capacity in the ECS to cool the avionics added throughout the life of air vehicle. Contemplated changes on both the

F-15 and F-16 will use up the 25-percent (25%) growth capacity originally designed into the ECS.

Because of the necessity to increase the cooling capacity of the F-15 air vehicle beyond the initial 25-percent (25%) requirement, a study was conducted to determine what changes could be easily made to the system. A small increase in primary heat exchanger core capacity, along with lowering avionics inlet air delivery temperatures, could result in a 37-percent (37%) increase in avionics cooling capacity. An early trade study identifying what changes could easily be made to the system to increase capacity could have resulted in these changes being considered in the initial design of the system. Using the growth capacity for cooling avionic equipment to lower operating temperatures will increase its reliability if accomplished correctly.

The F-14 air vehicle was wisely designed with approximately 25-percent (25%) growth capacity even though it was not required by specification. This capacity was utilized by avionics that were later added to the air vehicle. Further increase in capacity was not required only because the AIM-54 Missile was redesigned deleting the requirement for active cooling from the air vehicle allowing the capacity originally used on the missile to be reallocated to new avionics. Prior to this reallocation ECS studies were performed to meet the advanced projected long term of F-14 usage. It was determined that up to twice the cooling airflow would be required for avionic cooling compared to the baseline air vehicle. Proposed changes to increase cooling capacity included a larger primary heat exchanger with a resulting 30 percent (30%) increase in ECS cooling capacity with the addition of an aft located bootstrap air cycle system which could provide the additional cooling required. For additional internal source cooling, F-14 growth studies have shown that the addition of new larger duct and an auxiliary cooling fan using ambient air, and an increase in the ECS pressure regulator setting with increased air duct size can also provide additional cooling to the avionics.

The original F/A-18 air vehicle was designed with no growth. At the time of its design no avionic upgrades were anticipated; however, avionic additions soon required an expensive ECS upgrade prior to introduction of the air vehicle in the fleet. When the upgrade was made, again no appreciable growth was provided. As a result a second even more expensive upgrade to the ECS was required. The F/A-18E/F has been designed with cooling growth.

The historic trend in processing avionics has been the reduction in size and power to accomplish the same function as the past generation avionics. The size has been reduced by a greater percentage than the power, resulting in higher power density and as a result higher heat density. When avionics is upgraded, seldom does the upgrade maintain the same function as the baseline especially since the upgrade creates extra space. (There would be little reason to upgrade if the same function was retained.) As a result the avionic heat load increases rather then decreases when upgrades are made to new technology. The increase in heat density may pose additional problems if it exceeds the limits of the cooling medium being used. One example of this was the F-14 Weapon Control System Processor. The processor was upgraded from analog to digital technology, but the increased heat load required the addition of a fan for ground low flight speed operation.

A more recent trend is the use of COTS equipment, especially on large subsonic electronic aircraft. Although its heat load may be the same or less than specified to military or commercial aircraft standards, it will require more cooling from the ECS due to its lower temperature requirements.

D.4.4.4.17 Growth.

The ECS growth capacity shall be verified by engineering analysis, ECS laboratory testing, and flight tests. Dummy heat loads may be used for flight test verification of ECS growth capacity.

VERIFICATION RATIONALE (4.4.4.17)

Both analyses and test are required to ensure system growth capability. Analytical performance analyses show theoretical capability of the system. These analyses then need to be verified by laboratory and air vehicle ground and flight testing after the hardware is available.

VERIFICATION GUIDANCE (4.4.4.17)

The airframe contractor should conduct analyses early in the development program to ensure adequacy of growth capability for all ground and flight conditions. The subsystem test rig should simulate the nominal avionics and electrical loads of the baseline air vehicle, and it should be modifiable to increase the avionics and electrical loads by the specified amount. Any feature of the growth equipment that causes a performance perturbation of the baseline subsystem or necessary modification should be simulated and tested in the rig (such as additional distribution pressure drop or added components). Testing should show that the backup cooling provisions can provide the required cooling for the growth load under all applicable missions. Review of drawing data is required to verify if sufficient space has been allocated for planned future growth.

VERIFICATION LESSONS LEARNED (4.4.4.17)

(TBD)

D.5 PACKAGING

D.5.1 Packaging.

For acquisition purposes, the packaging requirements shall be as specified in the contract or order (see 6.2). When packaging of materiel is to be performed by DoD or in-house contractor personnel, these personnel need to contact the responsible packaging activity to ascertain packaging requirements. Packaging requirements are maintained by the Inventory Control Point's packaging activities within the Military Service or Defense Agency, or within the military service's system commands. Packaging data retrieval is available from the managing Military Department’s or Defense Agency's automated packaging files, CD-ROM products, or by contacting the responsible packaging activity.

D.6 NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.

D.6.1 Intended use.

The Environmental Control System descriptions in this appendix are intended for use in air vehicle systems developed to perform combat and combat-support missions in environments unique to military weapon systems.

D.6.2 Acquisition requirements.

Acquisition documents should specify the following:

c. Title, number, and date of the specification.

D.6.3 Component information

D.6.3.1 Bearings.

Bearings adequate for the loads, speeds, environmental conditions, and life requirements should be selected for use in the air cycle machine. Use of proper bearings is key to achieving long life in high-speed, rotating equipment. Ball bearings or self-energizing air bearings are used in current air cycle machines. Experience has shown air bearings possess the following advantages:

a. No lubrication system
b. No periodic maintenance checks required
c. Higher mean time between failures (MTBF)
d. On-condition overhaul

e. Bearing wear-out is non-catastrophic (no damage to wheels and scrolls)

f. Reduced repair and overhaul costs

g. Fewer spares required.

Air bearing air cycle machines are susceptible to adverse effects from contamination of the bearing cavity. It has been learned that oil, sand, dust, and moisture contamination within the air bearing can cause problems. The contamination can cause sticking of the foils, damage to the foil coating when the shaft rotates in the presence of sand, dust, and shaft corrosion.

Experience from the F-16 program has shown air bearing units should be exposed to the expected contaminants (oil, sand, dust, and moisture) in combination, and a significant portion of the required start-stop cycles should follow the contamination test.

Care should be taken in protecting the bearings during balancing (grinding) to prevent contamination (chips) from falling into the bearing cartridge and causing early failure of the ACM. This occurred in the F-5E ACM production phase.

Compressor bearing failures on the F-16 ACM resulted in a test unit being instrumented to measure thrust loads. The compressor bearing thrust loads were found to be well in excess of predicted values. This was considered a contributing factor to the bearing failures. As a result, a design change was incorporated.

Analyses should be conducted during the design phase to show that the bearings are adequate for the loads, speeds, and temperatures involved. Sufficient testing should be conducted during the ACM laboratory qualification test program to verify acceptable life of the bearings. For air bearing units, this testing should include the number of start-stop cycles expected throughout the operational life of the unit. Ensure air bearing units are qualified within oil-contaminated environments equivalent to engine bleed levels for deteriorated engines as well as the typical sand, dust, and humidity environments.

D.6.3.2 Air cycle machines.

Each turbine, fan, and compressor housing or scroll should be replaceable. Scrolls or housings are a high-cost part of the ACM. Experience has shown that overhaul costs can be minimized when the housing is not an integral part of the ACM and can be individually replaced.

Means should be incorporated to avoid air cycle machine turbine nozzle erosion. The turbine nozzles should be replaceable and should not be a portion of the torus or other major, disposable part. Turbine nozzle erosion is a common ACM problem, and the nozzles should be frequently replaced during overhaul. Dust separators and special nozzle ring materials and coatings can help prolong the life of turbine nozzles. The C-130 ACM nozzles were cadmium-plated to reduce nozzle erosion. However, this approach proved unsatisfactory since cadmium poisoning of crew is possible with this approach. Nozzle erosion can be evaluated during system and component testing, by inspecting nozzles after teardown and measuring flow rates before and after tests.

The verification of air cycle machine requirements should be in accordance with SAE AS4073.

Shaft-driven compressors require thorough verification of the safety of the design. Shaft-driven compressor failures have been a major cause of in-flight aborts in the AH-64A due to the potential for fire resulting in smoke in the cockpit.

D.6.3.3 Bleed ducts.

Individual duct sections should permit no leakage. Leakage at duct unions is permitted, subject to a system safety hazard analysis, and should be itemized and quantified by the Contractor, but the design of the bleed air system should not permit the total leakage or any specified joint leakage as determined by the Contractor to be exceeded for the service life of the air vehicle. This criteria includes any portion of the ECS (such as bleed air system, refrigeration package, or distribution system) where leakage presents either a safety hazard or a performance impact on the ECS.

A shaft driven compressor air duct design that required a rotary joint and an expansion bellows did not account for the axial loads on the duct mounting brackets imparted by the expansion and contraction of the bellows. This required a redesign of the duct mounting configuration.

Drawing inspection was sufficient to reveal that a shaft driven compressor air duct expansion bellows did not account for the axial loads on the duct mounting brackets imparted by the expansion and contraction of the bellows. The duct mounting configuration was then redesigned.

The duct design and installation practices of SAE ARP699 can be used as a guidance reference.

The contractor should conduct and document engineering analyses to define the thermal stresses in the bleed air ducting. The contractor should employ a design approach that seeks to mitigate the thermal stresses in bleed air ducts. Results of these analyses should be presented at the CDR and the design should be consistent with the analysis results. For example, if analysis indicated that expansion joints are required, then the design should have expansion joints. The SAE ARP699 should be used as duct design and installation guide to address the issue of thermal stresses.

D.6.3.4 Pneumatic actuated components.

Pneumatic actuated components should not fail due to the presence of condensed liquid water, ice or dust in the main flow path, in the sense lines or in actuators. Either the components should tolerate the presence of these contaminants or there should be specific design features to prevent their accumulation. Components should meet requirements when operating under normal or backup cooling mode.

On both the F-111 and F-105, engineering changes were required to correct moisture-related problems in pneumatic components. In the F-105, moisture in the pneumatic system caused corrosion and freezing problems in the components. To correct this problem, holes were drilled to purge water continuously and contact between dissimilar metals was prevented. These moisture problems were similar to those on the F-111.

Laboratory tests should determine the quality of the filtered air delivered to the pneumatic components. The tests should record particulate concentration, size distribution, and moisture content. Tests should be conducted with the pneumatic components installed in the production configuration so problems of moisture condensation in pneumatic lines, and such, can be identified. The following are recommended tests for verifying adequacy of pneumatic components:

a. Accelerated internal corrosion and humidity. All pneumatically-operated control components of the subsystem should be subjected to the following tests:

1. Components should be oriented in the same attitude as they will be installed in the air vehicle during all phases of testing.

2. All internal surfaces exposed to pneumatic air should be thoroughly wetted by supplying a solution of 5 percent (5%) (by weight) of sodium chloride in water to the component. Valves should be cycled 5 times from closed to open during the wetting operation.

3. The components should then be purged by use of factory air and all valves should be cycled as in item “2.", above.

4. The components should then be placed in 130°F ±5°F, 100 percent (100%) relative humidity environment and baked for 1 hour. At the conclusion of each bake period, the internal surfaces should be flushed with clear water and valves should be simultaneously cycled as in item “2.", above. A functional check should then be conducted to determine if a malfunction or degradation has occurred.

5. Items “2." through “4.", above, constitute one cycle. All components should be cycled as follow:

   (a.) 10 cycles with a 1-hour bake period,

   (b.) 10 cycles with a 2-hour bake period, and

   (c.) 10 cycles with a 5-hour bake period.

6. Each component should be disassembled and inspected at completion of each 10 cycles. Any evidence of corrosion, damage, or malfunction should be considered failure of the test.

b. Freezing condensate. All pneumatically-operated components of the subsystem should be subjected to the following test procedure:

1. Components should be oriented in the same attitude as they will be installed in the air vehicle.

2. The pneumatic components should be connected to an air source with a specific humidity of 154 grains of water/lb of dry air, and all valves should be cycled 5 times from closed to open to closed.

3. Immediately after conclusion of step “2.", above, the components should be depressurized, de-energized, and placed in a cold chamber for 1 hr at 0°F or lower until the entire unit is stabilized at the low temperature.

4. At conclusion of step "3.", above, and with components still in the cold chamber at 0°F, the components should be subjected to functional tests to determine that all components perform satisfactorily.

The tests cited above for pneumatic components were first used on the F-105 program to verify adequacy of redesigned components. The tests proved adequate since the components that passed these tests did not exhibit the problems with moisture that were noted on the original configuration.

D.6.3.5 Heat exchangers.

Laboratory tests should be conducted for the following:

a. proof and burst pressure
b. vibration and mechanical shock
c. pressure drop (all side)
d. thermal efficiency
e. thermal bypass functionality, as required
f. leakage
g. pressure and temperature cycling
h. salt fog.

A heat exchanger leakage test should demonstrate mechanical integrity at proof pressure levels after completion of vibration, shock, and endurance tests. The heat exchanger should be submerged in water, oriented in a manner that would reveal the formation of bubbles, and pressurized to its proof level. The test technician should watch for bubble formation in the heat exchanger for a 5 minute period. No discernible bubbles should be permitted for those heat exchangers, which if failed, could contaminate the crew or equipment with NBC or other toxic agents. If the heat exchanger cannot be oriented to reveal bubbles, then the header or a portion of the header should be removed to render bubble observance possible. The contractor should establish leakage requirements and conduct the test described above for non-contamination critical heat exchangers. For those heat exchangers that are susceptible to icing because of entrained water in the bleed air, the contractor should conduct sufficient laboratory tests to show that the control system either averts or controls ice development on the heat exchanger core. For either case, testing should show that the control system operates in a manner that requires no human intervention during ice formation or prevention and that resultant cooling or heating (or both) supply temperatures do not change by more than 1°F or flow rates change by more than .5 lbm/min. Icing tests are most easily and accurately accomplished by flight tests behind a spray tanker or in an icing tunnel. Flight tests in natural icing are possible, but desired conditions are difficult to find and the conditions encountered are hard to measure. If heat exchangers are susceptible to clogging due to foreign object ingestion, the contractor should conduct a test to determine the severity of the problem. This includes heat exchangers using water spray for added cooling. With water spray occurring the Contractor should inject dirt at a rate that simulates "brown out" field conditions. Changes in system performance should be observed and extrapolated as required to determine the allowable number of hours of operation in such a condition before the system must be cleaned. A teardown inspection should be conducted to determine the post test condition of the item.

Heat exchangers for Navy applications, particularly those where the operating temperature will exceed 650°F, should be tested to a salt fog test including sulfur using ASTM G85-85, Annex A4.

D.6.3.5.1 Ram air heat exchangers.

Ram air heat exchangers and their associated inlets should be located to avoid functional problems due to operation in icing conditions. The location of ram air heat exchangers and their associated inlets should avoid damage from foreign object ingestion. A means of cleaning and inspecting the ram air heat exchangers should be provided without the necessity of removing them from the air vehicle. Ram air heat exchangers and their associated ducting should not accumulate rain water. Ram air heat exchangers and their associated ducting and inlets should not pose a FOD hazard to the air vehicle engines. Ram air heat exchangers and their associated ducting and inlets should not pose an induction icing hazard to the air vehicle engines.

Icing of heat exchangers, ram air inlets, and ducting., can usually be avoided by careful design. In some cases, inlet ice protection may be required. Foreign object ingestion of grass, dirt, paper, and such, is a very important consideration for air vehicles with assault field operational requirements or unprepared field operational requirements. Inlets should be located to minimize the ingestion due to “prop" wash, engine exhaust, debris dislodged by the landing gear, and such. It may be impossible to prevent ingestion completely on tactical airlift air vehicles. In those cases, means for inspecting and cleaning the heat exchangers should be provided. The operational environment and operational requirements of the air vehicle should be considered in heat exchanger and inlet design.

Extensive problems were encountered on the C-130H due to heat exchanger icing and foreign object ingestion. It became a requirement to inspect and clean the heat exchangers every 300 hours or 6 months. Access to the heat exchanger is difficult, making this an expensive maintenance requirement. An engineering change proposal (ECP) was required to correct the icing problem.

The following should be considered for verification.

a. Drawing inspection and tests should be used to verify that ram air heat exchangers are free of functional problems due to operation during icing conditions.

b. Drawing inspection and tests should be used to verify that ram air heat exchanger inlets are located to avoid foreign object ingestion.

c. Inspection of drawings and air vehicle demonstrations should be used to verify a means of access for inspection and cleaning of ram air heat exchangers while installed in the air vehicle.

d. Analyses, air vehicle demonstrations and inspection of drawings should be used to verify the ram air ducting and heat exchangers do not accumulate rain water.

e. Analyses, air vehicle demonstrations and inspection of drawings should be used to verify that the ram air heat exchangers and their associated ducting do not pose a FOD hazard to air vehicle engines.

f. Drawing inspection and tests should be used to verify that ram air heat exchangers do not pose an induction icing hazard to the air vehicle engines.

D.6.3.5.2 Air to liquid heat exchangers.

Lea4.kage of fuel and some coolants into the air can create serious safety-of-flight problems, such as possibility of explosion or fire and the possibility of toxic fumes or odors entering the occupied compartments. Therefore, these incidents should be prevented by proper design practices. Heat exchangers that transfer heat between air and any liquid other than water should not introduce liquid or toxic vapors into an occupied compartment as a result of a single structural failure in the heat exchanger. Heat exchangers that transfer heat between air and any combustible liquid should not create a fire or explosion hazard as a result of a single structural failure in the heat exchanger.

One design solution uses a double wall construction between the air and the coolant in the heat exchanger to prevent intermixing of the coolant and air in the event of a heat exchanger failure. Another design solution is to have an intermediate loop to transfer the heat from the air to the ultimate heat sink (fuel). The intermediate loop would use a non-toxic coolant such as silicate ester coolant. Using this intermediate loop should prevent any possibility of a fire or explosion being created if fuel leaked into hot bleed air.

a. Drawing inspection and laboratory tests should be used to verify that a single structural failure does not result in leakage of fuel or toxic coolant fluid into the air of an occupied compartment.

b. Drawing inspection and laboratory tests should be used to verify that a single structural failure does not create a fire or explosion hazard as a result of a single structural failure in the heat exchanger.

D.6.3.5.3 Liquid to liquid heat exchangers.

Leakage of fuel into a coolant loop can possibly create serious safety-of-flight problems since the addition of air could result in auto-ignition. Therefore, this type of leak should be prevented by proper design practice. Leakage of coolant into fuel is not considered hazardous, but does normally result in degraded cooling system performance.

Heat exchangers that transfer heat from a liquid coolant into fuel should be designed so that a single structural failure in the heat exchanger will not result in fuel entering the liquid coolant loop, or in liquid coolant entering the fuel in amounts that pose any hazard for safe operation of the fuel system or engines.

During the F-15 AECS flight testing, the liquid-to-liquid fuel-coolant heat exchanger failed three times resulting in leaks between the fuel and coolant circuits. The leaks allowed the coolant system to pump the coolant (silicate ester) into the fuel. As the coolant level decreased, fuel was pumped into the liquid coolant lines. No methods existed for determining this condition other than the delayed symptoms of a hot cockpit or taking coolant samples for flash tests. Poor brazing was the major factor in the cause of leaks. Leakage of silicate ester into fuel was not considered a hazard.

a. Drawing inspection, laboratory tests, and ground and flight tests should verify that a single failure will not result in leakage of fuel into coolant fluid.

b. Drawing inspection, laboratory tests, analyses and ground and flight tests should verify that a single failure will not result in leakage of coolant fluid into the fuel to pose any hazard to the fuel system or engines.

D.6.3.6 Water boilers.

Water is an excellent heat sink because of its high, latent heat. However, the potential for serious problems exists with water use. As a result, a number of design features are necessary to reduce the possibility for serious problems. The likelihood of corrosion necessitates means for easy inspection and replacement of the water boiler and storage tank. Frequent servicing requires water fill and drain provisions. The high freezing point of water requires the boiler and storage tank not be adversely affected by repeated freeze and thaw cycles.

A means of inspecting the water boiler heat exchanger should be provided without the necessity of removing it from the air vehicle. The water boiler heat exchanger and tanks should not be an integral part of air vehicle structure. The water storage tank should have a readily accessible water fill port and overboard drain. The water boiler heat exchanger and associated tanks and plumbing should not be damaged by repeated freeze-thaw cycles.

The water tank within the F-111 air vehicle is an integral part of the fuselage structure. The cooling medium within the tank is a deionized water and 10-percent (10%) propylene glycol mixture. Initially, tank internal surfaces were coated with a polyurethane material, per MIL-C-27725. After 4 to 6 years of service, internal tank walls developed some pitting corrosion and cracks. Air vehicles are being brought into the depot for tank refurbishment. Refurbishment consists of stripping the internal tank coatings, performing a complete non-destructive inspection of tank surfaces, replacing cracked or heavily corroded structures, and treating less severely corroded areas. Then internal tank surfaces are cleaned, chemically conversion- coated, and repainted with an epoxy coating material This epoxy material exhibits better water resistance and bonding properties than the polyurethane material used in its place. Tank refurbishment entails approximately 400 man-hours and $5,500.00 materials cost per air vehicle. The water tank within the F-111 air vehicle is a small (25 gal capacity), complex configuration (webs, stringers, and beams), and has limited access. Herein lies one of the problems. For a tank coating to protect against corrosion, in particular under the extremely adverse conditions (violent boiling action) exhibited in the F-111, not only must the proper coating material be used but its application must be flawless. Due to the physical constraints of the tank, flawless reapplication of the coating is extremely difficult. Consequently, poor adherence and bubbling has been a persistent coating problem with reworked tanks. A second rework will have to be performed on most air vehicles, resulting in numerous additional rework and downtime hours.

V-band clamp-type joints are submerged in the water boiler of the F-111. These clamps are difficult to work on due to the limited accessibility and leaks at joints have occurred. When the system is shut off, the water can leak into the air ducting. When the system is turned on, the water is “slugged" through the ducting of the ECS. In this case, the leak occurred in the service air heat exchanger and the water was blown into avionics equipment along with the pressurization air.

Severe water carryover problems have been encountered on the F-111 and EF-111 air vehicles which required the installation of "baffles" to reduce the carryover. Water boiler design requires extensive testing to verify adequacy of the design.

Freezing problems were encountered on the B-58. Water froze in the tanks while the air vehicle sat on the ramp in cold weather. In several cases, the heat exchanger ruptured because of ice expansion and also from the overpressure due to trapped steam when the ice melted around the heat exchanger.

The F-111 also contained sacrificial zinc anodes in the water tank to help prevent corrosion. It was discovered that the zinc and the tank will reverse polarity under some conditions.

One very serious problem with the water tank in the F-111 is that once installed in the air vehicle, it becomes part of the air vehicle structure. Removing the tank after installation literally requires disassembly of the entire air vehicle.

The following should be considered for verification.

a. Inspection of drawings and the air vehicle should be used to verify a means of access for inspection of water boiler heat exchangers and storage tanks while installed in the air vehicle.

b. Inspection of drawings should be used to verify water storage tanks are not an integral part of the air vehicle structure. A demonstration should be conducted to show the replacement time for the water storage tanks, and the presence of an overboard drain and a readily accessible fill port.

c. Laboratory tests should be conducted to verify the ability of water boilers and storage tanks to withstand repeated freeze and thaw cycles.

Laboratory tests should be conducted for the following:

a. proof and burst pressure

b. vibration and mechanical shock

c. pressure drop (all sides)

d. thermal efficiency

e. thermal bypass functionality, as required

f. leakage.

A heat exchanger leakage test should demonstrate mechanical integrity at proof pressure levels after completion of vibration, shock, and endurance tests. The heat exchanger should be submerged in water, oriented in a manner that would reveal the formation of bubbles, and pressurized to its proof level. The test technician should watch for bubble formation in the heat exchanger for a 5 minute period. No discernible bubbles should be permitted for those heat exchangers, which if failed, could contaminate the crew or equipment with toxic agents. If the heat exchanger cannot be oriented to reveal bubbles, then the header or a portion of the header should be removed to render bubble observance possible. A teardown inspection should be conducted to determine the post test condition of the item.

On the B-58, the freeze-thaw test was accomplished by freezing the tank and allowing it to thaw by conduction to the outside ambient. In operational use, the tank may be frozen and then force-thawed by bleed air passed through the heat exchanger. In the case of the B-58, the water boilers failed in this condition because the water around the heat exchanger melted and started boiling while there was still a large block of ice in the tank. This resulted in very high pressures and failed the heat exchanger. Therefore, freeze-thaw tests should be conducted for all possible freeze-thaw conditions.

D.6.3.7 Duct couplings.

Without a safety feature, failure of the primary latching mechanism can result in separation of the joint and a high rate of bleed air leakage, which is a serious safety-of-flight hazard. Proper selection of couplings is critical to air safety. Maintenance aspects of coupling selection including acceptable leakage also require careful attention. Quick-disconnect couplings, if used in the bleed air ducts, should have a secondary latch feature so that the coupling integrity is maintained in the event of the failure of the primary latch mechanism. Couplings chosen should be consistent with the loads experienced at the respective junctions. Couplings that are frequently removed should be readily accessible and should have the capability to be reused without leakage. If joints require seals, the design should require them to be replaced after having been subjected to thermal and or mechanical loading, otherwise it should be demonstrated that they be reusable without causing increased leakage.

Bleed air-related failures are a major concern of the Aeronautical Systems Center at Wright-Patterson AFB OH and the Directorate of Aerospace Safety at Norton AFB CA. A study was conducted of specific USAF accidents and incidents for the period of January 1970 to September 1975 that related to the air vehicle ECS. This study identified 39 clamp failures as shown in table D-II.

TABLE D-II. Clamp failures.

REASON FOR FAILURE	NUMBER OF TIMES
Improper installation	14
Leaking or loose	10
Bolt	9
Clamp	4
Clamp off	1
Use of wrong clamp	1
TOTAL	39

These incidents resulted in high-dollar value losses, including the total destruction of an F-4 air vehicle due to fire.

Couplings are critical for safety and optimum ECS performance. Significant leaks in the bleed air system can cause fires, explosions, burnt insulation and subsequent loss of serviced subsystems, and structural damage if the leak pressurizes the compartment. Leaks in the distribution system are more benign with respect to safety, but avionics and cockpit cooling will still suffer. Excessive leakage can render cooling performance inadequate to support flight, and significant flight schedule delays may result because of poor access to ducts and couplings and lengthy repair times. Resolving these problems during manufacturing is more efficient than discovering and resolving them during the flight test program. Inspection should show that safety features are included in the design, but tests are mandatory to verify the failsafe features of the clamp. Inspection and tests are also necessary to assure proper hardware selection and that maintenance aspects are properly addressed.

A laboratory test should determine the suitability of couplings. This includes high temperature, high pressure bleed air and refrigeration pack applications, and it applies to metal couplings with a latching mechanism as well as to composite material type couplings that use “radiator hose type” clamps for fastening. Additionally, the contractor should submit coupling designs for review at CDR and indicate their previous usage. The test should simulate the coupling’s application by connecting two duct sections. The contractor should pressurize the system to proof levels at the required operating temperature and at the same time impose the required vibration environment. The test should compare the allowable leakage as determined by the contractor to observed leakage. To demonstrate service life integrity the contractor should devise an accelerated test, conduct it, and repeat the leakage test described above. The accelerated test may include elevating the temperature environment, vibration environment, pressure environment, stressing the ducting and couplings by deformation, or other suitable method determined by the Contractor. A leak test on air vehicle ducting should demonstrate coupling integrity after installation, but before flight. This test should include the bleed air system, the refrigeration pack, and the distribution system. The contractor should pressurize the ducting to proof levels and examine the joints for leakage by applying a soapy solution or by conducting an internally developed Standard Operating Procedure. This test should demonstrate that the total leakage allowed as determined by the contractor is not exceeded. SAE ARP699 contains additional guidance on duct coupling tests. A post-test teardown inspection should also be conducted to determine the condition of the hardware. Ease of coupling accessibility and replaceability should also be examined during design reviews, drawing inspections, and tests.

D.6.3.8 Pressurization control valves.

Dirt and foreign objects can cause malfunction of the pressurization controls. This is a significant safety-of-flight consideration because the malfunction of a safety valve can result in personnel injury or air vehicle damage. All pressurization control valves (outflow, safety, and negative pressure relief) should be located to minimize the entrance of dirt or foreign objects into the valves. Valves should not be located on the floor, under the floor, or other locations where dirt normally tracked into the air vehicle can easily fall, be swept, or kicked into the valves.

The outflow valves on the C-141 are located below the cargo floor in a location such that dirt and debris from the cargo compartment floor can be blown or swept into the valves. This has caused malfunction of the outflow valves and difficulty in maintenance.

Guidance for pressurization control valves requirements and testing are provided in SAE ARP1270. Endurance testing should be performed on the cabin pressure regulator valves and the cabin safety valves. Sampling tests are recommended for the cabin pressure regulator valves and the cabin safety valves.

In addition to the test required in SAE AS4073, the Fluid Resistance and the Contaminated Fluids tests of SAE ARP986 should also be performed on air valves.

D.6.3.9 Liquid cooling loops.

Liquid cooling loops:

a. should be designed so that no hazardous mists, vapors or liquids are introduced into the occupied compartments in the event of a single failure.

b. should indicate correct liquid level to maintenance personnel over the entire operating and non-operating temperature and pressure range.

c. should have dry quick disconnects for all equipment that have integral coolant flow paths.

d. should accommodate the removal and replacement of equipment without the need for replenishment of coolant or removal of entrained air in the coolant passages.

Coolant loop liquid level indication over the entire operating and non-operating temperature and pressure range should be provided. These systems should be designed for quick and easy maintenance, which includes accessible fill and drain provisions, and readily accessible and easily read level indications. When the liquid loop is accessible within the air vehicle, it may be desirable to place the level indicator in a location where it can be checked during flight. All line replaceable units of liquid cooling loops should have self-sealing disconnects. Liquid coolant connections to the cooled equipment should be a self-sealing, quick-disconnect type. It should not be necessary to refill and bleed liquid loops as a result of routine maintenance actions. Self-sealing, quick-disconnect connections are imperative for line replaceable units (such as liquid-cooled avionic equipment) to permit quick and easy maintenance. Quick-disconnects are preferred over valves because disconnects provide an instantaneous sealing of hoses or liquid-cooled components without loss of any coolant. Past experience has shown that disconnects are preferred over valves because of their quick-sealing capability. Experience with coolants has shown that without disconnects the coolants would be allowed to leak and cause physical damage to personnel and equipment. Coolant fluids selected for use in airborne liquid cooling loops should be non-toxic and non-hygroscopic and compatible with materials that they contact within the cooling loop. The coolant fluid should be compatible with the required operating and non-operating environment. Further guidelines for fluid selection are contained in SAE AIR1811. Silicate ester coolants have been widely used in airborne liquid cooling systems since the early 1970's. Operational problems and fire safety hazards have been noted with silicate esters. These fluids react with moisture to form a silica gel and an alcohol. The gel clogs flow passages and creates the possibility for arcing within avionics. The alcohol substantially lowers the flash point of the coolant. Polyalphaolefin is considered a coolant superior to silicate ester and its use should be considered for all applications that require a dielectric coolant. Increased operational readiness and meaningful improvement to reliability, maintainability, supportability, safety, and life cycle cost should be achieved with the use of PAO.

The following should be considered for verification.

a. Drawing inspection and laboratory tests should be used to verify that a single structural failure does not result in leakage of fuel or toxic coolant fluid into an occupied compartment.

b. Laboratory tests, analyses and air vehicle demonstrations should verify that the liquid coolant level is correctly displayed to maintenance personnel over the entire operating and non-operating temperature and pressure range.

c. Laboratory tests, analyses and inspection of drawings should verify that all liquid cooling loop equipment have dry quick disconnects if the equipment has integral coolant flow paths.

d. Air vehicle demonstrations should verify that equipment may be removed and replaced without the need to replenish coolant or remove entrained air in the coolant passages.

Laboratory tests should demonstrate that quick disconnects do not leak more than the contractor specified amount during connection, during disconnection, during use, or during the disconnection period. These tests should demonstrate acceptable leakage in the pressurized and unpressurized states and under the applications operating environment for pressure, temperature, and vibration simultaneously.

D.6.3.10 Vapor cycle loops.

Vapor cycle loops:

a. should be designed so that no hazardous mists, vapors or liquids are introduced into the occupied compartments in the event of a single failure.

b. should indicate the true refrigerant level to maintenance personnel over the entire operating and non-operating temperature and pressure range.

c. should not be adversely affected by negative “g” operation of the host air vehicle if the host air vehicle is capable of negative “g” operation.

d. should be tolerant of the phenomenon known as “slugging” during start up and other transient conditions. “Slugging” should not occur during normal, steady state operation of the vapor cycle system.

e. should not require discharge of the refrigerant during replacement of failed vapor cycle components that are not part of the refrigerant flow path.

f. should be capable of withstanding, without adverse affects, an internal vacuum at standard atmospheric pressure during the refrigerant charging process.

g. should be able to automatically detect and indicate to maintenance personnel, the presence of low lubricant levels, air, water, metal chips, or other contamination in the refrigerant charge.

The following should be considered for verification:

a. Laboratory tests, engineering analyses, ECS laboratory tests, ground tests and flight test should verify that no hazardous mists, vapors or liquids are introduced into occupied compartments in the event of a single failure.

b. Component tests, engineering analyses and air vehicle demonstrations should verify that the true refrigerant level is indicated to maintenance personnel over the entire operating and non-operating temperature and pressure range.

c. Component tests, engineering analyses and flight tests should verify that the vapor cycle refrigeration system is able to operate at all air vehicle attitudes and “g” levels.

d. Component tests, ECS laboratory tests and flight test should verify the tolerance of the compressor to the phenomenon known as “slugging” during start up and other transient conditions. These tests should also verify that “slugging” does not occur during normal, steady state operation of the vapor cycle system.

e. Inspection of drawings and air vehicle demonstrations should verify that replacement of failed vapor cycle components, that are not part of the refrigerant flow path, should not require discharge of the refrigerant.

f. Air vehicle demonstration should verify that the vapor cycle system can withstand, without adverse affects, an internal vacuum at standard atmospheric pressure during the refrigerant charging process.

g. Component tests, ECS laboratory tests, air vehicle demonstration and ground tests should verify that vapor cycle system can automatically detect and indicate to maintenance personnel, the presence of low lubricant levels, air, water, metal chips or other contamination in the refrigerant charge.

h. SAE AS4073 should be tailored to establish vapor cycle system verification.

Upon the completion of the component tests, a subsequent teardown inspection should be performed on the components to determine post-test conditions.

D.6.3.11 Fans.

All fans that may come into contact with air crew or ground maintenance personnel should not present any hazard of injury due to rotating blades. The rotating blades should be protected from foreign object damage. The total contribution of fans to the noise level in all occupied areas should be determined and limited, and consistent with overall air vehicle noise level requirements.

a. Inspection of drawings and hardware should be used to verify incorporation of means to prevent personnel injury by fan blades and to protect the fan against foreign object damage.

b. The noise level due to fans in all occupied areas of the air vehicle should be verified by ground test, flight test and crew evaluation.

Care should be taken to ensure all fan installations are inspected, especially those located on the tops and sides of equipment, where personnel might not see them but could touch them during maintenance, movement around the air vehicle. Laboratory containment tests should induce blade failures at the blade hub with 130 percent (130%) overspeed conditions, and the containment ring should prevent the penetration of blade fragments.

D.6.3.12 Component performance data.

The following data should be generated to support the system analysis. They should be considered for a data deliverable.

a. Heat exchanger thermal efficiency, pressure drop, weight, shape, materials, fin configuration, and core geometry and dimensions. Thermal efficiency and pressure drop data for the core should be presented as the product of the Stanton and Prandtl number and friction factor as a function of Reynolds number.

b. Performance data for air cycle machines, vapor compressors, fans, and liquid pumps

c. Pressure drop data for all distribution ducting, interconnecting ducting for the refrigeration pack, bleed air ducting, and other components contributing to the pressure drop of the system. Ducting layout and system installation drawings should be included.

d. Heat load summary of the equipment and avionics. The summary should itemize the heat loads, distinguish between the forced and ambient cooled equipment, identify the equipment's location in the air vehicle, and list the equipment's cooling requirement to satisfy its allocated reliability.

e. System description and schematic. The schematic should show all ECS components, indicate those locations where performance predictions for flow-rate, pressure, temperature, and humidity or enthalpy are made, indicate control set points, and correlate the analysis pressure drops to the respective locations on the schematic

f. Efficiency of components removing water and their dry and wet pressure drops.

g. Control algorithms, including protection control

D.6.3.13 Component qualification by similarity.

The SAE ARP986 provides an excellent guide to determine if qualification by similarity is a viable approach for qualification tests of any component, not just valves.

D.6.4 Acronyms.

The following list contains the acronyms/abbreviations contained within this appendix.

ACM	Air Cycle Machine
AECS	Advanced Environmental Control System
AOA	Angle Of Attack
AWACS	Airborne Warning And Command System
CDR	Critical Design Review
cfm	Cubic Feet Per Minute
CONOPS	Concept of Operations
COTS	Commercial Off-The-Shelf
EASY	Engineering Analysis System
ECP	Engineering Change Proposal
ECS	Environmental Control Subsystem
FMEA	Failure Mode Effects Analysis
FOD	Foreign Object Damage
FPD	Freezing Point Depressant
GFE	Government Furnished Equipment
IMC	Instrument Meteorological Conditions
INS	Inertial Navigation System
IPS	Ice Protection System

NBC	Nuclear, Biological, and Chemical (contamination)
OBIGGS	On Board Inert Gas Generating System
OBOGS	On Board Oxygen Generating System
PAO	Polyalphaolefin
psi	pounds per square inch
psia	pounds per square inch (absolute pressure)
psid	pounds per square inch (differential pressure)
psig	pounds per square inch (gauge pressure)
SLD	Supercooled Large Droplet
SRAM	Short-Range Attack Missile
TAS	True Air Speed
UHF	Ultra High Frequency
VMS	Vehicle Management System
WBGT	Wet Bulb Globe Temperature

D.6.5 Subject term (key word) listing.

Air

Avionics

Bleed air

Cargo

Contamination

Cooling

Crew station

Heating

Ice

Overbleed

Pressure

Rain

Temperature

Transparency

D.6.6 International standardization agreement implementation.

This specification implements STANAG 3208, Air Conditioning Connections; STANAG 3212, Diameters for Gravity Filling Orifices; STANAG 3315, Aircraft Cabin Pressurizing Test

Connections; and STANAG 3372, Low Pressure Air and Associated Electrical Connections for Aircraft Engine Starting. When amendment, revision, or cancellation of this specification is proposed, the preparing activity must coordinate the action with the U.S. National Point of Contact for these international standardization agreements, as identified in the ASSIST database at https://assist.dla.mil/online/start.

D.6.7 Responsible engineering office.

The office responsible for the development and technical maintenance of this appendix is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL. Requests for additional information on this appendix can be obtained from AFLCMC/ENRS, BLDG 28 RM 118, 2145 MONAHAN WAY, WPAFB OH 45433-7017 USA; DSN 674-5476; COMMERCIAL (937) 904-5476; ENGINEERING.STANDARDS@US.AF.MIL.

D.6.8 Amendment notations.

The margins of this specification are marked with vertical lines to indicate modifications generated by this amendment. This was done as a convenience only and the Government assumes no liability whatsoever for any inaccuracies in these notations. Bidders and contractors are cautioned to evaluate the requirements of this document based on the entire content irrespective of the marginal notations.

APPENDIX E

AIR VEHICLE FUEL SUBSYSTEM

REQUIREMENTS AND GUIDANCE

E.1 SCOPE

E.1.1 Scope.

This appendix provides the requirements, verifications, tailoring guidance, and background information for the Fuel Subsystem provided for in Part 1 of this specification. The appendix has been developed and coordinated by technical personnel from the Air Force, Navy, and Army and has been approved as an official guide for use by Government personnel for assistance in tailoring the air vehicle subsystems specification for acquisition and model specifications. This appendix is a mandatory part of the specification. The information contained herein is intended for compliance.

E.1.2 Structure.

The appendix structure replicates the structure of the Air Vehicle Subsystems Specification except it places each corresponding section 3 requirement and section 4 verification together.

E.1.3 Appendix.

This appendix provides tailoring guidance and background information for individual paragraphs of the Air Vehicle Subsystems Specification. Guidance gives recommendations on how to tailor the specification paragraph. Where ___(TBS)___ appears, the guidance paragraph provides recommended values or text that the using service may use to insert in the __(TBS)__. When contractors are expected to complete the _(TBS)__, the Guidance paragraph will so state. The Using Service makes the final decision on whom completes the __(TBS)__ in the specification. Finally, Lessons Learned are provided to give insight to past events that could impact the tailoring of the specification.

E.1.4 Deviations.

Projected designs for given applications which will result in improvement of the system performance, reduced life cycle cost, or reduced developmental cost through deviations from this guidance, or where requirements of the specification results in compromise in operational capability, should be brought to the attention of the using service.

E.1.5 Environmental impact.

Air Vehicle Subsystems will be designed such that their operation, maintenance, and repair may be accomplished without violating the most stringent environmental regulations applicable to locations where subsystems are used or supported. Compliance with environmental regulations will not prevent subsystems from achieving and sustaining mission performance capability. Materials, processes, and environmental control equipment necessary to meet these environmental requirements must currently be available in the Using Service's maintenance and supply system. The design will not use environmentally unsuitable materials such as ozone depleting fluorocarbons, chlorofluorocarbons, and halons, or highly volatile organic compounds in solvents and coatings during development, production, operation, maintenance, or repair. The Environmental Protection Agency maintains an online list of toxic chemicals and hazardous substances on its Ozone Layer Depletion Website at http://www.epa.gov/ozone/snap/ that should be consulted. The Significant New Alternatives Policy (SNAP) Program available thereon identifies substitutes for ozone depleting chemicals.

The contractor will conduct an environmental analysis of air vehicle subsystems.

E.1.6 Responsible engineering office.

The responsible engineering office (REO) for this appendix is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL.

E.2 APPLICABLE DOCUMENTS

E.2.1 General.

The documents listed in this section are specified in sections 3 and 4 of this handbook. This section does not include documents cited in other sections of this guide specification or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3 and 4 of this handbook, whether or not they are listed.

E.2.2 Government documents

E.2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this appendix to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

INTERNATIONAL STANDARDIZATION AGREEMENTS

AIR AND SPACE INTEROPERABILITY COUNCIL/
NORTH ATLANTIC TREATY ORGANIZATION

ASCC AIR STD 25/11	Diameters for Aircraft Gravity Filling Orifices
AASSEP-2	Pressure Refuelling Connections and Defuelling for Aircraft
STANAG 1135	Interchangeability of Fuels, Lubricants and Associated Products Used by The Armed Forces of The North Atlantic Treaty Nations
STANAG 3105	Pressure Refuelling Connections and Defuelling for Aircraft
STANAG 3212	Diameters for Gravity Filling Orifices
STANAG 3294	Aircraft Fuel Caps and Fuel Cap Access Covers
STANAG 3632	Aircraft and Ground Support Equipment Electrical Connections for Static Groundings
STANAG 3747	Guide Specification (Minimum Quality Standards) for Aviation Turbine Fuels (F-34, F-35, F-40 and F-44)
STANAG 7036	Fuels to be Introduced into and Delivered by The NATO Pipeline System (NPS)

(Copies of these documents are available at http://quicksearch.dla.mil, http://nso.nato.int, www.airstandards.org, and www.ihs.com to qualified users.)

COMMERCIAL ITEM DESCRIPTIONS

A-A-59281	Cleaning Compound, Solvent Mixtures

DEPARTMENT OF DEFENSE SPECIFICATIONS

JSSG-2000	Air System Joint Service Specification Guide
JSSG-2001	Air Vehicle Joint Service Specification Guide
JSSG-2006	Structures Joint Service Specification Guide
MIL-T-18847	Tank, Fuel, Aircraft, Auxiliary External, Design and Installation
MIL-A-25896	Adapter, Pressure Fuel Servicing, Nominal 2.5 Inch Diameter
MIL-DTL-27422	Tank, Fuel, Crash-Resistant, Ballistic-Tolerant, Aircraft
MIL-DTL-38999	Connectors, Electrical, Circular, Miniature, High Density, Quick Disconnect (Bayonet, Threaded, and Breech Coupling), Environment Resistant, Removable Crimp and Hermetic Solder Contacts, General Specification for

MIL-DTL-83413/6	Connectors and Assemblies, Electrical, Aircraft Grounding: Receptacles, Two Piece, with Inserts and Housings
MIL-PRF-87260	Foam Material, Explosion Suppression, Inherently Electrostatically Conductive, for Aircraft Fuel Tanks

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-464	Electromagnetic Environmental Effects Requirements for Systems
MIL-STD-810	Environmental Engineering Considerations and Laboratory Tests
MIL-STD-883	Microcircuits
MIL-STD-1290	Light Fixed and Rotary-Wing Aircraft Crash Resistance
MS24484	Adapter, Pressure Fuel Servicing, Nominal 2.5 Inch Diameter

(Copies of these documents are available online at http://quicksearch.dla.mil or from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia PA 19111-5094 USA.)

E.2.2.2 Other Government documents, drawings, and publications.

The following other Government documents, drawings, and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

EXECUTIVE ORDER

EO 13423	Strengthening Federal Environmental, Energy, and Transportation Management

(Copies of this document are available from www.archives.gov/federal-register/executive-orders.)

U.S. AIR FORCE TECHNICAL ORDERS

T.O. 00-25-172	Ground Servicing of Aircraft and Static Grounding/Bonding
T.O. 42B-1-1	Quality Control of Fuels and Lubricants
T.O. 42B1-1-14	Fuels for USAF Aircraft

(Copies of these documents are available at http://www.tinker.af.mil/technicalorders/index.asp to qualified users.)

U.S. AIR FORCE AIRWORTHINESS ADVISORIES

AA-01-05	Use of Aluminum Oxide (Al_2O_3) as a Grit Blasting Media during the Removal of Organic Coatings on USAF Aircraft Fuel Tanks
AA-04-03	Free Water and Microbial Growth in USAF Aircraft Fuels

(Copies of these documents are available to qualified users. Contact the USAF Airworthiness Certification Community of Practice Knowledge Owners at https://cs.eis.afmc.af.mil/sites/AeroEngDisciplines/Systems/Airworthiness/default.aspx .)

U.S. ARMY AND U.S. AIR FORCE TECHNICAL REPORTS

AFAPL-TR-75-70	Summary of Ignition Properties of Jet Fuels & Other Aircraft Combustible Fluids
AFAPL-TR-78-56	Static Electricity Hazards in Aircraft Fuel Systems
AFAPL-TR-78-89	Factors Affecting Electrostatic Hazards
AFFDL-TR-79-3047	Aircraft Integral Fuel Tank Design Handbook
AFWAL-TR-80-3100	Integral Fuel Tank Test Criteria and Methods
AFWAL-TR-85-2057	Aircraft Mishap Fire Pattern Investigations
USAAVSCOM TR 89-D-22A	Aircraft Crash Survival Design Guide Accession Number AD-A218 434

(Copies of these documents are available at http://www.dtic.mil/, and DTIC Online Access Controlled to qualified users; Defense Technical Information Center, 8725 John J. Kingman Rd., Suite 0944, Ft. Belvoir VA 22060-6218 USA.)

NAVAL AIR SYSTEMS COMMAND REPORT

NAVAIR 06-5-504	Fuels, and Fuel Systems

(Copies of this document are available from www.sae.org; SAE International, 400 Commonwealth Drive, Warrendale PA 15096-0001 USA; and www.ihs.com to qualified users.)

NAVAL OPERATING INSTRUCTIONS

OPNAVINST 3710.7	General Flight and Operating Instructions

(Copies of this document are available online at http://doni.daps.dla.mil.)

OPNAVINST 4790.2	The Naval Aviation Maintenance Program (NAMP)

(Copies of this document are available online at http://www.navair.navy.mil/logistics/4790/library/basic2j.pdf.)

FEDERAL AVIATION ADMINISTRATION

FAA Advisory Circular 20-53	Protection of Aircraft Fuel Systems Against Fuel Vapor Ignition Caused by Lightning
FAA Report DOT/FAA/CT-83/3	Users Manual for AC-20-53A Protection of Aircraft Fuel Systems Against Fuel Vapor Ignition Due to Lightning

(Copies of these documents are available at http://rgl.faa.gov and http://lessonslearned.faa.gov/PanAm214/DOT_AC20-53A.pdf, respectively; from the U.S. Department of Transportation, Federal Aviation Administration, 800 Independence Avenue SW, Washington DC 20591-0004 USA).

E.2.3 Non-Government publications.

The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

SAE INTERNATIONAL

SAE AIR1184	Capacitive Fuel Gauging System Accuracies
SAE AS1284	Standard Test Procedure and Limit Value for Shutoff Surge Pressure of Pressure Fuel Dispensing Systems
SAE AIR1662	Minimization of Electrostatic Hazards in Aircraft Fuel Systems
SAE ARP1665	Definition of Pressure Surge Test and Measurement Methods for Receiver Aircraft
SAE AIR4023	Aircraft Turbine Fuel Contamination History and Endurance Testing
SAE AIR4069	Sealing Integral Fuel Tanks
SAE AIR4246	Contaminants for Aircraft Turbine Engine Fuel System Component
SAE AS5877	Aircraft Pressure Refueling Nozzle
SAE ARP8615	Fuel System Components
SAE AS18802	Fuel and Oil Lines, Aircraft, Installation of
SAE AS33611	Tube Bend Radii

(Copies of these documents are available from www.sae.org; SAE International, 400 Commonwealth Drive, Warrendale PA 15096-0001 USA; and from www.ihs.com to qualified users.)

AMERICAN SOCIETY FOR TESTING AND MATERIALS

ASTM D471	Rubber Property—Effect of Liquids
ASTM D2276	Particulate Contaminant in Aviation Fuel by Line Sampling

(Copies of these documents are available from www.astm.org; American Society for Testing and Materials, 1916 Race Street, Philadelphia PA 19103-1187 USA; and from www.ihs.com to qualified users).

AEROSPACE INDUSTRIES ASSOCIATION OF AMERICA, INC.

AIA/NAS NASM1515	Fastener Systems for Aerospace Applications

(Copies of this document are available from www.aia-aerospace.org; AIA, 1000 Wilson Boulevard, Suite 1700, Arlington VA 22209-3928 USA; and from www.ihs.com to qualified users).

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION

ISO 12103-1	Road vehicles — Test dust for filter evaluation — Part 1: Arizona test dust

(Copies of this document are available from International Organization for Standardization; ISO Central Secretariat; 1, ch. de la Voie-Creuse; CP 56 CH-1211; Geneva 20; Switzerland; www.iso.org; and from www.ihs.com to qualified users).

E.2.4 Order of precedence.

Unless otherwise noted herein or in the contract, in the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

E.2.5 Streamlining.

The Air Vehicle Subsystems Specification has been streamlined. The documents listed in this appendix which are required for acquisition have the same status as those referenced directly in section 2 (first tier). All other documents referenced through tiering, may be used for guidance and information only.

E.3 REQUIREMENTS

E.4 VERIFICATIONS

E.3.1 Definition

E.4.1 Definition

E.3.2 Characteristics

E.4.2 Characteristics

E.3.3 Design and construction

E.4.3 Design and construction

E.3.4 Subsystem characteristics

E.4.4 Subsystem characteristics

E.3.4.1 Landing subsystem

E.4.4.1 Landing subsystem

E.3.4.2 Hydraulic subsystem

E.4.4.2 Hydraulic subsystem

E.3.4.3 Auxiliary power subsystem

E.4.4.3 Auxiliary power subsystem

E.3.4.4 Environmental control subsystem

E.4.4.4 Environmental control subsystem

E.3.4.5 Fuel subsystem.

The fuel subsystem shall supply fuel to the engine(s) on an uninterrupted basis and shall function satisfactorily under all operating conditions for the air vehicle. The fuel subsystem shall not limit air vehicle performance within installed engine and air vehicle operating limits. The fuel subsystem shall provide the following functions: fuel tankage, fuel control, fuel quantity gauging, engine fuel feed, fuel transfer, refueling, defueling, thermal management, fuel management, vent and pressurization capability, and all subsystem interfaces. The fuel subsystem shall provide for safe and reliable onboard control of fuel distribution, and engine feed under all normal and degraded operations. The subsystem shall comprise the necessary strength to satisfactorily react to the stresses encountered in all phases of the air vehicle operation. The fuel subsystem and its components shall provide the above for the complete service life of the air vehicle.

E.4.4.5 Fuel subsystem

The fuel system components shall be qualified for use in the air vehicle in accordance with the most current revision of SAE ARP8615, as specified by the procuring service.

E.3.4.5.1 General requirements

E.4.4.5.1 General requirements

E.3.4.5.1.1 Fuel designation.

Fuel(s) for the air vehicle shall be:

a. Primary fuel(s) (TBS 1).

b. Alternate/Restricted fuel(s) (TBS 2).

c. Emergency fuel(s) (TBS 3).

REQUIREMENT RATIONALE (3.4.5.1.1)

The fuel(s) which are expected to be used in the air vehicle should be identified.

REQUIREMENT GUIDANCE (3.4.5.1.1)

TBS 1 should be filled in with any fuel(s) which can be routinely encountered and used as a primary fuel. Primary fuel should be those fuels that are satisfactory for all steady state and transient operating conditions and for all transitions between the primary fuels. Jet A fuel with the military additive package, JP-8, JP-5 and their North Atlantic Treaty Organization (NATO) equivalents F-24, F-34, and F-44, respectively, (conforming to their applicable Defense Specifications (e.g., MIL-DTL-5624, MIL-DTL-83133, and ASTM-D1655) should be specified as "Primary Fuel". The military additive package consists of: Static Dissipater Additive (SDA), Corrosion Inhibitor/Lubricity Improver (CI/LI) additive, and Fuel System Icing Inhibitor (FSII).

TBS 2 should be filled in with alternate or restricted fuel(s). Alternate fuel should be defined as fuel authorized for continuous use where thrust is not adversely affected. The flight manual should define limitations and prolonged use may result in a change of maintenance cost. Some trim adjustments may be necessary with use. “Alternate” versus “Restricted” is simply a terminology difference between USAF and USN technical publications.

TBS 3 should be filled in with emergency fuel(s). Emergency fuel should be defined as fuel which may cause significant damage, limited to one flight, only for emergency evacuation or aerial refueling or countering emergency action.

REQUIREMENT LESSONS LEARNED (3.4.5.1.1)

A Department of Defense (DoD) Directive Number 4140.43 dated 5 December 1975 stated that all new turbine powered air vehicles should be designed to operate on middle distillate turbine fuel, JP-8, as well as JP-5 and JP-4. Shipboard based air vehicles will continue to require JP-5 fuel because of safety considerations in storing and handling fuel aboard ships. These fuels can be routinely encountered in worldwide deployment and should be considered in the design of the air vehicle systems. All other fuels should be designated alternate, restricted, or emergency fuels. The conversion of Air Force Bases from JP-4 to JP-8 has been completed. The need for and availability of JP-4 for new air vehicles remains unclear at this time. Reference Technical Order (T.O.) 42B-1-14 for a more detailed definition of primary, alternate, and emergency fuel. Consult NATO Standardization Agency STANAG 1135, STANAG 3747, and STANAG 7036 for Allied country fuel designations.

JP-8 +100 fuel additive: The thermal stability additive for JP-8 was developed by the Air Force Research Laboratory’s Propulsion Directorate (AFRL/RZSP) to increase the thermal stability of jet fuel by 100°F and increase the fuel’s heat sink capacity by 50 percent (50%). The +100 additive is a fuel injector cleaner additive package consisting of detergent, dispersant, metal deactivators and antioxidant. The additive was developed to facilitate fielding of future advanced fighter air vehicles requiring enhanced thermal margins for fuel. During field evaluation of the additive in F-16 air vehicles, benefits of reduced engine coking were reported. The Air Force has been evaluating the benefits of this additive in fighter and trainer air vehicles. However, the additive disarms the current generation of filter coalescer elements making them ineffective for removing water, and dirt. The Air Force developed an implementation method to inject the +100 additive downstream after the fuel has been filtered through current filters, for application on truck refueled air vehicles. A new generation of filter coalescer element is required to remove dirt and water from fuel with +100 additive so that fuel can be dispensed in a hydrant system. The Navy has expressed concerns on unique problem with filters for their ships and requires that a drop-in filter and coalescer element be developed before they use the +100 additive. The Army has voiced similar concerns on the additive implementation prior to filter development.

The three Services are currently working on a new-generation filter coalescer development. Initial prototypes have been tested, but would require significant modification to be used in existing Air Force, Army, and Navy filter coalescer vessels.

During the B-2 development phase, the primary fuel for the air vehicle was changed from JP-4 to JP-8. This was desired due to the requirement to refuel the air vehicle within a hangar and due to limited air flow for ventilating air vehicle compartments adjacent to the fuel tanks. The low volatility of JP-8 greatly reduced the probability of a fuel explosion. JP-4 was re-designated as an emergency fuel. With the routine exposure to JP-4 removed, other fuel subsystem changes could be made. The fuel tank pressurization system, which was mandatory for the fuel subsystem for hot JP-4, was deleted providing a reduction in system complexity and air vehicle weight along with an improvement in system maintainability. Also, fuel tank lightning protection was reduced due to the reduction in risk of fuel tank explosion.

The Air Launched Cruise Missile (ALCM) changed to a high density fuel to improve the range capability of the missile. The missile was volume limited and therefore, the increased pounds of fuel could be loaded in the existing tank volume. The fuel designated for ALCM has been defined by MIL-P-87107B. JP-9 is a mixture of three specific hydrocarbon compounds blended to obtain a freezing point below -65°F, high volatility to enable ignition of a cold soaked missile, a maximum viscosity of 80 centistokes at -65°F, very high stability and cleanliness, and no aromatic components to minimize material compatibility problems. A report on the long term evaluation of the effects of JP-9 on various fuel subsystem elastomers was issued by the Air Force Material Laboratory (AFML) reference AFML-MX-79-14, dated 8 March 1979. It was concluded that most of the fuel subsystem elastomers were compatible with JP-9. Two exceptions were identified. Chromate cured polysulfide exhibited shrinkage during long term storage and Nitrile o-rings exhibited excessive swell. A report on the compatibility of JP-9 fuel with metals was issued as AFML-MX-79-22. The report indicated that 2219-T87 aluminum alloy in contact with A286, 304 CRES, or cadmium plated steel fasteners is not compatible with water contaminated JP-9. JP-9 will be serviced in a clean, dry condition and the ALCM fuel tank will be sealed to prevent absorption of water into the fuel. A data accumulation plan was formulated by the prime contractor under the Effectiveness Verification Improvement Program to provide a data base to show that the fuel subsystem will operate correctly without oxidation, gum formation, or microbacteriological growth for a period of five years or longer.

E.4.4.5.1.1 Fuel designation.

Fuel subsystem required performance shall be demonstrated with the designated primary fuel which is most critical for each performance parameter.

VERIFICATION RATIONALE (4.4.5.1.1)

The ability of the fuel subsystem to perform each of its functions successfully must be verified to ensure the subsystem will meet the air vehicle needs. The proper and safe operation of the fuel subsystem, regardless of the fuel type, must be verified.

VERIFICATION GUIDANCE (4.4.5.1.1)

Fuel subsystem performance should be demonstrated with the designated primary fuel which is most critical for that parameter.

Performance limitations which are critical due to vapor and air evolution should be defined with JP-4, if JP-4 is designated as an alternate, restricted, or primary fuel.

Parameters which are critical to density and viscosity should be demonstrated with JP-5 or JP-8.

Gauging accuracy should be demonstrated with the fuel which provides the greatest error in the system.

VERIFICATION LESSONS LEARNED (4.4.5.1.1)

(TBD)

E.3.4.5.1.2 Material fuel resistance.

All materials used in the fuel subsystem shall be compatible with the air vehicle designated fuels. Use of copper, magnesium, and cadmium in contact with fuel are prohibited. __(TBS) materials are not allowed.

REQUIREMENT RATIONALE (3.4.5.1.2)

The material compatibility with the designated fuels should be applied at the air vehicle level, but has been repeated here for emphasis and to add lower level, unique fuel subsystem requirements.

REQUIREMENT GUIDANCE (3.4.5.1.2)

TBS should be filled in with consideration of the following:

All materials used in the fuel subsystem should be compatible with any air vehicle designated fuels, other fuel categories, and any purging or preservative fluids that may be used.

Magnesium should be prohibited from locations where fluid or moisture entrapment is possible. This restriction should also include the interior of fuel tanks where water can collect.

Fuel temperature range and aromatic content should be considered to ensure elastomer compatibility.

Particular attention should be given to potting compound compatibility.

REQUIREMENT LESSONS LEARNED (3.4.5.1.2)

Primary concern with current day conventional fuel in relation to material compatibility is the aromatic content, additives and the small quantity of non-hydrocarbons. Aromatics have high solvency tendencies and either dissolve or cause severe swelling of rubber. The prevalent non-hydrocarbons which are generally considered most detrimental to air vehicle systems are sulfur and sulfur compounds, water soluble components, gums and gum forming compounds, and naphthenic acid. These can result in corrosion of air vehicle parts made of copper, brass, nickel, or cadmium plated; cause deterioration of rubber packings and fuel cells; and clog fine mesh filters. Additives have been added to fuels to reduce these effects.

General experience indicates that Nitrile seals provide adequate performance with good durability down to approximately -40°F. At fuel temperatures above 160°F, Nitrile is subject to cracking especially if the seals are allowed to dry out. If these seals are used in a system with a fuel temperature above 160°F the seals will not leak when the seals are first installed; however, if fuel is removed from the system for periods as short as 30 to 60 days, the seals will leak when fuel is returned to the system. Fluorosilicone seals provide improved sealing below -40°F and above 160°F but at a higher cost and reduced durability, especially for moving seals. Fluorosilicone seals tend to swell when exposed to fuel and may be difficult to reinstall if removed during maintenance actions. If allowed to dry, the seals will return to the original shape. If the seals have been over stressed such as can occur in a variable cavity coupling when the coupling has been retorqued to stop a leak, the o-ring will appear like a packing, square shape, and will not return to original shape.

The Society of Automotive Engineers (SAE) committee, G-4, published AMS 7284, a new seal material specification for air vehicle fuel subsystems. The material was applicable for a temperature range of -65°F to +302°F.

In legacy specifications, metal tubing for fuel lines was required to be fabricated from stainless steel in accordance with MIL-T-8606 or aluminum alloy in accordance with WW-T-700. Minimum wall thickness was designated as 0.028 inch for aluminum and 0.020 inch for stainless steel. Although thinner wall thickness' could retain the required pressure, the minimum wall thickness is required to minimize handling and maintenance damage.

The prohibition of cadmium plating with fuel is presented in MIL-STD-1568; however, the prohibition of magnesium and copper with fuel is not included (cadmium and copper are covered by EO 12856, 3 Aug 93 to eliminate toxic chemicals and extremely hazardous waste). Both of these materials can react with surfactants of the fuel. Under hot fuel conditions copper can cause coking of the fuel. Magnesium should be restricted from locations where fluid or moisture entrapment is possible. This restriction should also include the interior of fuel tanks where water can collect.

E.4.4.5.1.2 Material fuel resistance.

Long term material fuel resistance shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.1.2)

Operation of a system with field supplied fuel for a short period of time does not establish material compatibility; long-term effects need to be verified.

VERIFICATION GUIDANCE (4.4.5.1.2)

TBS should be filled in with component level tests, inspection, and operation of the system.

Material fuel resistance should be verified by tests at the component level under all normal and extreme environmental conditions with all fuel types including primary and alternate. All other fuel types and fluids should be evaluated by analysis and test as required. The final proof should be the inspection and operation of the system. For the seal material, the verification should be in the proof pressure test of the component and the system, and the demonstration of a leak free system during operation of the air vehicle.

VERIFICATION LESSONS LEARNED (4.4.5.1.2)

All fuels have considerable variability allowed in the specification and any given batch could exhibit properties anywhere within the specified range. In order to cover the complete range of aromatic content TT-S-735 Type I and Type III test fluids have been used. The Type I fluid contains zero percent aromatics and the Type III fluid contains 30 percent (30%) aromatics. The 8-day fuel resistance test contained in the legacy mil-spec MIL-F-8615—which used TT-S-735 test fluid, wet and dry periods, and high and low temperatures—had been the basis to establish fuel resistance for components. MIL-F-8615 has been superseded by SAE ARP8615.

The test procedure was originally developed for Nitrile material and later adapted for fluorosilicone material. There has been strong evidence that the TT-S-735 Type I test fluid (iso-octane gasoline) does not produce the desired test effect of "minimum swell" for fluorosilicone.

During conversion from JP-4 to JP-8, fuel leaks often result when an air vehicle, which has been operating on JP-4, is was filled with JP-8 or JP-5. During the investigation of these fuel leakage phenomena, it was found the Type I test fluid can produce considerable swell in some materials. The Type I fluid following the Type III high aromatic test fluid was intended to produce a minimum swell (shrinkage from the previous condition) and verify that a good sealing contact of the seal material would remain. The component could pass the test with Type III and Type I test fluid, but would leak if the component was then subjected to a low aromatic fluid such as JP-7. At this time, investigation is under way to define a better test fluid. It is recommended JP-7 be used in place of the Type I test fluid for fuel resistance testing.

E.3.4.5.1.3 Fuel contamination.

Fuel subsystem contamination, as delivered to the engine, shall be no larger than (TBS 1). All fuel subsystem functions shall continue to operate with fuel contaminated as follows: (TBS 2).

REQUIREMENT RATIONALE (3.4.5.1.3)

Although fuel is normally serviced to the air vehicle in an extremely clean condition, fuel can become contaminated. Components must be able to tolerate gross contamination without malfunction. From the fuel subsystem component viewpoint, the primary concern is blockage of fuel flow or malfunction of the component such as preventing a check valve from closing. Since gross contamination is an unusual condition, wearout due to abrasive action of the contaminates is of little concern. Therefore, gross levels of contaminants which components must tolerate should be specified.

REQUIREMENT GUIDANCE (3.4.5.1.3)

TBS 1 should be completed with the maximum allowable particle size in fuel being delivered to the engine. This should be no larger than 2000 microns. A four to eight mesh screen on the boost pump inlets has been used in legacy fuel systems to ensure this contaminant particle size requirement is met.

TBS 2 should be completed with fuel system contamination. The following table outlines the contaminant, size, and quantity which has been used by legacy programs to qualify fuel systems and components for the air frame to define performance limitations. This table has evolved over many years and is based on inspection of contamination found in actual air vehicle fuel tanks. The table should be adjusted to account for contaminants expected during fabrication. Composite fiber should be considered for air vehicles with composite fuel tanks. (Refer to table E-I).

TABLE E-I. Fuel contaminants.

Contaminant Mixture		
Contaminant	Particle Size (Microns)*	Quantity (gms per 1000 liters)
Iron Oxide	0 – 5 5 – 10	19 1.0
Sharp Silica Sand	150 – 300 300 – 420	0.7 0.7
ISO 12103-1, A4 Coarse Test Dust	Mixture as provided by ISO document	5.3
Cotton linters	Staple below 7 U.S. Dept of Agriculture Grading Standards	0.07
Iron Chips	150 – 500	10
Aluminum Chips	150 – 500	10
Graphite Epoxy Composite	0 – 45 (23%) 45 – 150 (26%) 150 – 300 (8%) 300 – 425 (32%) 425 – 710 (11%)	5.2
Explosion Suppressant Foam (ESF) Particles** ESF contaminant is defined as foam in compliance with MIL-PRF-87260B.	1 – 100** Distribution is random utilizing method outlined and cut utilizing the methods in section 4.2.4 of MIL-PRF-87260B, excluding a hot wire cutter.	0.75**

NOTES:

* The contamination used for testing is graded by the sieve method. Particles considerably larger than 500 microns size can pass through the sieve. Particles in the 700 – 800 micron range have been found in certified test contamination samples.

** For air vehicles with fuel tank explosion suppression foam installed in the tanks, OR which may aerial refuel from tankers with ESF

The fuel subsystem should be able to operate with a free water content of 0.75 cubic centimeters per gallon. Water contamination has always been a problem with jet fuel. Water may be introduced at any transfer point between the refinery and the air vehicle tank and water will be introduced into tanks through an open vent by condensation of water vapor in the air. Although military fuel normally contains FSII, the component and the system design should accommodate this maximum water contamination since commercial fuels may be used in military air vehicles.

REQUIREMENT LESSONS LEARNED (3.4.5.1.3)

In many programs the development of the heat exchangers has been the responsibility of the subsystem designer requiring the cooling. As a result the "allowed pressure drop" of the fuel pass of the heat exchangers did not receive a critical review by the fuel subsystem team until the system level testing was accomplished. At test time, it was discovered the pressure drop did not account for contamination which could be encountered. This oversight can have a big impact on the suction feed capability of the engine. The fuel subsystem engineer must insure the pressure drop specified for the heat exchanger(s) meets the engine feed requirements and accounts for any abnormal feed conditions, especially contaminated fuel. In many cases, the flow path through the heat exchanger is through very narrow fin spacing. The fuel subsystem designer should consider the filtering effect of these fins. It may be desirable to provide a bypass valve. The F-16 has successfully operated without a bypass with a fin spacing of 0.060. The use of heat exchangers in the suction feed line should be avoided if possible. The system design should consider the need to flush the tanks after air vehicle assembly. Dirty fuel should not be routed through the heat exchangers since contaminates will be collected in the heat exchanger.

The airframe fuel subsystem should not be relied upon to provide filtration for the engine, other than basic fuel system protection levels. The fuel is normally delivered to the air vehicle in an extremely clean condition and can be delivered in the same condition to the engine except for foreign matter introduced during maintenance or from the atmosphere through the tank vents. Some dust can be expected to enter the fuel tanks through an open vent system. During manufacture of new air vehicles and during maintenance and repair activities, the fuel tanks must be cleaned of any foreign material prior to being released for engine run up and flight. If the tank and air vehicle configuration make it difficult to clean the tanks thoroughly, a temporary screen, installed in the engine feed line, could be used during engine run up and the first flight to trap any large particles that were missed in clean up. In the event it is deemed necessary to have a cleanable or replaceable filter element in the engine feed line, it should be located downstream of the engine shut-off valve and should be readily accessible for draining and maintenance. The screen should not be any finer than 40 mesh (approximately 400 microns). The filter assembly should incorporate a by-pass capability which does not flush the trapped material during by-pass. The filter assembly should incorporate an impending by-pass indicator which cannot be reset until the element is replaced.

The requirement to filter the fuel has been imposed upon the engine rather than the airframe. This results in the total weight and size of the filtration system being much less than it would have been if the airframe had supplied a line-mounted filter. Because the engine has a much larger fuel pressure range to work with, the resulting filter size will be smaller. The airframe fuel feed line has a very small allowed pressure drop due to the boost pump out suction feed requirement. A large filter size would be required to meet the pressure drop requirement.

Reference AIR 4023 and AIR 4246 for test procedures and contaminants for engine component testing.

Currently only KC-130 tankers have ESF in their fuel tanks.

E.4.4.5.1.3 Fuel contamination.

The ability of the fuel subsystem to limit particle sizes in the fuel delivered to the engine(s) shall be verified by __(TBS 1)__. The ability of the fuel subsystem to operate with contaminated fuel shall be verified by __(TBS 2)__.

VERIFICATION RATIONALE (4.4.5.1.3)

The ability of the fuel subsystem components to operate with contaminated fuel should be verified.

VERIFICATION GUIDANCE (4.4.5.1.3)

TBS 1: The ability to limit particle size in the fuel should be verified by inspection of the air vehicle.

TBS 2: The ability of the fuel subsystem components to operate with contaminated fuel as defined in table E-I, should be verified by component test. Operation of the system with the specified water contamination should be verified by system test on a fuel subsystem development rig and by component tests. During the tests the accumulation of ice should not obstruct moving parts, plug orifices or bleed holes, or block screens or filters.

VERIFICATION LESSONS LEARNED (4.4.5.1.3)

Air vehicles have operated for the last 20 years with components which have passed MIL-F-8615 and have not reported any serious operating problems due to contaminated fuel. This contamination table is believed to represent a conservative high level for normally expected contamination; however, levels higher than this can occur under rare instances. One common instance is when manufacturing oversight leaves debris such as cleaning rags in the tank. During the early operation of the B-2 it was found that there was an unusually high level of cotton linters in the fuel tanks which collected on the fins of the heat exchangers during engine operation. These fibers were thought to come from the cotton coverall and cleaning cloth of the workers during installation of the fuel components and sealing of the tanks. The roughness of the graphite composite tank material could account for the increase of cotton fiber as compared to that found in metal tanks. Improved flushing procedures were incorporated to insure removal of the contamination prior to engine operation and flight. Another source of contamination that should be considered is wire brushes used to clean areas for good electrical bonding. Wires from these brushes can pass through wire strainers. For systems which can be controlled in relation to cleanliness, the contamination level can be reduced to the controlled level. The Air

Launched Cruise Missile had the missile tanks and the fuel thoroughly cleaned prior to servicing to prevent contamination problems.

The test fluid used should contain the types and concentrations of the specified contaminant mixture. The fluid circuit should insure the contaminants remain in suspension in the fluid and enter the component under test. The contaminant should not be re-circulated so the contaminant can be continuously and uniformly introduced into the inlet of the component. If the fuel is filtered and re-circulated, then the fine particles which can penetrate the system filter will be re-circulated, causing a larger quantity of fine particles to enter the components. This is not detrimental to the test since the test checks for malfunction of the component and not wear of the surfaces. A small batch of test fluid with proportionate quantity of contaminant added one time should not be used. Pockets and voids in the system can trap and hold the total “proportioned” quantity of contaminant during the first pass through the test circuit and the remaining fuel flow will be contaminant free.

The component should be subjected to rated flow and pressure for $2^1/_2$ hours or 500 component operating cycles and then subjected to 10 to 25 percent (10 to 25%) of rated flow for $2^1/_2$ hours or 500 cycles. The operation of the component during this time should be in accordance with the component detailed specification. The above test should be repeated once. If the fuel flows in both directions when installed in a system, then the test should be conducted with flow in both directions. Following the above tests, the component may be flushed with fuel to loosen contaminants, but it may not be disassembled for cleaning. The component should satisfy a functional test, pressure drop test, and leakage test in accordance with the component detailed specification. See MAP 749 for related test procedures.

Reference SAE AIR 4023 and SAE AIR 4246 for test procedures and contaminants for engine component testing.

E.3.4.5.1.3.1 Fuel system icing continuous operation.

The fuel subsystem shall be so designed that icing will not adversely affect system operation.

REQUIREMENT RATIONALE (3.4.5.1.3.1)

The fuel subsystem must demonstrate acceptable performance under icing conditions. Aviation fuel contains an amount of dissolved water which can be released as free water as fuel temperature drops. If the temperature drops low enough ice crystals can form and collect on inlet screens, valves, and filters which can stop or slow fuel transfer and cause fuel distribution problems.

REQUIREMENT GUIDANCE (3.4.5.1.3.1)

The ability of the fuel subsystem to operate in conditions which could lead to fuel icing should be demonstrated.

REQUIREMENT LESSONS LEARNED (3.4.5.1.3.1)

The saturation level of aviation fuel can generally be correlated to ambient temperature; that is, aviation fuel at 80°F would have a total water content of 80 parts per million (ppm). As the fuel temperature drops, the amount of total water which can be entrained drops and the release of free water droplets occurscan come from the fuel. For example, cooling the fuel to 50°F would result in a new saturation limit of 50 ppm and 30 ppm free water would be generated. An air vehicle which receives fuel under warm ambient conditions and is then exposed to cold temperatures encountered during high altitude flight would see an increase in free water. If temperatures are low enough, ice crystals can form in the fuel and begin to block filters, screens, and other small passages. At +15°F, water solubility is only ~20 ppm; dissolved water can precipitate under typical flight temperatures. Potentially more important is total water expected on-board aircraft. Expected total water content depends on maintenance efficiency, flight and ground-time history, etc.

E.4.4.5.1.3.1 Fuel system icing continuous operation.

Fuel subsystem performance with water saturated fuel and under icing conditions shall be demonstrated by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.1.3.1)

The verification of fuel system operation should be demonstrated to ensure safety-of-flight conditions are met.

VERIFICATION GUIDANCE (4.4.5.1.3.1)

TBS should be filled in with system level tests at 0°F and the worst-case temperature encountered in flight is as follows:

Fuel should be saturated to 80 ppm to 90 ppm total water (Coordinating Research Council, Inc. Document Number 530 Aviation Fuel Properties, Section 2.11 and Figure 47) and tested at 0°F, and at the worse-case temperature encountered in flight). Test duration should be equivalent to one design mission including one in-flight aerial refueling (if required by air vehicle design) or a minimum of 3 hours, which ever is greater.

Tests of the fuel subsystem should be conducted to demonstrate satisfactory operation for the mission duration plus one in-flight aerial refueling (if the air vehicle is equipped with this is capability).

Systems and components should operate under normal system feed and transfer conditions (cycles and flow rates) for the temperatures specified below. Depending on component to be evaluated, operation for 3 hours at 80 ppm total water with typical operating flow rate may not provide sufficient total mass of water to fail component/filter, etc. Thought should be given to test component and implications of operating variables.

a. Fuel system tests. Tests on fuel systems should be conducted at 0° F and -40° F (or lowest design operational fuel temperature). All surfaces of fuel system components in contact with the fuel should be at or below the normal surface temperatures which will be encountered in operational use.

b. Test fuel. Testing should be conducted using the primary fuel of the procuring activity, JP-5 or JP-8. The fuel used should not contain any anti-icing additive. Care must be taken when results from this type of operation to that with a FSII are compared.

c. Procedure. The tests should be conducted with conditioned fuel as follows: Conditioning procedure for saturated fuel. (Figure of test set up can be provided as an example of an icing test rig):

1. Fuel should be at 80° F to 90° F. If the ambient temperature of the fuel does not meet the above requirement, circulate the fuel from the storage tank through a heat exchanger and back to the storage tank until the fuel has been heated to between 80°F and 90°F.

2. Establish a fuel flow from the storage tank through a transfer pump returning to the storage tank by way of a by-pass around the filter separator.

3. With flow established through the storage tank, atomize one (1) gallon of water per 1,000 gallons of fuel at a rate of approximately 50 cc per minute.

4. After all water has been atomized into the fuel in the storage tank continue circulation for approximately five (5) minutes. However, longer time may be required to saturate fuel fully and obtain a homogeneous mixture.

5. Close the bypass valve and direct the fuel flow through the filter separator to remove the excess water. Connect the outlet of the filter separator to the inlet of the test tank and fuel the test tank to the desired test volume. This may require several passes through the separator—especially if FSII was previously used.

6. Establish a circulation of the fuel in the test tank. Fuel circulation should be from the test tank through a cooling heat exchanger and back into the test tank. Actual cooling of the fuel should not be initiated at this time.

   Note: Circulation may be accomplished either by using the air vehicle fuel boost pump(s) or a separate circulating pump. If the air vehicle fuel boost pump(s) is (are) used to circulate the fuel, provisions should be included to isolate the cooling heat exchanger and associated plumbing from the air vehicle system during test.

7. Obtain fuel samples from three points in the test tank and analyze them using the Karl-Fischer method. The average quantity of total water from the three samples should contain between 60 ppm and 80 ppm (Coordinating Research Council, Inc. Document Number 530 Aviation Fuel Properties, Section 2.11 and Figure 47).

8. Utilizing the circulation through the cooling heat exchanger, cool the fuel in the test tank to the test temperature at a rate determined by the actual fuel cooling rate for the air vehicle. The fuel will be recirculated and agitated throughout the cool-down process and the final test will be conducted at steady-state. SAE ARP 1401A provides further details on testing.

9. While cooling the fuel in the test tank to the test temperature, obtain a single sample every 30 minutes from an in-line sampling point located in the cooling circuit plumbing and analyze it using the Karl-Fischer method. The total water content of the sample should be between 60 ppm and 80 ppm. Laboratory testing has indicated that as soon as the cooling begins, this measurement is for indication only since dissolved water will precipitate and there is no assurance a homogeneous mixture will be sampled at any given point in time.

10. Terminate the circulation through the cooling heat exchanger. This may require a portion of the flow to be bypassed back to the conditioning tank to maintain suspension

of water/homogeneity within the fuel. A cooling capacity may need to be retained to prevent fuel warming during test period. Control/maintenance of temperature of test component may also be important.

11. Run the test.
12. While running the test, obtain a single sample every 30 minutes and at the completion of the test from an in-line sampling point located in the test circuit plumbing and analyze it using the Karl-Fischer method. The total water content of the sample should be between 60 ppm and 80 ppm (for indication only, refer to Step 9.)

VERIFICATION LESSONS LEARNED (4.4.5.1.3.1)

AFRL/RZTG, US Air Force Fuels Research Lab, Wright Patterson AFB, OH, has conducted extensive testing of fuel system icing tests and is a good source for detailed lessons learned.

E.3.4.5.1.4 Fuel temperatures.

The fuel subsystem shall operate with fuel temperatures of __(TBS 1)__ minimum and __(TBS 2)__ maximum. The fuel subsystem shall not be damaged by ambient temperatures of __(TBS 3)__ minimum to __(TBS 4)__ maximum.

REQUIREMENT RATIONALE (3.4.5.1.4)

Even though thermal analysis can predict slightly different component temperatures for different locations within the air vehicle, a standardized temperature range is recommended for component design and test. Exceptions to the standard range should be handled on an individual component basis. For components which are impacted because the standard range is too severe, the temperature range can be moderated. For components which must operate outside of the standard range, the extreme temperatures must be used.

REQUIREMENT GUIDANCE (3.4.5.1.4)

TBS 1 through TBS 4 should be filled in with consideration given to table E-II. The fuel subsystem should be designed to operate in steady state conditions throughout the temperature range shown in table E-II.

TABLE E-II. Temperature environment.

	Fuel Temperature		Ambient Air Temperature	
	TBS 1	TBS 2	TBS 3	TBS 4
	Minimum Temp	Maxium Temp	Minimum Temp	Maxium Temp
Class I Fuel system which is not affected by fuel heating (1)	-65 deg F (1)	+135 deg F	-65 deg F operating -80 deg F non-operating	+160 deg F
Class II Fuel system with aerodynamic heating or when fuel is used as a heat sink	-65 deg F (1)	+175 deg F * * Max fuel temp as determined by engineering design analysis	-65 deg F operating -80 deg F non-operating	Max ambient temp as determined by engineering design analysis

(1) Due to location in hot compartments, the temperature requirement for some components in a class I fuel system may exceed the temperatures specified. These components shall be identified and the maximum temperature specified.

REQUIREMENT LESSONS LEARNED (3.4.5.1.4)

A standard environmental temperature range should be derived from the fuel subsystem design. Air vehicles typically have been designed to operate with fuel temperatures of -65 to +135°F and to withstand operating temperatures of -80 to -65°F and 135 to 170°F. Fuel operating temperatures higher than 135°F can be encountered with supersonic air vehicles, or air vehicles which use the fuel as a heat sink.

For elastomeric materials, time, as well as temperature, is pertinent. Intermittent exposure to high temperatures can be tolerated. A mission temperature and time profile should be used for design with elastomeric materials.

E.4.4.5.1.4 Fuel temperatures.

The effects of fuel and ambient temperature extremes shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.1.4)

Natural and induced environmental temperatures can affect the performance and durability of the fuel subsystem components.

VERIFICATION GUIDANCE (4.4.5.1.4)

TBS: The effects of fuel and ambient temperature extremes should be verified by analysis, component tests, and simulator tests, and aircraft tests.

The air vehicle fuel subsystem should be evaluated to ensure that icing does not adversely affect the operation of the air vehicle fuel system or the fuel system components' operation to include pumps, valves, filters, and screens. All fuel subsystem components' surface that are in contact with fuel should be at, or below, the normal surface temperatures that will be encountered in operational use.

VERIFICATION LESSONS LEARNED (4.4.5.1.4)

Some unmanned air vehicles have missions that include long durations at high altitudes. Additionally, next generation aircraft are using fuel to cool a greater number of components and subsystems, such as avionics, ECS, generators, engine components, etc. These increased thermal loads on and engine hot fuel recirculation configurations development air vehicles are creating induced environments that significantly increase the high temperature requirements of fuel subsystem components.

E.3.4.5.1.5 Proof pressures.

The fuel subsystem shall withstand repeated proof pressure applications without degradation in performance, failure, permanent deformation, or external leakage. No single failure in the system shall result in exceedance of proof pressure. The subsystem proof pressures shall be:

a. Engine feed proof pressure shall be __(TBS 1)__.

b. Fuel transfer proof pressure shall be __(TBS 2)__.

c. Refueling proof pressure shall be __(TBS 3)__.

d. Internal tanks proof pressure shall be __(TBS 4)__.

e. External tanks proof pressure shall be __(TBS 5)__.

f. Vents proof pressure shall be __(TBS 6)__.

REQUIREMENT RATIONALE (3.4.5.1.5)

A factor of safety for the maximum operating pressure of tubing and components must be specified. This is customarily done by specifying a proof pressure and a burst pressure in relation to the maximum operating pressure.

REQUIREMENT GUIDANCE (3.4.5.1.5)

TBS 1 through 6 should be filled in with their proper values with consideration given to the following:

a. Engine feed. The following should be a minimum requirement for engine feed systems using tank mounted boost pumps feeding to the engine fuel pumps. The engine feed system should be capable of withstanding a proof pressure of 2 times the maximum operating pressure without failure or distortion, a burst pressure of 1.5 times the proof pressure without rupture and a negative pressure of one atmosphere (14.7 psi) without air leakage into the system or collapse or damage of the components.

b. & c. Fuel transfer. & Pressure refueling. The pressure refueling subsystem should be capable of withstanding a proof pressure of 2 times the maximum operating pressure.

d. & e. Tank pressure safety factors. The fuel tanks should have a proof pressure capability as specified in JSSG-2006, Structures Joint Services Specification Guide.

f. Vent lines. Collapse pressure on vent lines running through tanks exposed to hydrostatic fuel heads due to air vehicle loads.

REQUIREMENT LESSONS LEARNED (3.4.5.1.5)

The following criteria were established by the pressurization paragraph in AFGS-87221 for any structural pressure vessel on an air vehicle.

The pressure differential between pressurized portions of the structure (including fuel tanks) and the atmosphere should be:

a. 1.33 times the maximum attainable pressure combined with one "g" flight loads, but not applicable to those pressure vessels which incorporate design features that require dual failures to exceed normal operating pressure.

b. 1.0 times the most negative and the most positive pressure attainable combined with maximum flight loads.

c. 1.33 times the maximum attainable pressure combined with the loads due to ground pressurization.

d. In order to define the total tank structural design criteria, the pressure criteria must be combined with applicable flight loads including loads from fuel slosh. Fuel tank pressurization is generally not necessary at lower air vehicle altitudes. If the fuel tank pressurization activation is delayed until the air vehicle is at higher altitudes, the impact of combining pressure loads with gust loads is minimized.

E.4.4.5.1.5 Proof pressures.

The ability of the fuel subsystem to withstand repeated sustained and repeated proof pressure applications without degradation in performance, failure, permanent deformation or external leakage shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.1.5)

The ability of the system to withstand repeated sustained and repeated proof pressure application should be determineddemonstrated.

VERIFICATION GUIDANCE (4.4.5.1.5)

TBS: The proof pressure capability of the entire fuel subsystem should be verified by analysis, component test, fuel system test rig, and installed system pressure tests prior to first flight, and as part of each air vehicle's acceptance test procedure.

The fuel tank proof pressure should be verified by analysis and ground tests on each fuel tank of each air vehicle.

The proof pressure capability of the refueling system should be verified by analysis and system pressure tests on an engineering test model of the system, and a pressure test on each air vehicle prior to acceptance.

VERIFICATION LESSONS LEARNED (4.4.5.1.5)

Proof pressure capability is an important strength consideration. Pressure transients can occur during normal or failure conditionmode operations. The B-2 and C-17 air vehicles experienced high pressure transients during aerial refueling that was not predicted. Trying to design refuel systems that maintain refuel surge pressures at or below normal operating pressures is unreliable, costly and results in a heavier total design solution. Having a proof pressure capability permits fuel subsystems to withstand pressure transients without permanent damage.

E.3.4.5.1.6 Burst pressure.

The fuel subsystem shall withstand burst pressure application without external leakage. The fuel subsystem burst pressures shall be:

a. Engine feed burst pressure shall be __(TBS 1)__.

b. Fuel transfer burst pressure shall be __(TBS 2)__.

c. Refueling burst pressure shall be __(TBS 3)__.

d. Internal tanks burst pressure shall be __(TBS 4)__.

e. External tanks burst pressure shall be __(TBS 5)__.

f. Vents shall be __(TBS 6)__.

REQUIREMENT RATIONALE (3.4.5.1.6)

The burst pressure requirement of the fuel subsystem should be defined at a level that will assure a sufficiently high margin of safety.

REQUIREMENT GUIDANCE (3.4.5.1.6)

TBS 1 through 6 should be filled in with their appropriate values, with consideration given to the following:

a. The fuel subsystem should be capable of withstanding a burst pressure of 1.5 times the proof pressure of the subsystem.

b. The fuel tanks should have a burst pressure capability of 1.5 times the proof pressure as defined in JSSG-2006, Structures Joint Service Specification Guide.

The pressure vessel may leak or lose function at burst pressure, but should not rupture or create shrapnel.

REQUIREMENT LESSONS LEARNED (3.4.5.1.6)

Fast closing valves can create high pressure transients and create high pressure spikes. These transients are valid pressure conditions to consider.

E.4.4.5.1.6 Burst pressure.

The ability of the fuel subsystem to withstand burst pressure application without external leakage shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.1.6)

Verification of burst pressures should be considered safety critical.

VERIFICATION GUIDANCE (4.4.5.1.6)

TBS should be filled in with consideration given to the following:

a. Burst pressure capability should be verified by component tests of every component in the fuel subsystem.

b. The burst pressure capability of the fuel subsystem should be verified by analysis and component tests.

c. The burst pressure capability should be verified by testing on at least one tank that is considered to be the most critical on a structural test article. The remaining tanks burst pressure capability should be verified by analysis.

VERIFICATION LESSONS LEARNED (4.4.5.1.6)

The B-2 and C-17 air vehicles experienced high pressure transients in operational vehicles that were not identified during development. Burst capability provided a margin of safety for these unknown pressure conditions.

E.3.4.5.1.7 Surge pressure.

Surge pressure shall not exceed the associated proof pressure of the fuel subsystem.

REQUIREMENT RATIONALE (3.4.5.1.7)

Surge pressure must be limited to ensure pressures do not exceed the system pressure capability. Surge pressures could occur when refueling valves on the air vehicle are closed and during rapid power reduction. Stopping a column of moving fuel can result in a pressure wave being generated within the system which would be considerably higher than the steady state pressure during flow conditions. The maximum allowable values for surge pressure should be specified to maintain the required margin of safety of the system.

REQUIREMENT GUIDANCE (3.4.5.1.7)

Surge pressures should not exceed proof pressure of the fuel subsystem specified in E.3.4.5.1.5, which states the proof pressure is "2 times the maximum operating pressure." However, if observed surge pressures are greater than 2 times the operating pressure limit, the system and component must be qualified to the observed surge pressure. Qualification includes standard proof pressure criteria of no leakage or permanent deformation.

One atmosphere negative pressure should not collapse the line.

The frequency of pressure pulses should be evaluated for fatigue of tubing and components.

The rate of closure of control (including refuel, transfer and engine feed) refuel valves should not cause surge pressures in excess of the proof pressure of the system.

Surge pressures can occur during ground and aerial refueling, and any other time the fuel subsystem is operating.

REQUIREMENT LESSONS LEARNED (3.4.5.1.7)

Maximum surge pressure for refueling systems. The prediction of the magnitude of pressure surges in air vehicle fuel subsystems due to high rate fueling and fuel transfer is important in designing systems which will not exceed the specified maximum proof pressure and also to determine limit pressures so that lightweight systems can be designed. The analysis of surge pressures for a particular fuel subsystem should include the air vehicle system and the characteristics of the piping system external to the air vehicle. This should include ground trucks, ground hydrant systems, and aerial refueling systems. The number of predicted pressure cycles should be used to determine the fatigue capability of the tubing.

Pressure surge is a transient flow and has a flow rate that varies rapidly with time. Any operation which causes a sudden change in flow may initiate a pressure surge wave through the fuel subsystem. Typical operations in fuel subsystems which should be analyzed for surge pressure development include:

a. Closing of fuel shut-off valves causing fluid deceleration.

b. Opening and closing of multiple fuel valves simultaneously that occur during system operation.

c. Closing of check valves. Check valves generally do not have a controlled closure rate, making them prime sources to generate surge pressures.

d. Parallel operation of fuel pumps.

e. Starting and stopping of fuel pumps.

If fluid was flowing in a pipe and a pipe valve that closed instantaneously, the fluid immediately next to the valve would have its velocity reduced to zero. If the fluid was incompressible and the pipe wall was inelastic, then the fluid in the entire pipe would be brought to rest immediately and the pressure would be infinite. However, fluids are compressible and tube walls elastic; therefore, the pressure rise is not infinite and the pressure manifests itself as a wave which starts at the valve and travels up and down the pipe reflecting off the ends.

A method for predicting surge pressure in air vehicles and a method for controlling surge pressure by the control of valve closure rates is presented in NAVAIR 06-5-504 (Coordinating Research Council Aviation Handbook – Fuels & Fuel Systems). The analysis has never been completely correlated with a laboratory test program or an air vehicle fuel subsystem and is therefore presented only as an approximate solution. Reference SAE ARP1665 and SAE AS1284 for additional information.

Surge pressures in engine feed and transfer systems. Surge pressures as high as 400 psig have been observed in engine feed lines as a result of stopping fuel flow during rapid power reduction. These surge pressures have always required some air vehicle modifications to reduce the surge or to strengthen the line. In transfer systems, surges are caused by level control valves closure. In the F-4 air vehicle, the transfer level control valve had a very narrow deadband of operation; meaning it opened to allow a small fuel transfer and then closed. At cruise power, the valve opened and closed about ten times per minute resulting in fatigue failure of the transfer pumps. Although the peak pressure pulse was only about 30 psig, each pulse resulted in 5 to 10 bending cycles for the impeller vanes causing early fatigue failure. The cyclic pressure was prevented by changing the valve so that the valve would not reopen until the fuel level was reduced considerably.

Ground operation during which a running engine is shutdown by closing the airframe mounted feed line shut-off valve will result in high negative pressures being imposed upon the feed line downstream of the closed valve. This line should be designed to withstand a full, one atmosphere, negative pressure without failure.

A USAF bomber incorporates pilot operated level control valves (LCV) to control fuel into a tank. There are eight tanks on each air vehicle and two LCVs per tank. Operation of a LCV is performed by commanding a solenoid to open a flow path from the LCV controller into the tank. This flow path allows for a pressure difference across a non metallic diaphragm, which provides an axial force to move a poppet allowing flow into a tank. The pressure on the diaphragm is provided by supply pressure from the refuel manifold and is controlled by a metering orifice. The manifold is drained to capture any residual fuel thus increasing usable fuel. Draining of the manifold is a source of air in the system. The design is such, that whenever air is present in the diaphragm, back pressure through the metering orifice is reduced since the orifice was originally sized for JP-8 properties. As the air in the manifold is cleared and fuel flow is established against the poppet assembly, the force to close the LCV is increased because of the change in density between air and fuel. However, the air in the controller and diaphragm area has not cleared and can not provide adequate force to maintain an open position of the poppet. This change in flow characteristics causes rapid closure of the poppet generating high transient pressure spikes. The spikes were estimated to be between 650 and 700 psig. The bomber fuel system was designed for nominal, proof and burst requirements of 120, 240 and 360 psig respectively. Results of high surge pressure on the fuel subsystem:

a. Ruptured diaphragm--failure of LCV to operate.

b. Refuel subsystem design limits exceeded. The high surge pressure (Over 650 psig) propagated through part of the refuel subsystem, before attenuating, causing potential static and durability problems with tubing and component.

c. Vent Subsystem was not designed for a ruptured manifold during ground or aerial refueling. A Failure Modes and Effects Criticality Analysis (FMECA) was created for a ruptured refuel manifold component and determined the failure would result in unrestricted flow into a tank that may exceed the pressure/flow capability of the vent system. Such a condition would result in fuel tank pressures that would exceed limit load and ultimate load of the fuel tanks.

d. Corrective action:

    1. Ruptured diaphragm: The contour of the poppet assembly was redesigned to allow a slower transition from full flow to no flow eliminating the rapid valve closure condition. Additionally, a pressure relief valve was incorporated into the housing limiting any pressure transients to 95 psig.

2. Refuel subsystem: Analysis was conducted to determine which components experienced pressures transients above the design limit. These parts were removed and replaced with new parts.
3. Vent system undersize: Orifices were installed in the ground and aerial legs of the refuel manifold to limit the pressure and flow into a tank under failure conditions equal to the fuel tank structural capability.

Ensure two-phase flow is considered as part of system pressure transient analysis.

Ensure fuel system components are designed to a duty cycle that accounts for all pressure transient conditions. Adequate residual strength should remain at the end of the expected life to withstand one worst case pressure transient.

Ensure vent and refuel subsystems are designed to prevent fuel tank damage and rupture under worst case fuel flow into a tank.

E.4.4.5.1.7 Surge pressure.

Surge pressure levels in the fuel subsystem shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.1.7)

Surge pressures are common occurrences in fuel subsystems.

VERIFICATION GUIDANCE (4.4.5.1.7)

TBS: Surge pressure levels should be verified by analyses, component tests, fuel system test rig, and instrumented aircraft ground and flight tests. The surge pressures should be monitored during flight test for further verification.

VERIFICATION LESSONS LEARNED (4.4.5.1.7)

The ability to conduct surge demonstrations on an air vehicle is very limited due to inability to obtain sufficient instrumentation in the right location. Therefore, surge pressure testing can best be conducted on an engineering development fuel subsystem where more instrumentation can be installed and test conditions can be better controlled. Also, danger of damaging an expensive test air vehicle is eliminated. After completion of testing on the modeltest rig, a limited demonstration using nominal conditions, and key instrumentation locations can be conducted on an air vehicle.

Surge pressure in the engine feed subsystem can best be verified under actual flight test conditions since it is very difficult to simulate engine response on a simulator. Responsive instrumentation must be used to measure the surge. Pressure transducers of the strain gauge type with a response on the order of ten milliseconds have been used with a galvanometer lightbeam oscillograph of like response. Slow response instrumentation will not measure surge pressure adequately. Reference SAE ARP1665 for recommendations on surge pressure testing.

E.3.4.5.1.8 Thermal expansion relief.

Positive and negative pressure relief for fuel thermal expansion and contraction shall be provided for all closed plumbing segments of the fuel system.

REQUIREMENT RATIONALE (3.4.5.1.8)

Thermal expansion of fluid in a fixed volume can cause extreme pressures capable of bursting the system and rupturing fuel system components and plumbing. Additionally, fuel spills can create a hazardous condition for maintenance personnel as well as creating an environmental cleanup problem.

REQUIREMENT GUIDANCE (3.4.5.1.8)

Thermal expansion pressure relief should be required for all closed plumbing segments where positive and negative pressures greater in excess of than the operating pressure limits could result. Negative pressure relief should also be considered.

REQUIREMENT LESSONS LEARNED (3.4.5.1.8)

All segments of a system, such as a fuel volume enclosed between two valves, or a tank compartment closed by a shut-off valve or a check valve, should be reviewed to insure pressures due to expanding and contracting fuel can be relieved.

E.4.4.5.1.8 Thermal expansion relief.

The incorporation of required thermal relief provisions shall be verified __(TBS)__.

VERIFICATION RATIONALE (4.4.5.1.8)

Generally thermal expansion is verified by fuel subsystem analysis, and component qualification testing. However, hot weather deployments or tests in climatic chambers should be considered if there are small margin levels for tank expansion.

VERIFICATION GUIDANCE (4.4.5.1.8)

TBS: The incorporation of required thermal relief provisions should be verified by analysis, inspection, and component and system level testing.

VERIFICATION LESSONS LEARNED (4.4.5.1.8)

Thermal management requirements are creating higher temperature delta conditions for the fuel subsystems. Thermal expansion relief capability is necessary to prevent rupture of pressure vessels.

Be sure to evaluate both normal and extreme potential pressure levels (including fuel head heights). When setting thermal relief values for valves, unacceptable fuel migration can result if thermal relief values are set too low. Thermal relief capability should prevent damage to the fuel system without creating unacceptable system characteristics, such as uncommanded fuel migration from tank to tank.

E.3.4.5.1.9 External fuel leakage.

There shall be no external fuel leakage from the fuel subsystem during normal operating conditions including ground (a shore and aboard ship) and in-flight refueling on land and aboard ship.

REQUIREMENT RATIONALE (3.4.5.1.9)

External leakage of fuel is always a matter of concern. Although external leakage may not always be a safety hazard, the presence of fuel odor will cause concern, and may result in unnecessary maintenance activity to troubleshoot the source. Additionally, fuel can damage other materials such as asphalt parking flightline aprons, and result in very costly environmental cleanup activities. Fuel leakage limits for flight operations are specified in NAVAIR 01-1A-35, Work Package 11.

REQUIREMENT GUIDANCE (3.4.5.1.9)

External leakage should be explicitly prohibited.

REQUIREMENT LESSONS LEARNED (3.4.5.1.9)

The decrease in aromatic content resulted in fuel leakage due to changes in seal swell during conversion from JP-4 to JP-8. During early fuel seal design activity and material selection, consideration should be given to new alternate fuels being developed that have a potential of becoming an operational fuel requirement for the fuel system being developed.

E.4.4.5.1.9 External fuel leakage.

External leakage shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.1.9)

Ensure durability requirements based on required, expected operational useful life of the fuel system (which should be related to the specified useful life of the air vehicle) are included in fuel sealing requirements.

VERIFICATION GUIDANCE (4.4.5.1.9)

TBS: External leakage prevention should be verified by analysis, component testing, manufacture testing, (i.e., production tests, acceptance tests, etc.) and inspection during the ground and flight tests program.

VERIFICATION LESSONS LEARNED (4.4.5.1.9)

Fuel leaks can be a major source of creating non-mission-capable conditions for operational air vehicles. Adequate verification during development can avoid problems for deployed systems.

E.3.4.5.1.10 Compartment drains and fuel leakage path control.

Compartment fuel drainage, including aerial refueling receptacle installation drainage and probe bay drainage, and complete fuel leakage paths shall be provided to remove water and fuel or(due to external leaksage), and any other fluids to a safe location outside of the air vehicle under ground and flight conditions.

REQUIREMENT RATIONALE (3.4.5.1.10)

Consideration must be given to the removal of water and fuel leakage from compartments adjacent to fuel tanks and compartments which contain fuel lines or components in order to prevent the accumulation of fluids within the air vehicle. Accumulating fluids can cause damage to fuel cells and surrounding components and equipment due to corrosion or material incompatibility. This could create hazardous conditions due to fuel vapor concentrations.

REQUIREMENT GUIDANCE (3.4.5.1.10)

Compartment fuel drains and leaakage paths should be installed to remove water and fuel (present for any reason, but primarily resulting from spillage or leaks) to a safe location outside the air vehicle. No drained or leaked fuel should be allowed to collect on the air vehicle, other than in the intended onboard containers. Leakage paths should be coordinated with ventilation air so that the flow is in the same direction, to increase the overboard movement of leaking fuel and vapor.

All areas surrounding fuel tanks should be drained to:

a. Remove the fire hazard resulting from any fuel spillage or leakage.
b. Prevent prolonged contact of fuel with external tank surfaces, which could result in outside exterior activation of nonmetallic fuel cells. Consideration should be given to ensure the drainage openings will remain open at all times throughout the useful life of the air vehicle.

All compartments containing fuel components, including tank cavities, should be drained. Drains should be arranged so that no trapped fluid can accumulate at any place in a compartment.

In the past, minimum drain hole or tube sizes were $^{3}/_{8}$-inch diameter, except for self-sealing tank cavity drains which were ½ inch.

General considerations for drain systems should include:

a. Drain lines should be as short as possible. There should be no traps in the drain line where water can collect and freeze.
b. Fuel leakage drain path outlet drains will not be interconnected to fluid seal drains that are intended to drain a fluid during normal operation of the air vehicle. In general, drains should not be inter-connected, and their locations should be well marked so that the drains can be easily found by personnel.
c. Operation of drain valves should be automatic and simple.
d. Fuel should not drain on or near any system that could result in a hazard (i.e., landing gear where ignition could result from hot brakes, auxiliary power system exhausts, electronics, etc).

e. Drains should not be located forward of air scoops or openings where fuel can enter the air vehicle in flight.

f. Drain size configuration may need to consider Low Observable (LO) design requirements.

REQUIREMENT LESSONS LEARNED (3.4.5.1.10)

(TBD)

E.4.4.5.1.10 Compartment drains.

The presence and suitability of compartment drains shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.1.10)

Drainage provisions should be verified on the air vehicle to ensure proper compliance with the design requirements.

VERIFICATION GUIDANCE (4.4.5.1.10)

TBS: The presence and suitability of compartment drains should be verified by analysis, inspection, and ground and flight test demonstration, as necessary to verify adequate leakage path control, including flow capacity.

VERIFICATION LESSONS LEARNED (4.4.5.1.10)

A fluid dye test can be conducted from all drain line discharge points where there may be a possibility of fuel discharge in flight to determine compliance with the drainage design requirements. The test should be repeated with flaps extended, bomb bay open, and at the maximum angle of attack experienced during flight, landing, take off (or catapult and arrestment) for each source which may be influenced by changes in the air flow and pressure distribution due to such air vehicle configuration. All drains must be verified to provide positive drainage throughout all flight regimes. Previous Programs have had issues with no drainage due to high pressures at the drain outlet.

A low-cost flight test was conducted on the F-16 aerial refuel cavity drain. A balloon, filled with poster paint, was installed on the receptacle in a manner so that it ruptured when the slipway opened in flight. The poster paint flowed through the drain and marked the exterior of the air vehicle. The markings showed that the drainage did not enter an engine compartment ventilation air scoop.

E.3.4.5.1.11 Electrical fault and explosive atmosphere.

All fuel subsystem components located in an explosive atmosphere flammable zone shall be capable of operating without initiating an explosion, including under electrical fault conditions.

REQUIREMENT RATIONALE (3.4.5.1.11)

Freedom from explosive hazard is a safety requirement required for all components exposed to an explosive atmosphere located in a flammable zone.

REQUIREMENT GUIDANCE (3.4.5.1.11)

In a flammable zone, explosive atmosphere is ever present or should be assumed to be present under all operating modes unless special equipment or techniques are applied to ensure freedom from explosive atmosphere.

Electrically-operated components are a prime source of sparks due to normal operation such as occurs with switch or relay contacts or due to internal faults. Component housings should be capable of containing any internal electrical fault without failure of the housing. No internal explosion should propagate to the outside of the housing or generate an unsafe condition. Where possible, electrical equipment should be isolated from the fuel to minimize the possibility of fuel leakage and fuel vapor coming into contact with electrical equipment. A second aspect is the need for adequate electrical bonding between components and structure such that fault currents flowing across bonding interfaces do not cause arcing, sparking, or hot spots. Part of this concern is the possibility of safety wire or other debris being in parallel with the intended bond path and sharing the fault current. Past testing has shown that limiting voltages across bonds for available fault currents to 0.1 volts should prevent explosions. The required bonding resistance should be calculated by dividing the available fault current into 0.1 volts. MIL-STD-464A can be used as a reference to determine bonding requirements.

There are two design approaches follow to design equipment to operate safely within an explosive atmosphere:

1) Intrinsically Safe – Where possible (e.g., fuel quantity gauging system components), the best approach for design of equipment which may operate within an explosive atmosphere is to have an intrinsically safe design. An intrinsically safe design is one in which the energy present is not adequate to ignite an explosive hydrocarbon/air mixture. The typical design value for verification of a design as intrinsically safe is maximum energy of less than or equal to 0.02 millijoules. This is approximate an order of magnitude below the minimum ignition energy required to ignite flammable hydrocarbon vapor in air.

2) Explosive Atmosphere Compatibility – This approach verifies the equipment is capable of operating in an explosive atmosphere without igniting the vapor. There are three subsets to this general approach as follow:
    a. Verify the system is capable of operating within an explosive atmosphere without igniting the explosive mixture. (Reference MIL-STD-810, Method 511, Procedure I [Explosive Atmosphere].)
    b. Verify the electrical elements of the equipment are isolated within a housing which will prevent any ignition of explosive vapor within that housing from

propagating outside of the housing. (Reference MIL-STD-810, Method 511, Procedure II [Explosion Containment].)

c. Verify the electrical elements of the equipment are isolated within a hermetically sealed compartment, such that explosive vapor cannot reach the electrical elements.

Refer to appendix G, Fire and Explosion Hazard Protection, for further guidance on requirements for components located in flammable zones.

REQUIREMENT LESSONS LEARNED (3.4.5.1.11)

For components which must contain an internal fault, adequate clearance must be provided within the housing to insure an arc will not burn a hole or create a hot spot on the housing if fault occurs. Dry bays adjacent to fuel tanks are considered flammable leakage zones. Even though these areas are not intended to contain fuel, leaks can occur; therefore, components installed in these areas should be capable of operating in an explosive atmosphere. Qualification criteria for equipment located in a flammable leakage zone is different than equipment located in flammable zones. Equipment in a flammable leakage zone should produce an ignition source under normal operating conditions. Equipment in a flammable zone should not produce an ignition source under normal and failure conditions.

One area of concern is the clearance between the stator and the housing for pump electrical motors. The F-111 used a separate “slow blow” circuit breaker for each of the three phases that powered the fuel boost pumps. During ground maintenance, the circuit breakers were pulled to prevent the pump from running. Occasionally, a single breaker would accidentally be pushed in for a short time. This caused one phase in the pump winding to overheat. The pump would operate after the damage occurred but later there would be an arc from the winding to the housing. The slow blow circuit breakers permitted the arc to be sustained long enough to burn a hole in the housing. Test showed that the arc would not occur if the clearance between the housing and the stator wires was increased from .030 to .060. The maintenance procedures were also changed to require collars on the circuit breakers when they are pulled.

E.4.4.5.1.11 Electrical fault and explosive atmosphere.

The ability of the fuel subsystem components to operate, including fail-safe condition, in explosive atmosphere without initiating an explosion shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.1.11)

The capability of components to operate in an explosive atmosphere should be verified prior air vehicle installation since this is a safety requirement.

VERIFICATION GUIDANCE (4.4.5.1.11)

TBS: The capability of components to operate in an explosive atmosphere should be verified by analysis of the electrical circuit if the approach selected is intrinsically safe electrical circuit design and by component tests if the approach selected is explosive atmosphere compatibility. Electrical bonding resistance should be verified by test using an electrical bonding meter.

TBS: The capability of components to operate in an explosive atmosphere should be verified by component tests. Electrical bonding resistance should be verified by test using an electrical bonding meter.

Explosive atmosphere testing should be conducted in accordance with MIL-STD-810, Method 511.2, Procedure I or II, as applicable. Procedure I is for components (sealed or unsealed) operating in a fuel vapor laden potential fire zone environment without igniting the environment. Procedure II is intended for determining the ability of equipment cases to contain an explosion or flame. If explosive atmosphere compatibility is planned to be verified via hermetic sealing of electrical elements of equipment, that hermetic seal should be verified by test in accordance with MIL-STD-883, Method 1014.

VERIFICATION LESSONS LEARNED (4.4.5.1.11)

A fire protection zone analysis is critical to determine the level of protection required for component qualification. See appendix G, Fire and Explosion Hazard Protection, for further guidance.

E.3.4.5.1.12 Failure criteria.

A single failure of a component of the fuel subsystem or any other subsystem supplying power to the fuel subsystem shall not prevent the completion of the air vehicle's primary mission. Two failures in the fuel subsystem shall not cause critical structural failure or prevent recovery of the air vehicle. __(TBS)__ are excluded from the single failure criteria.

REQUIREMENT RATIONALE (3.4.5.1.12)

The ability for the fuel subsystem to operate with single and double failure should be designed into the system.

REQUIREMENT GUIDANCE (3.4.5.1.12)

TBS: There are several situations in a system where it may not be practical to provide redundant components, redundant functions, or redundant flow paths. These items should be recognized and exempted from a strict interpretation of single failure: fuel tubing, engine feed shut-off valves, and the aerial refueling deployment mechanism are typically not redundant. Refer to MIL-STD-1798 for additional guidance on defining various system criticality levels.

REQUIREMENT LESSONS LEARNED (3.4.5.1.12)

Current fuel subsystem designs have assumed that fuel tubing does not fail and therefore should not be subjected to the single failure criteria. It is not practical to install redundant tubing in an air vehicle. In addition to the extra tubing, additional valvinges would be required to isolate each redundant branch from the other and additional sensors would be required to determine when a branch had failed. The criteria for design, installation, and test of a fuel tube must be very conservative toconsider the expected usage and environments to ensure tubing and component integrity minimize the possibility of a fuel tube failure. See MS33611 for suggested tube bend criteria and scratch tolerance.

It is not practical to provide a redundant flow path to the engine to overcome a failure of an engine shut-off valve. The engine shut-off valves are opened prior to engine start and should remain open until engine shut down. A special safety circuit should be defined to prevent the valve from moving from the selected position in the event of an electrical short on the valve. This safety circuit insures the flow path to the engine will remain open during flight.

The only solution to failure of the deployment mechanism of the aerial refueling receptacles is to provide an additional aerial refueling installation on each air vehicle. Again, this is not practical. The deployment mechanism should be designed and tested to verify a sufficient high reliability for mission completion. However, adequate integrity should be considered as part of the receptacle. Refer to MIL-STD-1798 for additional guidance on ensuring integrity of mechanical systems.

E.4.4.5.1.12 Failure criteria.

The effects of failure on the fuel subsystem shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.12)

The fuel system on a weapons system provides critical safety and mission functions.

VERIFICATION GUIDANCE (4.4.5.12)

TBS: The effects of failures on the fuel subsystem should be verified by analyses, fuel system test rig, ground test, and flight test.

VERIFICATION LESSONS LEARNED (4.4.5.12)

A failure effect demonstration test program should be conducted based upon the result of an analysis.

Testing on the fuel system test rig should demonstrate critical failure mode operation, health monitoring, and component fault isolation capability of the system. When the failure effect has been demonstrated during subsystem tests, the tests need not be repeated on the air vehicle. The failure demonstrations should be described in the failure analysis report.

E.3.4.5.1.13 Fuel plumbing.

The fuel system manufacturer shall prepare a plumbing document covering the installation of the fuel system plumbing that defines the following:

1) Tubing alignment criteria,
2) Illustration of plumbing relative to tanks, structure, or subsystem plumbing, and wiring;
3) Description and illustration of clamp types;
4) Fuel plumbing inspection criteria;
5) Special Inspection procedures, where applicable;
6) Design criteria for determining tube wall thickness;

7) Test Requirements for fuel system plumbing (design verification and build verification); and

8) __(TBS)__.

REQUIREMENT RATIONALE (3.4.5.1.13)

Installation of fuel system planning should be identified and documented to enhance system robustness and repeatability in the manufacturing process.

REQUIREMENT GUIDANCE (3.4.5.1.13)

Ideally, a program plumbing installation document will be a deliverable item under the program's contract, but should at least be available for review by the program office. This document should be updated after SDD and reviewed for each LRIP/FRP lot and following significant fuel system design changes.

(TBS): Include any items unique to the air vehicle which have not be addressed by the previously-listed items.

REQUIREMENT LESSONS LEARNED (3.4.5.1.13)

The B-1 program did not have sufficient test requirements for the fuel system plumbing during manufacture, leading to an excessive rate of fuel leaks and aircraft refusals at the completion of assembly.

E.4.4.5.1.13 Fuel plumbing.

The documentation of fuel system plumbing installation shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.1.13)

The documentation of fuel system installation must be verified.

VERIFICATION GUIDANCE (4.4.5.1.13)

(TBS): Provide the method by which the documentation will be verified. Verification should consist of inspection of the provided document.

VERIFICATION LESSONS LEARNED (4.4.5.1.13)

(TBD)

E.3.4.5.1.13.1 Fuel line support and routing.

Fuel line design and routing shall conform to SAE AS18802. Fuel lines should be adequately supported to prevent deflection beyond (TBS 1), due to internal pressures or flight maneuvers. Minimum clearance of (TBS 2) inches should be provided to prevent chafing of lines with the airframe, other lines, wiring, or components.

REQUIREMENT RATIONALE (3.4.5.1.13.1)

Fuel line support requirements must be provided to ensure that pipe bending due to induced loading and deflections/expansion due to internal pressure due not cause the pipes to contact other aircraft structure, leading to chaffing and eventual failure, causing a catastrophic fuel leak/fire hazard.

REQUIREMENT GUIDANCE (3.4.5.1.13.1)

All fuel lines should be routed in the most efficient manner to obtain maximum protection against battle damage. Where possible, fuel lines should be routed through the fuel tanks to minimize fuel losses and fire resulting from combat damage or fitment failure. Fuel lines which may be damaged due to maintenance, cargo handling, personnel traffic, or normal aircraft use should be protected. Access for maintenance and inspection of line joints of the fuel system must be provided.

TBS 1 should be acceptable deflection. Table E-III should be used to define maximum support distances; otherwise, SAE AS18802 criteria should be used. Unlined metal support clamps will not be used on metal fuel lines.

TBS 2 should minimum clearance between lines and other lines/airframe/components.

TABLE E-III. Fuel line support distance.

Tube Size (Inches)	Maximum Distance between Supports (Inches)
1 and smaller	24
1¼ to 1¾	27
2	31
2½	33
3	34½
4	37½
5 and over	40

REQUIREMENT LESSONS LEARNED (3.4.5.1.13)

(TBD)

E.4.4.5.1.13.1 Fuel line support and routing.

The adequacy of fuel line support and deflection tolerances shall be verified by _(TBS)_.

VERIFICATION RATIONALE (4.4.5.1.13.1)

This is a safety of flight requirement that necessitates rigorous verification. Fuel lines deflecting and chaffing on aircraft structure have led to numerous fuel leaks and fire incidents.

VERIFICATION GUIDANCE (4.4.5.1.13.1)

(TBS): the means by which this requirement will be verified must be provided. Static load testing on an "iron bird," as well as computer modeling of structural deflections due to flight maneuvers and tubing pressurization, should be considered.

VERIFICATION LESSONS LEARNED (4.4.5.1.13.1)

(TBD)

E.3.4.5.1.14 Subsystem isolation.

Each refueling subsystem (including any associated manifold) shall be capable of being isolated from the fuel pressure resulting from the normal operation of the air vehicle's fuel subsystem or any other refueling subsystem. For those designs where manual activation is required to provide the isolation, the manual activation shall be capable of being initiated by _(TBS)_.

REQUIREMENT RATIONALE (3.4.5.1.14)

This is an integration, operational, and safety requirement. Damage or breakage to any refueling subsystem (including any associated manifold) must not interfere with the proper operation of the air vehicle's fuel subsystem and any other refueling subsystem (including aerial) installed on the air vehicle. Fuel pressure resulting from normal operation of the air vehicle's fuel system must be isolated from the refueling subsystem(s). In addition, if the air vehicle incorporates multiple refueling subsystems, they must be isolated from each other so that damage within one subsystem will not prevent the ability to use the other subsystem(s) safely and complete the aerial refueling process successfully.

REQUIREMENT GUIDANCE (3.4.5.1.14)

TBS: Specify which crew or aircraft service support member(s) should be provided this capability.

REQUIREMENT LESSONS LEARNED (3.4.5.1.14)

Isolation has typically been accomplished by either a check valve or by a manually or motor operated control valve. If a motor operated control valve is used, consideration must be given for a manual override and access to the valve so that a single failure of the valve will not prevent the capability to refuel the air vehicle.

E.4.4.5.1.14 Subsystem isolation.

The ability to isolate each refueling subsystem from the air vehicle's fuel subsystem and any refueling subsystem shall be verified by _(TBS)_.

VERIFICATION RATIONALE (4.4.5.1.14)

It should be verified that each refueling subsystem can be isolated from the air vehicle's fuel subsystem and any other refueling subsystem to ensure that no single failure hazards are introduced to the air vehicle, that single failures do not compromise the proper operation of the air vehicle's fuel subsystem, and that single failures do not prevent the air vehicle from safely and successfully refueling from any other refueling subsystem.

VERIFICATION GUIDANCE (4.4.5.1.14)

TBS: Specify ground demonstration and test of each refueling subsystem.

VERIFICATION LESSONS LEARNED (4.4.5.1.14)

The ground demonstration should simulate failures of the various refueling subsystems to verify that one subsystem can be isolated from the other and the air vehicle's fuel subsystem. If manual activation is provided for any isolation feature, that capability should be verified along with the adequacy and accessibility of the activation method.

E.3.4.5.2 Engine feed

E.4.4.5.2 Engine feed

E.3.4.5.2.1 Engine fuel feed interface.
The interface parameters __(TBS)__ which affect engine operation shall be required between the air vehicle fuel subsystem and the engine.

REQUIREMENT RATIONALE (3.4.5.2.1)

The primary function of the fuel system is to provide fuel flow to the engine. To do this, the critical physical connection(s), and fuel pressure, temperature, and flow conditions should be defined.

REQUIREMENT GUIDANCE (3.4.5.2.1)

The required interface parameters should be specified in the engine and airframe Interface Control Document (ICD).

TBS should be filled in with the following suggested interface parameters.

a. Physical:
   1. Connection type and size
   2. Connection loads
   3. Connection location(s)
b. ICD conditions:
   1. Primary and alternate fuel(s)
   2. Temperature (Maximum, Minimum)
   3. Pressure (Maximum, Minimum)
   4. Flow rate (Maximum, Minimum)
   5. Flow rate maximum. rate of change
   6. Vapor liquid ratio (V/L) (Maximum)
   7. Fuel contamination (Type, Size, Quantity)
   8. Engine heat rejection loads

The determination of the engine fuel flow and pressure requirements involves:

The fuel subsystem should supply the required amount of fuel at the required pressures for operation of the engine throughout its complete operating range including starting and augmentation, with the following conditions on the engine:

a. Minimum fuel temperature corresponding to a fuel viscosity of 12 centistokes, to a specified maximum.

b. Fuel pressure from true vapor pressure of the fuel plus 5 psig to 50 psig (relative to the atmosphere), with a vapor liquid ratio of zero. This should be tailored and control by engine ICD.

REQUIREMENT LESSONS LEARNED (3.4.5.2.1)

During the initial years of WW II, it had been recognized that Net Positive Suction Head (NPSH), commonly used in the commercial pumping industry for single boiling point fluids, was not adequate to define the possible two-phase condition that could be generated in air vehicle fuel systems using wide boiling range hydrocarbon fuels. Hence, the Coordinating Research Council (CRC) was asked to advise on the DoD on this matter and subsequently provided a section to the CRC Handbook on Vapor Lock (January 1946 edition) which presented the means for predicting Vapor-Liquid ratios in dynamic fuel systems using hydrocarbon fuels.

Requirements for turbojet powered air vehicle that limited air vehicle fuel delivery systems to 3 and then subsequently 4 inches of mercury line drop (tank to engine inlet) at a specified flight altitude, usually 6000 feet, and at the specified engine power setting identified in the engine model specification. The objective of this requirement was to create a worst case situation, “No assistance from tank boost pumps”, at a nominal to high power setting. This led to conclude that the vapor-liquid ratio (V/L) parameter should be used as the design criterion for the condition of fuel at the air vehicle and engine interface.

The emergency “no assistance from the air vehicle boost pumps” interface fuel condition in MIL-E-5007 was established at 0.45 V/L. This value was established on the basis of the calculated V/L for a single engine fighter using high vapor pressure Aviation Gasoline at 6000 feet fuel tank altitude, 110°F fuel temperature and 4 inches of Hg line loss (tank to engine inlet), at a specified engine power level (fuel flow rate) plus a safety margin. Turbo propeller powered air vehicle specifications, usually cargo type, specified a V/L requirement of 0.30 because of the difference in performance needs. In later years the use of lower vapor pressure fuels (primarily JP-4) did ease the need for high V/L capabilities at the airframe and engine fuel system interface; however, retention of the 0.45 and 0.30 V/L values is considered justifiable for safety and return flight margins after battle damage with air vehicle power and support sub-systems inoperative.

In modern fighter air vehicle, the fuel is used as the heat sink for many of the air vehicle subsystems. In these systems, it is impractical to design for “no assistance from the air vehicle boost pumps” because the fuel temperatures in many cases are above 200°F. In these designs, adequate redundancy of pumps and power sources must be provided to prevent loss of pump operation.

E.4.4.5.2.1 Engine fuel feed interface.

The fuel subsystem engine interface shall be verified by <u>(TBS)</u>.

VERIFICATION RATIONALE (4.4.5.2.1)

Due to the safety nature of the requirement it should be verified.

VERIFICATION GUIDANCE (4.4.5.2.1)

TBS: The fuel subsystem engine interface should be verified by fuel system simulator test and air vehicle ground and flight tests.

The performance of the engine feed subsystem for normal operation should be verified by test. The following critical parameters should be defined for the test:

a. Engine power setting. - Determines the fuel flow rate.

b. Altitude range for test.

c. Maximum fuel temperature.

d. Reid vapor pressure of test fuel.

e. Fuel filter condition (if applicable) impending by-pass.

VERIFICATION LESSONS LEARNED (4.4.5.2.1)

(TBD)

E.3.4.5.2.2 Fuel availability.

Fuel shall be available to the engine(s) on an uninterrupted basis under all air vehicle ground and flight conditions including __(TBS)__.

REQUIREMENT RATIONALE (3.4.5.2.2)

The primary function of the fuel subsystem is to deliver fuel to the engine(s). The key words in the requirement are “uninterrupted” and “under all air vehicle ground and flight conditions.” The air vehicle fuel subsystem must be extremely reliable and assure that fuel is always available to power the engines, throughout any flight maneuver.

REQUIREMENT GUIDANCE (3.4.5.2.2)

Fuel availability to the engines should be required for all conditions in the air vehicle’s operational envelope and known extreme conditions.

TBS should be filled in with consideration given to the following conditions ([percent] refers to total feed tank fuel at the end of maneuver):

a. Normal ground attitude (1 percent)

b. Take off attitude including shipboard operations (2 percent)

c. Level flight attitude (landing pattern condition, low gross weight, low airspeed, low altitude) (1 percent)

d. Landing attitude (touchdown) (2 percent)

e. Maximum pitch attitude expected during climb out and landing (20 percent)

f. Maximum rate of climb with corresponding attitude (20 percent)

g. Maximum rate of dive with corresponding attitude (10 percent)

h. Maximum roll with corresponding attitude (20 percent)

i. Negative “g” conditions required by defined missions (10 seconds, maximum power, 20 percent)

j. Low or zero “g” flight required by defined missions

k. 90° zoom (20 percent)

l. 90° dive (10 percent)

Fuel flow requirements should be determined by the most critical air vehicle flight conditions which affect the sizing of lines, rating of pumps, power consumption, valves, and the general system configuration. The high speed conditions at different points in the altitude spectrum, and the maximum rate of climb at any point in the altitude envelope, should determine the critical flow requirement.

a. Negative and zero “g”. Most air vehicles experience periods of flight at negative “g”. Fighter air vehicles are typically required to endure negative “g” flight for 10 seconds at maximum afterburner (AB) fuel flow and up to 30 seconds at maximum military fuel flow. This capability has been justified for inverted flight during aerial combat and aerobatics in which air vehicles can be required to endure this condition for up to 30 seconds or more. Additionally, research and other specialized air vehicles may be required to endure periods of flight in nearly zero “g”. There has been no standard approach developed for bomber and transport air vehicles.The ten-second negative “g” requirement at the maximum engine fuel flow should be recommended for fighter type air vehicles unless or until mission analysis justifies a change. For bomber and transport air vehicles, negative “g” should only occur under emergency type conditions which are extremely difficult to predict and define.

b. Multi-engine feed independence. In multiengine air vehicles, it should be possible to cut off fuel flow to any engine without affecting the flow to the remaining engines. When the fuel flow to any engine or combination of engines is cut off, it should be possible to use fuel from any fuel feed tank and transfer tank for the remaining engine(s). A separate feed tank and separate feed lines for each engine is desirable. It may be cost effective on two engine non-combat air vehicles to use one main feed tank for both engines, but the feed systems should be independent.

REQUIREMENT LESSONS LEARNED (3.4.5.2.2)

Engine feed and transfer system reliability is improved by using the least number of operating components in the line between the tank and the engine, and by minimizing the effects that a component malfunction can have. It is also important to minimize influences external to the fuel subsystem by:

a. Locating the feed line where it can be protected from maintenance induced damage, gunfire, material thrown by the landing gear, and other equipment failures.

b. Locating as many of the other fuel lines as possible inside of fuel tanks, and by using plug-in components to minimize fuel tank entry, to minimize the effect of leakage and fuel subsystem disassembly. Special attention must be paid to equipment outside the fuel tank that covers a plug-in component. That equipment should be designed to minimize the effort required to unplug the item. In particular, the functional checkout after reassembly should be minimized.

c. Providing alternate sources of electrical or hydraulic power.

d. Using components that are resistant to fouling by contaminants (including ice).

e. Locating suction feed outlets close to the engine feed shut-off valve to minimize points of possible air ingestion during suction feed.

Under some transient conditions, the fuel pressure at the engine connection may fall below normal for a few seconds, but the system should be capable of full and rapid recovery without degrading engine performance. Within the allowable air vehicle and engine operating envelope, the fuel subsystem should not limit air vehicle performance or cause engine malfunctions, especially when transitioning from boost “on” to boost “off” feed mode.

Systems have been produced where a normal air vehicle maneuver or a normal control function momentarily interrupts flow to the engine. One example is on the Airborne Laser Laboratory air vehicle. When switching to engine feed from the body fuel tank, air inclusion in the body tank tubing caused momentary engine power roll back. Another example occurred on the F-105. When feeding the engine from the aft fuel tank in a prolonged nose down attitude of the air vehicle, the uncovered boost pump resulted in fuel starvation of the engine even though there was considerable fuel aboard the air vehicle. The primary difficulty in the design of the engine feed subsystem is to define reasonable extreme limits of operation such as attitude, temperature, and rate of change of altitude and flow demand.

Main tank feed pumps should be located in a baffled bay (hopper) which allows fuel to flow into the bay through check valves that prevent fuel from flowing out of the bay during a low fuel level attitude change. The B-52 G and H models had numerous cases of engine flameout due to the main tank pumps not being located in baffled bays. This resulted in uncovered pumps during low fuel conditions.

a. Negative and zero “g”. The B-2 fuel subsystem design started with an arbitrary requirement of ten seconds at negative “g”. The fuel subsystem contractor proposed gravity activated, double ended inlets to meet this requirement. A mission analysis was conducted to define the requirement and it was determined that it was not possible for the B-2 to be subjected to a single duration of ten seconds at negative “g”. The requirement was conservatively estimated to be three seconds. The boost pump inlet design was modified to meet the three second requirement.

b. Multi-engine feed independence. The early F-4’s had a common pumping system into a “Y” connection which fed both engines. The arrangement allowed several twin engine flameouts to occur.

E.4.4.5.2.2 Fuel availability.

Fuel availability to the engines on an uninterrupted basis under all air vehicle ground and flight conditions shall be verified by __(TBS)___.

VERIFICATION RATIONALE (4.4.5.2.2)

Verification of fuel availability should be considered a safety critical condition.

VERIFICATION GUIDANCE (4.4.5.2.2)

TBS should be filled in with analysis, simulator tests, ground, and flight tests. Fuel flow performance of each engine feed subsystem should be verified. A performance analysis of the fuel and transfer subsystem should be conducted including all single and multiple failures affecting fuel subsystem operation. The test program should be a demonstration of the analysis by test in a test rig and in the air vehicle. The test rig should include at least one actual engine fuel pump and it should include provisions to simulate fuel return from the engine to the pump inlet, if applicable. Also, on air vehicles where hot fuel is returned from the engine to the tank, that system should also be included.

Fuel flow during negative or zero “g” should be verified by component bench tests and flight tests. An “inverted flight box” test can be used to simulate encountering negative “g” conditions and trapped air release to evaluate negative “g” recovery. Testing should continue beyond the required period of negative “g” to demonstrate that the system can recover to the positive “g” flight mode.

VERIFICATION LESSONS LEARNED (4.4.5.2.2)

Fuel subsystem simulators have proven to be an effective way to integrate and test a fuel subsystem. The simulator can be a total fuel subsystem simulation for smaller fighter type air vehicle and rotary-wing air vehicles or a half system for simulation of larger symmetrical bomber and transport type air vehicles.

The use of a simulator allows early identification of design errors in functional components and in system routing prior to the availability of an actual airframe. Corrections can be made to the hardware and the hardware available for installation into the number one air vehicle without a delay in the program. The fuel subsystem simulator will provide a high degree of confidence for correct operation of the fuel subsystem on first flight.

Simulators have been produced which have a simulated altitude capability, simulated temperature capability, both hot and cold, and attitude capability, pitch and roll.

A fuel subsystem simulator requires engineering judgment to define the extent of simulation that is practical. The exact duplication of the air vehicle is not always practical or possible. The fuel tanks are generally of a steel construction or of heavy aluminum plate for improved strength to allow pressure to the extreme limits without fear of failure. As a result the exact mold lines of the air vehicle skins may not be achieved and some very precise measurements for fuel gauging accuracy may not be possible. It is recommended that the fuel subsystem be treated as an engineering development tool. It is not cost effective to use air vehicle production quality control procedures to inspect and control the simulator. The simulator should not be viewed as the primary method to qualify the fuel subsystem; however, the data and test results should be reviewed using engineering judgment for its applicability to the qualification process.

Verification of fuel availability should be by a combination of tests on a fuel subsystem simulator and air vehicle tests. Critical attitudes and extreme temperatures can be best established and held on a simulator. Dynamic conditions such as rate of climb, rate of roll, or uncoordinated maneuvers can best be tested during air vehicle flight test. Careful attention should be given to defining critical combinations of test conditions including failure conditions.

E.3.4.5.2.3 Flow performance.

Fuel flow performance of each engine feed system shall provide __(TBS 1)__ of the maximum fuel consumption of the engine plus one additional engine at __(TBS 2)__ power condition, if multi-engine, plus any fuel flow required for cooling purposes or motive flow for jet pumps.

REQUIREMENT RATIONALE (3.4.5.2.3)

Fuel flow requirements vary with airspeed, altitude, gross weight, air vehicle configuration, and other variables.

REQUIREMENT GUIDANCE (3.4.5.2.3)

TBS1 and TBS 2 should be filled in with consideration given to the following:

For single engine air vehicles the feed system should provide flow for 100 percent of the maximum fuel consumption of the engine in addition to any fuel flow for Auxiliary Power Unit (APU) operation cooling purposes and motive flow for fuel driven pumps. This condition should be analyzed for all operating conditions including steady state and transient conditions.

For multiple engine air vehicles, a feed system should provide flow for crossfeed of at least one additional engine at full power; therefore, the engine feed system should provide a minimum of 200 percent of the maximum fuel consumption of the engine plus any fuel flow required for cooling and motive flow.

Engine crossfeed. The engine feed system for each engine should be capable of supplying fuel to any other engine on the air vehicle. The capability of supplying fuel from any tank to any or all engines is a desirable feature on a multiengine air vehicle and for a single engine air vehicle from any tank to the engine.

Tank to tank transfer should be a separate subsystem from the engine feed system.

REQUIREMENT LESSONS LEARNED (3.4.5.2.3)

Potential growth fuel flow should be included in determining flow performance. Fuel flow growth for transport type air vehicle is a real possibility. Ten to fifteen percent growth should be considered.

Engine crossfeed and cross transfer. In systems where fuel must be transferred from a transfer tank or auxiliary tank to a main tank before delivery to the engine, failure in the main tank or damage to the main tank results in loss of even greater quantities of fuel. Fuel trapped in transfer tanks can also cause center-of-gravity (c.g.) problems as fuel in the other tanks of the system is used. Transfer and crossfeed capability provide greater system flexibility. The transfer capability should be available after a single failure. It may not be practical to maintain an engine crossfeed in the afterburner mode; therefore, an expected level of engine performance should be specified in the requirement.

Transfer systems in which fuel from more than one tank is transferred at the same time should be designed to be insensitive to the effect of unequal performance of the transfer pumps. In a common transfer system, the pumps of the same part number design can operate at slightly different output pressure. The pump with the higher operating pressure can dominate and supply all of the flow, especially at low flow rates, and may cause an undesirable transfer tank depletion sequence.

E.4.4.5.2.3 Flow performance.

Fuel flow performance of each engine feed subsystem shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.2.3)

Engine feed flow performance should be considered safety and mission critical.

VERIFICATION GUIDANCE (4.4.5.2.3)

TBS should be filled in with consideration given to the following:

The flow performance of each engine feed system should be verified by analyses and tests on a simulator and during flight tests.

For multi engine air vehicles, crossfeed of the engine(s) on one side of the air vehicle from the fuel tank(s) on the opposite side of the air vehicle should be verified by a flight demonstration or a fuel subsystem simulator for extreme attitudes and on the air vehicle during flight tests for normal operations. The critical conditions for the demonstrations should be identified by an analysis of the subsystem and the mission profiles.

VERIFICATION LESSONS LEARNED (4.4.5.2.3)

Both, fuel temperature and altitude, as well as rate of change of altitude, have a great effect on the ability of the feed system to deliver fuel. These critical parameters should be clearly stated in the test procedures. Flow performance tests should be conducted in association with fuel availability tests and be practical in respect to air vehicle altitude.

E.3.4.5.2.4 Emergency feed.

The engine feed subsystem without normal boost pump(s) operation shall provide fuel to the engines operating at __(TBS 1)__ power settings for altitudes up to __(TBS 2)__ feet with fuel temperatures of __(TBS 3)__.

REQUIREMENT RATIONALE (3.4.5.2.4)

Most military air vehicles use power boosted fuel feed systems for normal operation except for some Army rotary wing vehicles which use suction systems during normal operation. Since any power system can fail, it is necessary to be able to start and operate the engines following any failure affecting boost pump operation. The fuel quality in relation to V/L ratio must be within the interface requirements of the engine.

REQUIREMENT GUIDANCE (3.4.5.2.4)

TBS 1 should be filled in with the proper power rating.

TBS 2 should be filled in with a minimum of 10,000 ft.

TBS 3 should be filled in with a minimum of at least 120°F.

For any single failure in the feed subsystem, the subsystem should provide sufficient fuel flow to maintain take-off power to a minimum altitude of 10,000 feet with a fuel temperature of at least 120°F. If a higher temperature is predicted as a result of ground operation or solar heating, the higher temperature should be used.

REQUIREMENT LESSONS LEARNED (3.4.5.2.4)

The principal factors affecting the suction feed capability are the Net Positive Suction Head (NPSH) requirement of the engine pump at the engine connection, type of fuel, and fuel temperatures. The expected performance under specified failures should be established in terms of power setting of the engine altitude that must be obtained, fuel temperature and the number of failures which should be considered. Dual failures must be considered and specified in a design which contains dual boost pumps, a boost pump with tank pressurization, or a crossover system. Fuel temperature, fuel vapor pressure, fuel head and the condition of any fuel filters in the system have an influence on the suction feed capability of a system.

The flow path from the fuel tank to the engine is critical. Bubble collection high points should be eliminated. If the engine is taken to a high power setting on suction feed, air bubbles will form in the fuel. When the fuel flow is reduced, the air bubbles will collect in any high pockets in the line. When the fuel flow is again increased, the collected bubble (one large bubble) will eventually be washed downstream into the engine.

The F-15 uses engine fuel flow to cool hydraulic and airframe mounted accessory drive oil systems. It was observed that the low pressure levels during suction feed operation were incompatible with the high fuel temperatures resulting from oil cooling. As a result, an emergency boost pump was added to provide the necessary fuel pressure when the main boost pumps are inoperative.

Pressure drops through emergency feed lines are a critical parameter to consider when defining requirements. Changes in altitude during emergency feed conditions should also be considered.

E.4.4.5.2.4 Emergency feed.

Emergency feed subsystem performance shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.2.4)

Simulated flight conditions for emergency feed conditions should be used to define test conditions.

VERIFICATION GUIDANCE (4.4.5.2.4)

TBS: The feed subsystem performance should be verified by analysis, demonstration, and component test. The test parameters of critical fuel temperature, vapor pressure of the test fuel, and, if there is a filter or strainer in the engine feed path, the condition of the filter or strainer (clean or dirty) should be specified.

VERIFICATION LESSONS LEARNED (4.4.5.2.4)

The critical test parameters can best be established and repeated on a system simulator. A number of test runs are generally required to prove repeatability. Flight demonstrations can be conducted at conditions which are not necessarily the most critical for data comparison with the simulator tests. An emergency back-up system should be tested to verify performance. A test of an emergency system which does not include all of the elements of that system is of limited value.

E.3.4.5.2.4.1 Priming.

The fuel subsystem, where suction feed is the normal operation, shall provide the capability for priming, as required by the engine(s) and APU with fuel from __(TBS)__. The fuel subsystem shall be designed to prevent loss of engine feed system prime in the event of an engine(s) shutdown.

REQUIREMENT RATIONALE (3.4.5.2.4.1)

Priming of a system that uses suction feed as a means of engine or APU feed should be considered a safety critical function.

REQUIREMENT GUIDANCE (3.4.5.2.4.1)

TBS should be filled in with aviation turbine fuels from –65°F up to 135°F and possible extreme transient conditions with fuel up to 160°F. However final temperatures should be based on a thermal analysis of the expected usage.

REQUIREMENT LESSONS LEARNED (3.4.5.2.4.1)

Some unmanned air vehicles have had engine performance problems because of suction feed of high vapor pressure aviation gas.

E.4.4.5.2.4.1 Priming.

The capability of the fuel system to prime the engine(s) and APU shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.2.4.1)

Priming of a fuel system that relies on suction feed for normal operation should be verified to ensure high levels of integrity.

VERIFICATION GUIDANCE (4.4.5.2.4.1)

TBS should be filled in with analysis, fuel subsystem testing and flight testing with air vehicle turbine fuels at design fuel temperatures and ambient pressure extremes.

VERIFICATION LESSONS LEARNED (4.4.5.2.4.1)

The B-2 uses suction feed as a back up to engine feed. Contaminated fuel caused blockages in the heat exchanger on the flow path to the engine. Because of this contamination, the system went into suction feed. Fuel system simulator testing simulated the loss of pressurized flow and confirmed suction feed performance prior to incorporating the design on the aircraft.

E.3.4.5.2.5 Feed tank available fuel.

The fuel feed tanks shall provide at least __(TBS)__ percent available fuel at the normal landing attitude and power setting.

REQUIREMENT RATIONALE (3.4.5.2.5)

The feed tanks are the last tanks in the air vehicle to empty and the maximum available fuel should be provided in the landing attitude.

REQUIREMENT GUIDANCE (3.4.5.2.5)

TBS: The main fuel feed tanks should have at least 99 percent available fuel at the normal landing attitude and power setting. For fuel transfer tanks, including external tanks, at least 99 percent fuel availability at cruise attitude should be used as a design goal.

REQUIREMENT LESSONS LEARNED (3.4.5.2.5)

The flight profiles in the landing sequence involve both nose down and nose up conditions, steep turns, as well as positive and negative accelerations and uncoordinated maneuvers (such as side slip). The system design must consider all these forces acting on the fuel in order to insure a steady flow of fuel to the engines and maximize the available fuel. The available fuel for each main feed tank is all fuel down to the first evidence of flow interruption under reasonably expected feed conditions during the landing sequence. A good main tank design can achieve an available fuel quantity of 99 percent (less than 1 percent is unavailable). The goal of the designer should be to minimize unavailable fuel; however, specifying a requirement for available fuel greater than 99 percent could impose a cost or weight penalty on the tank which cannot be justified. The unavailable fuel trapped in transfer manifolds need not be considered for the main tank. Fuel should be drained from transfer and refueling manifolds and made available to the engines to minimize the weight penalty to the air vehicle.

E.4.4.5.2.5 Feed tank available fuel.

The availability of fuel from the main tank(s) down to the point of flow interruption shall be verified for flight attitudes including approach and landing by _(TBS)_.

VERIFICATION RATIONALE (4.4.5.2.5)

Engine feed should be considered a safety critical function.

VERIFICATION GUIDANCE (4.4.5.2.5)

TBS should be filled in with analysis, fuel system simulator rig tests, and air vehicle ground test.

VERIFICATION LESSONS LEARNED (4.4.5.2.5)

This testing can be combined with other necessary testing such as fuel tank and fuel gauge calibration or c.g. travel testing. Ground tests of the air vehicle should be positioned in the desired approach and landing attitude and fuel pumped down until the fuel pressure falls below the required engine interface requirement. The fuel remaining at this time is unavailable.

E.3.4.5.2.6 Engine fuel line shut off capability.

Each engine fuel line shall have an emergency fuel shut off and in-flight reopen capability.

REQUIREMENT RATIONALE (3.4.5.2.6)

The pilot must have the capability of stopping fuel flow into the engine compartment. Emergency shut off (commonly called fire shut-off valve) which can change position when an electrical fault occurs cannot be tolerated in the fuel subsystem, especially in the engine feed system.

REQUIREMENT GUIDANCE (3.4.5.2.6)

An emergency shut off (commonly called fire shut-off valve) should be provided close to, but not in, the engine compartment to minimize fuel entering into the engine compartment fire zone after activation of the valve. The valve should be capable of being reopened from the cockpit.

Engine shutoff and reopen time requirements are derived from engine fire protection and engine feed requirements, respectively.

Preference for type of actuation such as electrical, cable, or pushrod operation may be indicated. Electrically operated valves have typically been used in the current generation of air vehicles. Electrical valves should be of a fail safe design to prevent uncommanded closure in the event of a short circuit or mechanical forces.

Some installations may require both a tank shut off and a valve and a fire shut-off valve to minimize the quantity of fuel which can drain into the engine compartment after the valve is closed and to minimize the length of unprotected line which can drain the tank if the line is broken.

The crew systems and human factors engineers should be interfaced with when establishing the location, actuation, and knob selection of the emergency fuel shut-off control in the crew station. The marking of the emergency fuel shut-off control should be coordinated with crew system design engineers. A fail safe circuit should be incorporated for each valve. Ground operation of the valve should also be considered in establishing its location. In many cases, the valve is used for shutting off fuel to the engine during maintenance operations. Also, it is desirable for firemen to be able to shut off flow for a crashed air vehicle. For multi-engine air vehicle, the manual operation should be clear to the ground personal. All valves should require similar operation; for example up for open; down for closed.

The shut-off valve should be located out of engine rotor burst zone. It should be able to cease fuel flow upstream of the rotor burst zone.

External markings should be placed on the air vehicle to identify to the ground fire crew where to access the emergency shut off valve(s).

REQUIREMENT LESSONS LEARNED (3.4.5.2.6)

A fail safe circuit diagram is illustrated in MIL-V-8608A, Amendment 2. There have been numerous engine flameouts on Air Force air vehicles as a result of valves closing due to electrical shorts. As a result of these incidents a failsafe wiring circuit was developed. This wiring diagram was published in MIL-V-8608. This failsafe circuit has proven to be very effective in eliminating uncommanded valve closures.

Fuel shut-off valves flow control. The valve should have the capability to shut off or open fuel flow.

There are several design features which should be considered for inclusion into the design of a shut-off valve, as follow:

a. Position indication

b. Manual override capability

c. Replaceable actuator as subassembly

It is very beneficial to be able to determine visually the open or closed position of a valve without disassembly of the valve or relying on observation of flow. An external position indicator should be provided.

Manual override, the ability to open or close the valve without the use of electrical power, is a very desirable design feature for maintenance actions. Some existing designs have used the override lever to also provide a valve position indication. The manual override feature should provide the ability to completely close or open the valve.

The actuator can be integral to a component or can be attached as a subassembly. Since actuators are a predominant mode of failure of a fuel valve, actuators provided as a subassembly which can be replaced without removing the valve body from the fuel flow path can improve the maintainability of the system. The B-52H air vehicle has eight fuel shut-off valves located between the engine and the fuel tank. Two different valve types made by different manufacturers are being installed in the air vehicle interchangeably. With a failed actuator the repair job may be a small or a major job depending on the valve which is installed. When the defective valve is the preferred one, then usually all that is required is replacement of the motor assembly. When the installed valve is the non-preferred item, then a relatively long and tedious process of defueling the fuel tank and removing and replacing the entire valve assembly is required.

As a result of F-16 air vehicle uncommanded loss of thrust events, a series of modifications were made to the air vehicle fuel shut off-valves. It became apparent the need to test the fail safe mechanism of the valves with and without applied mechanical forces. In specific, we should test for the effect of natural and induced environments such as vibration or other extraneous forces normally encountered in service in combination with electrical failure.

E.4.4.5.2.6 Engine fuel line shut off capability.

Emergency fuel shut off capability shall be verified by _(TBS)_.

VERIFICATION RATIONALE (4.4.5.2.6)

Testing and operation of the shut-off valve and fail safe mechanism is required during component test, simulator rig test and during ground test to assure safety of flight. Closing of the fire shut-off valve during high fuel flow conditions can result in high surge pressures in the airframe fuel lines and in very low pressure in the engine fuel lines.

VERIFICATION GUIDANCE (4.4.5.2.6)

TBS should be filled in with consideration given to the following:

The operation of emergency shut-off valves should be verified by component tests, simulator test and air vehicle ground test. Valves should be tested for fail-safe features with and without applied mechanical forces.

The emergency shut off should be demonstrated under the maximum fuel flow likely to be encountered with pressure instrumentation in both the airframe and engine fuel lines. The operation of a fail-safe feature for fuel valves should be verified by component tests.

VERIFICATION LESSONS LEARNED (4.4.5.2.6)

A MIL-V-8608A valve was used as the main engine fuel-shut off valve in the F-16. While looking into a problem involving uncommanded loss of engine thrust, it was discovered through component testing that the valve could migrate from an open position to a closed position given a loss of electrical power to the valve coupled with mechanical forces; that is, fuel flowing through the valve and the valve experiencing the vibration spectrum for this particular installation. The MIL-V-8608A specification did not require the valve to be designed to protect against such a condition. The lessons learned from the F-16 installation indicates that the valve's typical application would require that the valve not change position due to an electrical failure or due to mechanical forces and have the valve tested accordingly.

E.3.4.5.3 Auxiliary power unit (APU) or jet fuel starter (JFS) interface.

The interface parameters shall be required between the air vehicle fuel subsystem and an APU or JFS: __(TBS)__.

REQUIREMENT RATIONALE (3.4.5.3)

The airframe fuel subsystem normally provides fuel for the APU's and JFS's. In order to ensure fuel flow and pressure interface requirements are met, physical connection(s), fuel pressure, temperature, and flow conditions should be defined. The critical physical connection and flow conditions should be specified.

REQUIREMENT GUIDANCE (3.4.5.3)

TBS: The required interface parameters should be specified. Steady state, transient conditions, natural, and induced environments should be considered when defining APU or JFS interfaces. The following parameters from Appendix C, "Auxiliary Power Subsystem", should be suggested:

a. Physical.
    1. Connection type and size
    2. Connection loads
    3. Connection location
b. Fuel conditions.
    1. Flight operable (yes, no)
    2. Altitude start and run
    3. Temperature (maximum, minimum)
    4. Pressure (maximum, minimum)
    5. Flow rate (maximum)

REQUIREMENT LESSONS LEARNED (3.4.5.3)

APU and JFS functions may have unique operating conditions that include cold soaked conditions as well as short operating times.

E.4.4.5.3 Auxiliary power unit (APU) or jet fuel starter (JFS) interface.

The fuel subsystem interface with the APU or JFS shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.3)

APU and JFS interfaces can be a safety or mission critical function.

VERIFICATION GUIDANCE (4.4.5.3)

TBS: The fuel subsystem interface with the APU or JFS should be verified by analysis, ground, and flight demonstrations tests.

VERIFICATION LESSONS LEARNED (4.4.5.3)

APU ground simulation labs have been successfully used to reduce risk during production.

E.3.4.5.4 Fuel management.

The fuel subsystem shall provide for normal transfer of all fuel to the engine(s) without action by the crew to control sequencing, fuel c.g., or operation of pumps. Fuel management shall not allow the air vehicle c.g. to exceed safe operating limits. The fuel subsystem shall provideconsider control for thermal management when fuel is used as a heat sink. Priorities of the fuel management system shall be included in the design.

REQUIREMENT RATIONALE (3.4.5.4)

The desired degree of automation for control of the subsystem should be specified. This is a flight critical function and its integration affects air vehicle safety. Priorities of the fuel subsystem must consider criticality levels.

REQUIREMENT GUIDANCE (3.4.5.4)

The degree of automation has a large impact on subsystem design and crew workload. The fuel management system should not permit a shift in the fuel c.g. which will allow the air vehicle to exceed the safe operating flight envelope dictated by the flight control system. Fuel management as a result of transfer, fuel depletion, or loading, should not allow the air vehicle c.g. to exceed safe operating limits. Fuel management systems should satisfy the following basic criteria:

a. Simplicity. This begins with the design and arrangement of the fuel subsystem itself, such as locating tanks to provide gravity feed and transfer, or sequencing tanks by using tank pumps having a different pressure. As the fuel subsystem becomes more complex. More control functions should be imposed, making the subsystem less reliable.

b. Automatic operation. The fuel subsystem design should be such that minimum attention of the crew is required. For air vehicles operated by a single pilot the fuel feed and transfer subsystem should provide for automatic transfer of all fuel to the engine feed tank(s) without requiring any action by the pilot to control sequencing, fuel c.g., or operation of pumps. Automation of operations eliminates the problem of slower human response times and air vehicle survivability is enhanced if the crew's attention is not diverted unnecessarily to fuel management. The level of automation for fuel transfer should be coordinated with crew systems and human factors engineers. For air vehicles operated with a second pilot or a flight engineer, a semiautomatic system may be used where the crew members provide control for tank sequencing, pump operation, and crossfeed. The system should not require any immediate crew attention or action for normal flight conditions.

   Transfer pump(s) should be shut off automatically when the tank is empty.

c. Minimum effect on flight control. Fuel depletion from multiple tanks should be managed to control c.g. shift within established limits for the balance of the air vehicle. The fuel management subsystem should consider failure modes of the subsystem as well as all expected loading and flight conditions. Supersonic flight may require a programmed shift in air vehicle c.g. due to the change in the center of lift of the air vehicle.

d. Redundancy. The fuel management subsystem itself should incorporate redundant features to allow for some degree of continued functional control of the fuel subsystem in the event of fuel management failure. The engine feed and transfer subsystem should provide two independent and isolated methods of moving fuel out of each feed tank on the air vehicle, except for jettisonable external tanks where only one method is required.

The design approach should meet the fuel subsystem criteria for single and double failures. After the first failure (computer failure considered the worst single failure) the air vehicle should be able to complete the mission and after the second failure it must be possible to make a safe recovery of the air vehicle. After the second failure, it must be determined if the fuel quantity information is necessary for safe recovery of the air vehicle.

MIL-STD-1798 can provide additional guidance on criticality definitions.

REQUIREMENT LESSONS LEARNED (3.4.5.4)

The fuel management subsystem should not require movement of fuel solely for c.g. control except where dictated by air vehicle configuration. The fuel subsystem designer should attempt as a goal to provide for simple sequencing of fuel transfer to maintain the c.g., both laterally and horizontally within the required broad limits. More complex air vehicle arrangements may require rapid fuel transfer to obtain an optimum c.g. position.

The F-102, F-106, and B-58 had complex fuel c.g. control systems and required rapid shifts of fuel during the transition between subsonic and supersonic flight. System failures requiring a rapid, unplanned for, change from supersonic to subsonic flight, could result in air vehicle fuel c.g. being out of limits in the subsonic mode.

The use of computer control is expected to replace manual operation for all new air vehicle. Most new systems have a completely automatic control system which accomplishes engine feed, c.g. management, thermal management and provides failure information of the fuel components to the warning and caution display. The B-2 system contains three computers and uses an active-standby architecture. The primary computer controls the fuel subsystem. In the event of a failure of the primary computer, the bus controller turns off the primary computer and activates the secondary computer. The secondary computer removes control of the system from the primary computer and takes over operation of the system. This removing of control of the primary computer is necessary in the event that the failure mode of the primary computer would not allow the primary computer to turn off. In the event of failure of the secondary computer, control is transferred to a manual panel. The third computer provides only fuel quantity information to the manual panel and critical warnings and cautions.

Flameouts have occurred on several fighter air vehicles due to empty main tanks while considerable fuel was aboard in transfer tanks. Engineering change proposals were incorporated in the F-105 and F-4C to switch back to the transfer mode automatically when the low level light is illuminated. This automatic feature was very useful under combat conditions.

E.4.4.5.4 Fuel management.

Verification of the fuel management shall be accomplished by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.4)

Fuel management is a safety and mission critical function.

Fuel system complexity and redundancy requirements require significant testing and troubleshooting in order to assure full performance verification. The fuel management system is a safety critical function and its integration with the air vehicle control must be verified.

VERIFICATION GUIDANCE (4.4.5.4)

TBS: Fuel management will be verified by analysis, component tests, software integration testing, fuel system simulator test, ground tests and flight tests.

The verification of this requirement should be by analyses component testing, integration testing, air vehicle ground and flight tests.

Fuel subsystem simulators should be used to demonstrate fuel c.g. changes and fuel transfer operation under simulated flight conditions and power settings. Tests should also be conducted under engine inoperative conditions on multiengine air vehicles and under gravity feed conditions.

Flight and ground testing should be used to measure the performance of the fuel delivery, integration with the Vehicle Computer Management System (VCMS) and interface with the crew.

Dedicated flight testing of the fuel management system during Engineering and Manufacturing Development (EMD) should not be required. Instead, suitable information regarding fuel management system operation and performance should be gathered during testing of other subsystems or air vehicle missions such as full integration testing including failure modes with VCMS which at least includes the processing hardware and software and adequately models sensors and pumps.

VERIFICATION LESSONS LEARNED (4.4.5.4)

The operation of the subsystem will be demonstrated during routine flight tests. Only malfunctions or inadequate operations need to be recorded during the flight tests. The override function should be operated to demonstrate correct operation.

Test configurations should include all planned external and auxiliary fuel tanks and useful load configurations, all expected fuel management control situations, and air vehicle attitude extremes. Each test should be performed with the air vehicle in its normal flying attitude for each condition. Fuel should be removed discharged from the engine feed lines at the proper flow and pressure. c.g. versus air vehicle gross weight for various tank sequence plots should be prepared and compared with the previously calculated data.

E.3.4.5.4.1 Fuel transfer.

The rate of fuel transfer into the engine feed tank(s) shall not limit air vehicle performance. All fuel transfer tanks shall provide at least ___(TBS)___ percent available usable fuel during air vehicle cruise conditions and attitude.

REQUIREMENT RATIONALE (3.4.5.4.1)

On systems which have multiple transfer fuel from tanks (with or without auxiliary or external) tanks to a main tank, the transfer capability should be equal to or greater than such that the feed tank(s) are maintained full until all transfer fuel has been depleted for all air vehicle engine consumption rates to the engine. If the transfer rate is not sufficient, the main tank can be depleted even though there is additional fuel onaboard the air vehicle and the system is operating correctly. The preferred location of the tank siphon tube outlet or transfer pump location is determined by the attitude of the air vehicle when the last fuel is removed almost depleted from the tank.

REQUIREMENT GUIDANCE (3.4.5.4.1)

TBS: It is desirable for the rate of fuel transfer to any single main tank should to be equal to or greater than the maximum rate of fuel consumption of the engine. Air vehicles should normally be in the cruise attitude when the last fuel almost depleted is removed from the transfer tanks.

The fuel should be available for transfer in level flight at the maximum flow rates to a fuel level of 2 inches above the pump inlet and then at a reduced flow rate until depleted.

REQUIREMENT LESSONS LEARNED (3.4.5.4.1)

When maximum engine flow rate is large high relative to the quantity of fuel onboard the air vehicle, as is the case of afterburning fighter air vehicles that have an afterburner capability, the transfer rate need does not have to match maximum engine capability. When theis transfer rate is not equal to engine flow, an acceptable compromised rate should be identified and the operating conditions should be defined.

The object is to maximize available usable fuel and to minimize weight penalties due to unusable fuel; however, there is a practical limit. For large flat tanks, the pump location and attitude for removal of the last lower quantitiesy of fuel is extremely critical. Very slight changes in attitude can cause a significant quantity of fuel to change location. It is not cost effective to add additional pumps to reduce the unavailable unusable fuel quantity to an insignificant amount. A trade study should be conducted to determine the optimum equipment for the minimum unavailable unusable fuel. The capability of the fuel lines to be purged should also be considered.

In the transfer subsystem, where fuel is transferred from a transfer or auxiliary tank to a main tank, momentary flow interruptions can be tolerated. For transfer conditions, where fuel is pumped directly from a transfer tank to an engine, the system must be evaluated for flow interruptions. This is especially true for air ingestion during the switch over from main tank to transfer tank.

E.4.4.5.4.1 Fuel transfer.

The rate of fuel transfer to the feed tanks shall be verified by __(TBS 1)__. The maximum availability ofusable fuel quantity in the transfer tanks shall be verified by __(TBS 2)__.

VERIFICATION RATIONALE (4.4.5.4.1)

Tests should be conducted to establish the flow rate and the sequence of usage from the transfer tanks.

VERIFICATION GUIDANCE (4.4.5.4.1)

TBS 1: The rate of fuel transfer to the main tank(s) should be verified by analysis and simulator tests.

TBS 2: The maximum availability of usable fuel quantity in the transfer tanks should be verified by analysis, and ground tests, or flight tests.

VERIFICATION LESSONS LEARNED (4.4.5.4.1)

For flight testing, the transfer tanks can be depleted in-flight and then after landing, the air vehicle must be positioned in the best optimum attitude position for draining and measuring the remaining fuel in the fuel tanks. For a ground test, the air vehicle must be positioned to a simulated cruise attitude and deflected structure (wing tips) deflected corresponding to the cruise attitude before the fuel is pumped out.

E.3.4.5.4.2 Refuel control mode.

The distribution of fuel into the air vehicle when aerial refueling through the _(TBS 1)_ receiver aerial refueling subsystem shall be controlled by __(TBS 2)__.

REQUIREMENT RATIONALE (3.4.5.4.2)

This is an operational and integration requirement.

REQUIREMENT GUIDANCE (3.4.5.4.2)

TBS 1: Identify the specific receiver aerial refueling subsystem on the air vehicle.

TBS 2: Specify whether the fuel distribution into the air vehicle when aerial refueling through the particular receiver aerial refueling subsystem will be automatically controlled or manually controlled. If manually controlled, also specify which crew member(s) will have this control capability. In single-seat air vehicles, the pilot obviously should be given this capability. When the co-pilot is required to perform any aerial refueling process, the control capability should be provided. In some receptacle installations, only the flight engineer should be provided this capability.

REQUIREMENT LESSONS LEARNED (3.4.5.4.2)

(TBD)

E.4.4.5.4.2 Refuel control mode.

The ability to control fuel distribution when aerial refueling, including aerial refueling through the (TBS 1) receiver aerial refueling subsystem shall be verified by (TBS 2).

VERIFICATION RATIONALE (4.4.5.4.2)

The ability to verify correct fuel distribution throughout the air vehicle fuel subsystem when onloading from tanker aircraft is critical due to the catastrophic consequences of putting an aircraft out of CG limits.

VERIFICATION GUIDANCE (4.4.5.4.2)

TBS 1: identify the specific receiver aerial refueling subsystem on the air vehicle.

TBS 2: specify ground demonstration and flight demonstration.

VERIFICATION LESSONS LEARNED (4.4.5.4.2)

(TBD)

E.3.4.5.5 Fuel quantity measurement and indication.

Fuel quantity measurement shall be provided to indicate the weight and distribution of all fuel on the air vehicle within (TBS) accuracy.

REQUIREMENT RATIONALE (3.4.5.5)

Display of measurement information regarding the weight and distribution of the usable versus total (usable + unusable) fuel onboard, and unusable (drainable + trapped) fuel are critical parameters to know for the safe operation of the air vehicle.

REQUIREMENT GUIDANCE (3.4.5.5)

Fuel gauging capability and display information should be provided for every air vehicle. Fuel gauging should measure all tanks where significant usable fuel is contained in the air vehicle, including external tanks. The required gauging system accuracy should be commensurate with the air vehicle flight control requirements, and consider the maneuvering requirements (dependent on the mission requirements) and center of gravity requirements.

TBS should be filled in with one of the following given the gauge class:

Gauges should be of the following classes and should produce the specified accuracies when installed in the air vehicle:

Class I: +/- 4% of indication, +/- 2% of full scale

Class II: ± /-2% of indication, +/- 0.75% of full scale

Class III +/- 1% of indication, +/- 0.5% of full scale

Quantity indicators in tanks containing flammable fluids should be designed so that no "single electrical failure" in any part of the circuit, inside or outside the tank, could cause a spark or arc, with an energy greater than 0.2 millijoules, within the tank. If transformers are used for power supply to the gauges in the tank, electrostatic grounded shields should be applied between the two windings, if a short between the primary and secondary winding could cause a spark or arc, with an energy greater than 0.2 millijoules in the tank. USN/USMC aircraft typically use Class II probes unless system requirements dictate more or less precise fuel quantity measurements.

REQUIREMENT LESSONS LEARNED (3.4.5.5)

Fuel quantity gauging accuracy requirements should consider measurement accuracy, attitude effects, fuel sloshing, component (fuel probe) location installation restrictions and fuel property variability. Where the gauging system forms a part of an automatic fuel management subsystem then redundancy requirements should be considered to ensure fail safe operation. Reference SAE AIR1184 for additional information.

a. Fuel probe electrical connectors. In previous air vehicle designs, MIL-C-38999 connectors were used on the probe harnesses inside the fuel tanks. This design was used in the F-22 air vehicle connector. During the air vehicle ground testing, several erratic probe readings were reported. After installation of the connectors, it was found to be very difficult to visually determine if the connector was installed properly and a tightness check could not be accomplished satisfactorily. The investigation team determined that a USAF bomber air vehicle had experienced similar problems. The F-22 developed a special procedure to tighten these connectors properly. USN fuel quantity probes typically have used captive screw type fasteners for attaching probe harnesses to the individual probes. This type of connection has proven to be highly reliable and lightweight. Captive fasteners should be used to reduce the risk of FOD in the fuel system.

b. Ultrasonic fuel probes. The F-22 program office selected these probes due to potential weight savings and reliability improvement. The probes had been demonstrated on commercial air vehicles. The probes in the F-22 application were susceptible to air bubbles that were generated due to vibration or agitation in the fuel tanks. The vibration levels in a fighter air vehicle are obviously much higher than those of a commercial transport class aircraft, especially during buffet loads with weapons bay doors open. The probes would lose their ultrasonic signal, and in many cases the signal would not return. This loss of signal was caused by the foam and bubbles present inside of the probe tube assembly. The result of this issue was to change-out all ultrasonic probes in the fuselage with capacitance-type probes.

E.4.4.5.5 Fuel quantity measurement.

The fuel quantity measurement subsystem requirements shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.5)

Fuel quantity accuracy verification is important to ensure safe quantity and center of gravity measurements. Ground conditions should also be assessed to ensure safe towing, maintenance, and taxi, and to prevent tip over.

VERIFICATION GUIDANCE (4.4.5.5)

TBS: The fuel gauging system requirements should be verified by analysis, by fuel simulator testing, and by an air vehicle ground calibration and demonstration.

VERIFICATION LESSONS LEARNED (4.4.5.5)

The installation and calibration of the gauging system on a fuel subsystem simulator will permit early discovery of errors. Early discovery may permit correction before procurement and installation of hardware and software on the first air vehicle.

E.3.4.5.6 Fuel tank

E.4.4.5.6 Fuel tank

E.3.4.5.6.1 Fuel expansion space (ullage).

Each fuel tank shall have an expansion space above the fuel level with the air vehicle at normal ground attitude to allow for the expected thermal expansion of the fuel. The expansion space shall be __(TBS)__ with the air vehicle in a normal ground attitude.

REQUIREMENT RATIONALE (3.4.5.6.1)

Space must be provided in each fuel tank to allow for the expected thermal expansion of the fuel. Even in regions of moderate temperatures, fuel stored in underground tanks will generally be considerably cooler than the day time ambient air temperatures. After servicing, the fuel will warm up and expand. On an open vent fuel tank, insufficient thermal expansion space will result in fuel being spilled overboard.

REQUIREMENT GUIDANCE (3.4.5.6.1)

An expansion space to prevent tank overflow should be provided in each fuel tank.

TBS should be filled in based on the expected usage and natural and induced environment. Additionally, the thermal expansion properties of any fuel type expected should be considered as an important parameter. The following conditions have been used in previous designs:

The expansion space should be equal to or greater than 3 percent of the total fuel volume of the tank with the air vehicle in a normal ground attitude. If overboard leakage is critical such as with Navy air vehicles on ships, then a 75°F temperature increase (5 percent) should be specified.

For air vehicles which will be serviced and then flown a short time thereafter, similar to airline type operations, then a lesser amount of temperature differential such as 37°F (equivalent to 2 percent expansion space for JP-4) should be specified.

Approximately 1 percent expansion space should be acceptable for aerial refueling.

REQUIREMENT LESSONS LEARNED (3.4.5.6.1)

Air vehicle attitude affects the fuel shut off level and therefore affects the expansion space. The expansion space after refueling should provide for a normally expected air vehicle attitude including expected variations in cargo or stores. A tolerance should be specified for unlevel refueling areas.

For tank arrangements where a number of tanks or cells are connected to function as a single tank the expansion space for the total cluster can be provided in one of the cells.

Air Force Regulation AFR 86-14 specifies requirements for grades for U.S. Air Force runways and aprons, as follow:

a. Runways: 0.167 percent per 100 foot of runway

b. Runway intersections: 0.4 percent maximum

c. Taxiways and shoulders: 3.0 percent maximum, except for Air Force multi-mission facilities, a maximum of 1.5 percent.

FAA criteria for tank ullage is 2-percent volume and does not include criteria for aerial refueling. This is acceptable for commercial aircraft that rarely remain in one place full of fuel for long durations where large temperature swings are encountered. This may become an issue for commercial-derivative military aircraft with long-duration alert requirements (such as the KC-46) which may be fueled during cold periods and remain full when the ambient temperature has experienced greater than 50 degree temperature swings—in this case, top-offs may need to be prohibited, or other operational or design changes considered.

E.4.4.5.6.1 Fuel expansion space (ullage).

Fuel expansion space at normal ground attitudes for each tank or cluster of tanks shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.6.1)

Air vehicle ground testing should verify that there is sufficient expansion space for all attitudes of the air vehicle resulting from different loading conditions on the air vehicle.

VERIFICATION GUIDANCE (4.4.5.6.1)

TBS: Fuel expansion space should be verified by analysis and by ground tests.

VERIFICATION LESSONS LEARNED (4.4.5.6.1)

The tests should verify that there is sufficient expansion space for all attitudes of the air vehicle resulting from different loading conditions. This can be accomplished by filling the air vehicle to the maximum required capacity and then adding a measured quantity of fuel until overboard leakage is observed. If tank volume is not critical, that is, there is excess ullage available, then only analysis may be required. If there is a high confidence in the analysis capability, then ground testing may be avoided. For pressurized tanks, it should be verified that the interior of the vent lines are not part of the expansion space which can hold fuel so that depressurization of the tank will not blow the trapped fuel out of the vent. The analysis attitudes and test attitudes should account for the expected apron and runway attitude variation in each axis. A minimum of 2.0 percent grade should be expected for attitude variation.

E.3.4.5.6.2 Fuel tank low point drainages.

Each tank design shall incorporate the capability to remove condensate water and sediments from the low point of each tank.

REQUIREMENT RATIONALE (3.4.5.6.2)

Fuel will absorb water from the atmosphere. With time and a decrease of temperature, water will separate from the fuel and settle to the bottom of the tank. Condensate water and contamination should be removed from the fuel tanks to prevent accumulation to a level which could affect engine operation. Fuel tanks should be designed such that there is only one low point in each tank.

REQUIREMENT GUIDANCE (3.4.5.6.2)

This is a safety requirement and should not be tailored.

For large air vehicles tanks of 1000 gallons or larger, an automatic water removal system should be considered as part of the system design. With an automatic drain system, sump (i.e., low point) drains or a sump scavenge system should also be incorporated to permit manual draining of the sump and to verify correct operation of the automatic system. For small tanks, only the low point drain valves should be required and are usually sufficient.

A sump should be provided to collect water. Experience has shown that a sump which is 0.25 percent (0.25%) of the tank volume is adequate to collect the sediment which is likely to occur. In the past, sump volume design was based upon 0.75 cubic centimeters (cc) of free water per gallon of fuel in excess of saturation.

REQUIREMENT LESSONS LEARNED (3.4.5.6.2)

The C-5A water removal system, which mixes water from the bottom of the tank with fuel being fed to the engine, has proven to be effective in removing water. The B-2 and Boeing 747 have incorporated an in-flight water scavenge.

There should be a means of verifying the proper operation of the water removal system if automatic water removal or scavenge systems are incorporated. The C-17 has experienced significant fuel tank corrosion and subsequent fuel contamination problems due to the clogging and resulting reduced effectiveness of the water scavenging system.

Ensure tank drains are recessed into the tank or suitably protected to prevent actuation during a crash. Minimize the number of line-mounted drain valves. Design valves are to be positive locking in the closed position.

Water accumulation is known to contribute to microbial growth in fuel tanks.

E.4.4.5.6.2 Fuel tank low point drainages.

The ability to remove condensate water from each tank shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.6.2)

Excessive free water in the fuel can cause serious complications for the air vehicle fuel and propulsion systems. For more information on microbial growth/fuel issues, reference Airworthiness Advisory AA-04-03, Free Water and Microbial Growth in USAF Aircraft Fuels.

VERIFICATION GUIDANCE (4.4.5.6.2)

TBS: The ability to remove condensate water should be verified by ground tests. Sump capacity should be verified by ground tests.

VERIFICATION LESSONS LEARNED (4.4.5.6.2)

Sump capacity tests can be conducted in conjunction with water removal tests. The sump capacity of each tank can be obtained by measuring the fuel removed from the sump after all possible fuel has been pumped from the tank by the air vehicle pumps with the air vehicle in the normal ground attitude.

E.3.4.5.6.3 Fuel tank cleanliness.

When delivered to the procuring agent, the fuel tanks should contain no more than __(TBS 1)__ milligrams per gallon (gal) of solid contaminant and __(TBS 2)__ fibers per quart of fuel beyond that contained in the fuel when the air vehicle is refueled.

REQUIREMENT RATIONALE (3.4.5.6.3)

A level of cleanliness should be established for the air vehicle fuel tanks is required prior to the delivery of the air vehicle to ensure additional maintenance above that required due to normal air vehiocle operation is not required. It is impossible for the tanks to be absolutely clean; therefore, an allowable limit must be specified.

REQUIREMENT GUIDANCE (3.4.5.6.3)

TBS 1: The tank should add no more than 16 milligram (mg) of solid contaminant per gallon.

TBS 2: The tank should add no more than 40 fibers longer than 1500 microns per gallon of fuel serviced to the tank.

REQUIREMENT LESSONS LEARNED (3.4.5.6.3)

A cleanliness requirement for fuel tanks should be incorporated in the acceptance test procedure for each air vehicle.

For air vehicles with explosion suppression baffle material (fuel foam) installed in the tanks, an acceptable increase in solid contamination is 2 mg/gal over that serviced to the air vehicle during filling. This cleanliness level could be obtained in two to three cycles of fill and drain of the foam filled tanks. Emphasis should be placed on draining tank sumps and on periodic checking of fuel strainers, since foam in low areas of the tank will have a tendency to collect higher concentrations of foreign particles.

Lint fibers were a difficult problem for the B-2 air vehicle. The fibers were believed to have come from the cotton coveralls of the fuel tank workers or the cleaning rags used in the fuel tank sealing process. The flush cleaning process did not effectively remove this contamination in production air vehicle number 1 and production air vehicle number 2. After flushing, sump samples were taken and the samples examined visually as suggested by T.O. 42B-1-1. The procedure allows 10 or less fibers to be in a one-quart sample. The samples appeared acceptable. After taxi tests and early flights, cotton fibers were found on the face of a heat exchanger in the engine feed line. More extensive flushing procedures and fuel quality inspection procedures were incorporated. The defuel line used to remove the fuel after flushing contained a screen. This screen was inspected for fibers after each flush defueling. When the screens appeared clean, sump samples were taken. The sump samples were filtered to measure solid contaminant, and then the filter paper was inspected under a microscope for fibers. It became obvious that short fibers which could not be detected visually could be counted under the microscope. The inspection procedures were modified to require that only fibers longer than 1500 microns in length be counted. For production air vehicle number 3, eight flushes were required to pass the less than ten fiber count. The procedure could be over conservative, requiring too many flushes, and a higher fiber count could be tolerated without any system impact. It must be determined during flight testing if fuel slosh will free or flush additional fibers into the heat exchangers. If no unacceptable level of contamination is found, it may be possible to relax the ten fiber limit on fuel samples.

E.4.4.5.6.3 Fuel tank cleanliness.

The cleanliness state of each fuel tank shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.6.3)

The cleanliness state of each fuel tank should be verified by ground test.

VERIFICATION GUIDANCE (4.4.5.6.3)

TBS: The cleanliness state of each fuel tank should be verified by repeated fueling, sampling, and defueling procedures until the fuel is verified to meet the required cleanliness. The microscope method should be used for measurement of the fiber content. This should be accomplished by draining fuel from the tank sump and testing in accordance with the bottle method of T.O. 42B-1-1 or ASTM D2276-73, Appendix A2.

VERIFICATION LESSONS LEARNED (4.4.5.6.3)

Operational aircraft air vehicles experienced contamination due to fuel tank rework and cleaning procedures. For further information on these tank cleanliness/contamination issues, reference Airworthiness Advisory AA-01-05, Use of Aluminum Oxide (Al_2O_3) as a Grit Blasting Media during the Removal of Organic Coatings on USAF Aircraft Fuel Tanks.

E.3.4.5.6.4 Integral tank sealing.

Integral fuel tank sealing shall be in accordance with JSSG-2006, Structures Joint Services Specification Guide handbook.

REQUIREMENT RATIONALE (3.4.5.6.4)

Fuel tank quality and integrity is a major problem for the fuel subsystem area for the life of the air vehicle.

REQUIREMENT GUIDANCE (3.4.5.6.4)

Refer to the JSSG-2006, Structures Joint Services Specification Guide handbook.

REQUIREMENT LESSONS LEARNED (3.4.5.6.4)

AFFDL-TR-79-3047 was prepared by North American Rockwell Corporation under contract to the Air Force Flight Dynamics Laboratory in accordance with standards established by the ASD Fuel Tank Working Group. This handbook contains the most current design guidance for integral fuel tanks with input and coordination from most prime airframe manufacturers. AIR STD 4069 was published by SAE to provide additional guidance.

All fuel tank wall penetrations and leak paths (seams) should be sealed with two fuel seals (primary barrier). Redundant fuel tank seals are desired to minimize fuel tank leaks. A faying surface seal in combination with a fillet seal or an o-ring with a fillet seal or double o-rings are all considered double seals. If the sealing integrity of each seal cannot be verified individually, then the double seals should be considered one barrier, the primary barrier. If the sealing integrity of both seals can be tested and verified, the double seals can be considered a double barrier.

Sealant may be required over fastener heads and nut plates for lightning protection in addition to that required for sealing.

The F-16 full scale development (FSD) air vehicle had numerous fuel leaks due to (1) poor quality of hole preparation, rivet installation, and sealant application; (2) lack of fillet seals in many areas due to no access for application; and (3) the choice of blind rivets (NAS 1921, MS90353, and MS90354) which were unable to fill the poorly prepared holes properly. These problems were resolved by the addition of 16 access doors to the fuselage integral tanks, the replacement of blind rivets by bucked rivets, threaded bolts, structural screws, and hi-lok fasteners. The use of pilot hole drilling and drill blocks to improve hole quality was incorporated along with the use of rotating fixtures to improve sealant application. Also, permanently attached nuts were used in inaccessible areas to allow retorqueing of verification of torque on leaking bolts or bolt replacement.

Integral Fuel Tank Sealing Related Lessons Learned:

a. Fastener area. Blind rivets or blind bolts in sealing areas were prohibited by MIL-STD-1515, requirement 213, para 3.6. Generally there should be tighter controls on hole drilling for sealing fasteners. All holes should be drilled with automatic feed equipment rather than hand held equipment. Where practical, always use interference fit fasteners for better fluid sealing, that is, fasteners having a minimum of 0.002-inch interference per inch of fastener diameter. If interference fit fasteners are not used, then the alternate choice should be a sealing type fastener with wet (sealant) installed. All non-interference fasteners should be overcoated coated on the wet side (cap sealed) to enhance sealing. Do not use cadmium plated fasteners in contact with fuel or sealant to insure good compatibility with sealant and proper adhesion to the fastener surface. If dry film lubricant is required on a fastener, it should be a “baked” on type rather than “air” dried. If a supplemental lubricant is used such as cetyl alcohol, it must be removed after installation of the fastener and prior to any sealant application. At this time there is no list of approved fasteners covered by military or industry documentation for sealing fuel tanks. MIL-STD-1515 requirement 125 defines the requirements for fuel sealing fasteners and integral fuel tanks.

b. Sealing and sealant types. Three basic sealant types are approved for use in integral fuel tanks: non-curing groove injection materials (fluorosilicones and cyanosilicones), curing and thermo setting adhesive sealant.

There are three classes of elastomer seals used in fuel tank components and access doors: Nitrile, fluorosilicone and fluorocarbon. The best material for overall durability is Nitrile type, but is limited in high temperature resistance. The fluorosilicone has better high and low temperature capability but is less resistant to abrasion and compression set. The Viton has the best high temperature resistance, but is not good for low temperature. The best method of sealing access doors in fuel tanks is with elastomeric o-rings or molded seals. Flat gaskets or sealant type seals are much less reliable and tend to leak more often because they take a permanent set with time. Purging fluids having low or no aromatics tend to result in elastomer leakage since the elastomers can shrink with the removal of the aromatics. Good integral fuel tank sealing requires: good structural joint design, good sealant application and quality control, and good quality sealant and sealers. Most leakage seems to occur at fasteners or areas where large structural gaps occur. Poor application of sealant is also a contributor to leaks which are due in many cases to poor personnel training and sealing techniques. Cleanliness in the fuel tank sealing area during fabrication and installation is of primary importance. An environmentally controlled area or controlled hanger is preferred. Sealing should not be done where painting, oiling, drilling or similar activities are also occurring because surfaces to be sealed may inadvertently become contaminated which, in turn, adversely affects sealant application. The use of MIL-C-38736 cleaner and adhesion promoter (PR-148) has been found to enhance fuel tank sealing by insuring clean surfaces for sealant application. Provide good access to areas and fasteners that must be sealed. The wing to fuselage interface is one area that is often over looked and should be given special scrutiny. The development and availability of good illustrative technical orders are imperative.

A design, fabrication, and quality assurance program should be conducted for fuel tanks, during research, development, and production of the air vehicle. Fuel tank quality and integrity is a major problem area for the fuel subsystem area for the life of the air vehicle. It is essential that a quality program be established that will address fuel tank problems until after production is completed.

E.4.4.5.6.4 Integral tank design.

Integral fuel tank design shall be verified by (TBS). See JSSG-2006, Structures Joint Services Specification Guide handbook.

VERIFICATION RATIONALE (4.4.5.6.4)

It is essential that a verification program be established that will address possible fuel tank problems.

VERIFICATION GUIDANCE (4.4.5.6.4)

TBS: Verification should be accomplished by analysis, test, and inspection in accordance with JSSG-2006, Structures Joint Services Specification Guide handbook. Any incorporation of “Not Recommended” design methods in the new tank design should be explained and justified.

VERIFICATION LESSONS LEARNED (4.4.5.6.4)

Test criteria and guidance can be found in AFWAL-TR-80-3100.

The incorporation of two seals on all fuel tank penetrations and leak paths should be verified by inspection of tank drawing and air vehicle hardware.

Seal verification can be accomplished by pressurizing the inner seal (primary barrier) and inspecting the cavity drain for leakage, then pressurizing the drain cavity and inspecting the secondary seal (secondary barrier) for leakage.

E.3.4.5.6.5 Bladder tank cavity.

The structure or cavity surrounding a bladder tank shall be vented, and contain and control any fuel leaks in the bladder tank cavity at normal air vehicle level attitudes to the designed-in drainage control paths. Drainage control paths shall be provided to remove any bladder fuel leakage which may occur.

REQUIREMENT RATIONALE (3.4.5.6.5)

All structure interfaces, joints, and seams surrounding bladder tanks should be vapor and liquid tight. Deliberate drains and drain paths should be provided for the cavity to ensure all flammable fluids are routed safely overboard, and do not collect anywhere within the air vehicle.

REQUIREMENT GUIDANCE (3.4.5.6.5)

This requirement should be considered safety critical. The cavity drain acts as a drain for the low volume between the bladder and the air vehicle structure. The drain should be used for removing condensed moisture or fuel which may have leaked from the fuel cell fittings, O-rings, or diffused through a cut/tear in the the bladder, and should allow for continual continuous drainage overboard. The termination outside of the air vehicle should be of such design that any discharge fluid does not re-enter or impinge on the air vehicle during flight.

In addition to drainage, the volume between the structure and fuel cell should be adequately vented. In an altitude climb, air should be expelled from the volume to prevent cavity overpressure. The venting of the cavity during a dive may also be safety critical and is necessary to prevent fuel cell collapse and should be investigated.

REQUIREMENT LESSONS LEARNED (3.4.5.6.5)

The drain provision for self-sealing bladders may need to be a larger diameter than for standard bladder tanks. If not protected from fuel on the outside of the fuel cells through the use of a vapor barrier, fuel spills can cause a reaction with and deterioration of the self-sealing material, which is generally not protected from fuel on the back side. Strongly recommend Original Equipment Manufacturers (OEMs) provide exterior barrier protection to prevent activation from the outside in.

The F-15 air vehicle experienced increased fuel leakage reports during the United States Air Force fuel conversion from JP-4 to JP-8. Leakages from the fuel cell bladder tank fittings were reported. Accumulated fuel leakage in the cell folds actuated the self-sealing bladder and resulted in cell rupture in flight.

Tank bladder leaks began occurring with increasing frequency during the fuel conversion. The bladder tank leakage was corrected by (1) tightening up quality control in bladder manufacture, (2) instituting more stringent bladder acceptance procedures, and (3) developing procedures to insure a greatly improved bladder-to-cavity fit. This experience showed that constant attention to quality control is imperative in the manufacture of bladder fuel tanks.

For fighter applications, a check valve allows overboard leakage but does not allow backward air-to-flow through the drain. This traps a vacuum between the bladder and the cavity wall and prevents movement of the bladder during a dive. It is believed that this feature has contributed to the high reliability of the system.

E.4.4.5.6.5 Bladder tank cavity.

The sealing, venting, and draining of bladder tank cavities shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.6.5)

Verification of the bladder tank cavity sealing, venting, and draining is necessary to ensure the reliability and durability of the fuel bladders is not adversely affected and should be based on peace-time failure modes as well as survivability and vulnerability requirements.

VERIFICATION GUIDANCE (4.4.5.6.5)

TBS: The sealing of bladder tank cavities should be verified by analysis, component testing, and ground tests prior to the installation of the bladders. Bladder-type fuel tanks should be capable of passing material compatibility tests for the expected natural and induced environments.

VERIFICATION LESSONS LEARNED (4.4.5.6.5)

Aromatic content of fuel has affected bladder tank seal swell.

E.3.4.5.6.6 Internal auxilary fuel tanks removable tank support.

Rigid, internal, removable auxiliary fuel tanks shall be supported and restrained to prevent rupture and movement when subjected to the flight inertia load factors and emergency landing crash load factors specified for the air vehicle in accordance with MIL-STD-1290. The tanks shall be integrated into the air vehicle's internal fuel system for the purposes of fueling, defueling, transfer control, quantity gaging, venting, and pressurization. The tanks shall be able to be fueled and defueled both through the air vehicle's internal fuel system (reference E.3.4.5.8.4, and E.3.4.5.8.13) and directly via the tank's refuel port. It shall be possible to verify the quality of fuel in the fuel tanks in accordance with OPNAVINST 4790.2J.

REQUIREMENT RATIONALE (3.4.5.6.6)

The manner in which rigid, internal, removable fuel tanks are mounted is a safety issue and failure should not be permitted under the defined loads. The tanks should be integrated into the air vehicle internal fuel system in order to minimize pilot, crew, and maintainer workload associated with the auxilary fuel tank operation.

REQUIREMENT GUIDANCE (3.4.5.6.6)

Tank support strength should accommodate flight load factors and emergency crash load factors.

REQUIREMENT LESSONS LEARNED (3.4.5.6.6)

Rigid, internal, removable tanks should be supported to prevent failure under crash loads. Lug or screw mountings in the wall of the tank, even though this area is reinforced, has proven to be the first area of failure in an overload condition. A failure of the lugs will generally pull a section from the tank wall resulting in severe leakage. Mounting the tank in a cradle with tie down straps has proven to be more reliable than lugs in the tank wall. A crash resistant bladder installed in the cavity will provide much improved performance under crash conditions.

E.4.4.5.6.6 Internal auxilary fuel tanks removable tank support.

The support capability under crash loads for rigid internal fuel tanks shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.5.6.6)

Verification of removable internal auxiliary fuel tanks is a safety critical function to avoid injury or death to personnel under normal and transient conditions as well as under crash loads.

VERIFICATION GUIDANCE (4.4.5.6.6)

TBS: The tank support capability should be verified by component tests on the tank.

VERIFICATION LESSONS LEARNED (4.4.5.6.6)

Some applications of removable internal auxiliary fuel tanks require the capability to stack cargo on top of the tanks. This additional load can create a unique design load.

E.3.4.5.6.7 External tanks.

The tanks shall be designed to be structurally capable of satisfactorily reacting to flight induced aerodynamic and inertia loads including __(TBS)__. The tanks shall be integrated into the air vehicle's internal fuel system for the purposes of fueling, defueling, transfer control, quantity gaging, venting, and pressurization. The tanks shall be able to be fueled and defueled both through the air vehicle's internal fuel system (reference E.3.4.5.8.4, and E.3.4.5.8.13) and directly via the tank's refuel port.

For external fuel tanks intended for use on Naval aircraft (shipboard operations), the requirements of MIL-T-18847 section 3.15 shall be met.

REQUIREMENT RATIONALE (3.4.5.6.7)

If the air vehicle's mission requires the use of external tanks, the number, size capability, and location of the tanks should be identified.

If tanks are to be used on carrier-based aircraft, survivability requirements must be met.

REQUIREMENT GUIDANCE (3.4.5.6.7)

Values for blanks must be derived for each type air vehicle from its required missions. TBS should be filled in with consideration given to the following:

For Navy application, inertial loads should include catapult and arrestment landing loads. The fuel tank should be in accordance with MIL-T-18847.

The basic arrangement of the air vehicle, armament requirements, and the desired range should drive the requirement for external tanks. Some mission objectives could be achieved without external tanks; however, the use of external tanks provides much greater flexibility for the air vehicle. If this flexibility is desired by the user, the requirement for external tanks should be stated as an operational capabilities requirement in the air vehicle specification. The external tank and its captive carry tiedown hard points should be typically strength analyzed to satisfactorily react to all flight induced aerodynamic and inertia loads.

For jettisonable external tanks, the components for the vent control, fuel level control, and level control shutoff valve pre-check, if required, should be placed in the air vehicle unless system trade studies justify the increase in tank cost.

External tanks should not preclude the use of weapons on any store station not used by an external tank. Ground clearance should be sufficient to prevent ground contact under any combination of the following static or dynamic ground conditions:

a. One or more flat tires

b. One or more shock absorbers flat

c. Pitching and rolling or both caused by variations in anticipated runway and taxiway surfaces.

In addition, sufficient clearance and access will be provided for installing, filling, draining, and removing the tank.

For carrier-type air vehicles, the tank installation must clear the catapult bridle and the catapult bridle must not strike the tank at the end of the launching run.

The tank cannot obstruct a satisfactory barrier engagement of the aircraft.

REQUIREMENT LESSONS LEARNED (3.4.5.6.7)

It is difficult to add external tank hard points, fuel tubing, vents, and controls after the basic layout and design of the air vehicle has been completed. If external tanks are desired, the requirement should be identified early in the program.

For jettisonable tanks, a large number of tanks can be consumed in combat conditions; therefore, the external tanks will be considerably simpler and cheaper if the functional components are incorporated in the air vehicle. The weight of these components must be carried by the air vehicle even when the external tanks are not being carried by the air vehicle.

Navy has experienced loss of life due to catastrophic structural failure of nestable tanks on air vehicle carriers.

E.4.4.5.6.7 External tanks.

External tank number, size capability, and location shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.6.7)

The requirement for store compatibility with the air vehicle, and how many of what size tank must be installed at one time, must be verified.

VERIFICATION GUIDANCE (4.4.5.6.7)

TBS should be filled in with consideration given to the following:

The number, size, and location of external tanks should be verified by inspection.

The strength capability of the external tank and its captive carry tiedown hard points should be verified by static testing. The strength for catapult and arrested landing should be verified dynamically by test.

The detail design requirements for the tanks should be covered in the other appropriate sections of the specification such as vent section, and the transfer section.

VERIFICATION LESSONS LEARNED (4.4.5.6.7)

Function of the external tanks should be considered safety and mission critical.

E.3.4.5.6.8 External tanks installation time.

External tanks shall be capable of being installed or removed in __(TBS)__.

REQUIREMENT RATIONALE (3.4.5.6.8)

External tanks are generally designed for rapid installation or removal for fighter-type air vehicles to permit rapid reconfiguration of an air vehicle in relation to armament load and mission. On some other type air vehicles the external tanks are semi-permanently mounted. The requirement for rapid installation or removal must be defined.

REQUIREMENT GUIDANCE (3.4.5.6.8)

TBS should be filled in based on JSSG-2001 and required missions and turn around times or, in the absence of a firm operational requirement for rapid turn around, with a maximum of 15 minutes for the installation or removal of an external tank by a maximum of three people.

REQUIREMENT LESSONS LEARNED (3.4.5.6.8)

Installation times should be based on the expected usage and natural and induced environments of the system.

E.4.4.5.6.8 External tanks installation time.

External tanks installation and removal time shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.6.8)

The requirement for store compatibility with the air vehicle, and how many of what size tank must be installed at one time, must be defined.

VERIFICATION GUIDANCE (4.4.5.6.8)

TBS: The external tank installation or removal should be verified by analysis and demonstration. Conditions for the demonstration such as equipment availability, number of personnel allowed, space limitations due to revetments, and residual fuel in tank should be specified.

VERIFICATION LESSONS LEARNED (4.4.5.6.8)

Conducting verification demonstrations under operational conditions will provide the most realistic information to include in technical data.

E.3.4.5.6.9 External tank capability.

External tanks and their mounting provisions shall be capable of carriage and operation at __(TBS 1)__ and shall be jettisonable at speeds up to __(TBS 2)__.

REQUIREMENT RATIONALE (3.4.5.6.9)

The need for and intended use of external tanks should be specified. A requirement for supersonic flight for an external tank has a great impact on the design.

REQUIREMENT GUIDANCE (3.4.5.6.9)

TBS 1 should be filled in with the air vehicle operational envelope within which external tanks will be expected to function. The required operational envelope for external tanks must be derived from the mission profile of the air vehicle.

TBS 2 should specify the maximum speed at which external tanks may be jettisoned.

The requirement to carry external tanks at supersonic speeds or to jettison the external tanks prior to supersonic flight should be defined.

REQUIREMENT LESSONS LEARNED (3.4.5.6.9)

External tank design and interfaces should consider static and dynamic loading conditions as well as ground handling and maintenance.

E.4.4.5.6.9 External tank capability.

External tank operational envelope and jettison capability shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.6.9)

Sufficient tests should be conducted to verify the complete carriage and jettison speed envelope.

VERIFICATION GUIDANCE (4.4.5.6.9)

TBS: External tank speed and jettison capability should be verified by analysis and flight test. Sufficient tests should be conducted to verify the complete carriage speed envelope and the jettison envelope.

VERIFICATION LESSONS LEARNED (4.4.5.7.9)

Sufficient integrity should be designed into the tank and tank interfaces to meet operational and life requirements.

E.3.4.5.6.10 Self-sealing tank.

Self-sealing and partially self-sealing fuel tanks (and associated backing board if required) shall be necessary to self-seal after puncture from __(TBS 1)__ ordnances. The quantity of fuel to be protected shall be __(TBS 2)__.

REQUIREMENT RATIONALE (3.4.5.6.10)

The protection level for self-sealing tanks must be demonstrated by performance of a gunfire resistance test.

REQUIREMENT GUIDANCE (3.4.5.6.10)

These values should be derived for each type air vehicle. Also, these requirements should be considered in conjunction with the survivability and vulnerability requirements.

TBS 1 should be filled in with the size of the projectile against which the tank is expected to seal.

TBS 2 should be determined by mission analysis of the quantity of fuel in the tank after the tank has been punctured.

For fighter style air vehicles, self-sealing tanks that provide sufficient fuel from the longest mission to return to base should be considered.

Metallic fuel lines should not be installed in contact with the walls of a self-sealing tank.

Air vehicle fuel tanks should be self-sealing according to the appropriate type, class, style, and protection level per design specification MIL-DTL-5578.

REQUIREMENT LESSONS LEARNED (3.4.5.6.10)

Current tank configurations can seal against various ordinances as detailed in design specification MIL-DTL-5578 and as defined by the protection level assigned to the tank design.

In the Vietnam war, many air vehicles were modified to provide five minutes of protected fuel. Five minutes was sufficient to allow a damaged air vehicle to get out to sea for ditching and permit a safer rescue operation.

E.4.4.5.6.10 Self-sealing tank.

The protection level adequacy of self-sealing and partially self-sealing fuel tanks shall be verified by __(TBS 1)__. The quantity of protected fuel shall be verified by __(TBS 2)__.

VERIFICATION RATIONALE (4.4.5.6.10)

Self sealing fuel tanks are required to withstand an ordinance hit and be gun fire resistant with respect to not allowing leakage or tank failure after such hit. Component testing is used for such verification.

VERIFICATION GUIDANCE(4.4.5.6.10)

TBS 1: The adequacy of the self-sealing tanks should be verified by component testing. If the air vehicle contains two or more self-sealing tanks, the most complex shaped tank should be used for the test.

TBS 2: The quantity of protected fuel should be verified by analysis and component testing.

VERIFICATION LESSONS LEARNED (4.4.5.6.10)

The fuel tank used in the test should have an air vehicle structure with an adequate backing board for realistic results. Adequate test structures are difficult to obtain, if not provided for in the basic program plan.

E.3.4.5.6.11 Fuel tank location and separation.

Fuel tanks located adjacent to compartments which contain ignition sources shall be separated from such compartments by a second liquid-tight and vapor-tight barrier in addition to the barrier provided by the tank. A means to determine if the primary barrier (tank wall) has failed shall be provided.

REQUIREMENT RATIONALE (3.4.5.6.11)

Additional protection from fuel leakage must be provided for all areas of the air vehicle where there is a high probability of igniting fuel vapors.

REQUIREMENT GUIDANCE (3.4.5.6.11)

The following should be considered ignition source compartments: personnel, cargo, gun, engine or any compartments which contain an ignition source.

In air vehicles without crashworthy fuel systems, the fuel tanks should not be located over personnel compartments and should not be located in personnel or cargo compartments on a permanent basis.

Potential fire and ignition hazards should be protected from fuel leakage so that a single failure or single seal omission of the primary fuel barrier will not permit fuel leakage or spillage into these areas.

For air vehicle areas where there is a high probability that fuel leakage can be ignited, double barriers should be provided and sealing integrity verified. The fire zones and ignition zones should be separated from potential fuel leaks by a secondary barrier with a cavity between the two barriers. Secondary barriers may contain only one seal.

Each fuel barrier should be capable of being tested and the area between the two barriers should be continuously drained and vented to ambient conditions outside of the ignition zone. The drain outlet should be inspected for leakage which indicates a failure of the primary barrier.

A secondary fuel barrier should be required to prevent a single failure (leak) in the primary fuel barrier causing a fire hazard. The venting and draining of the cavity between the two barriers should permit detection of any leaks in the primary barrier. Without this feature, a single failure could go undetected until a failure of the secondary barrier occurs. The secondary barrier should address the pressure criteria which can occur in the cavity for normal leakage conditions and for testing.

All areas surrounding fuel tanks should be drained and ventilated to remove the fire hazard resulting in any fuel spillage or leakage. The drainage and ventilation openings should remain open at all times.

Location of fuel tanks above engine compartments should be avoided. If fuel tanks must be located above engine compartments for justifiable reasons, provisions should be made to prevent leakage of fuel into engine compartments or onto exhaust systems. A ventilated and drained space should be provided between fire wall and tank to afford safe disposal of any fuel leakage from the tank. In the event of an engine fire, insulation should also be provided to prevent ignition within the tank or in the shrouded air space.

REQUIREMENT LESSONS LEARNED (3.4.5.6.11)

This requirement applies to all types of fuel tanks, including permanent, temporary cargo, external and other types.

E.4.4.5.6.11 Fuel tank location and separation.

The fuel leakage protection for fire and ignition zones shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.6.11)

The freedom of fuel leakage from double barriers should be verified by analysis and inspection.

VERIFICATION GUIDANCE (4.4.5.6.11)

TBS: Fuel leakage protection for fire and ignition zones should be verified by leak tests of the primary and secondary barrier and proper draining and ventilation system.

VERIFICATION LESSONS LEARNED (4.4.5.6.11)

The B-2 and F-22 conducted fuel tank durability tests using scaled fuel tank mock-ups to ensure tank barriers could meet life requirements.

E.3.4.5.6.12 Tank access doors.

Each fuel tank shall have an access door(s) to permit __(TBS)__.

REQUIREMENT RATIONALE (3.4.5.6.12)

Good access to all interior parts of a fuel tank is necessary to permit inspection, cleaning, and repair of the tank.

REQUIREMENT GUIDANCE (3.4.5.6.12)

TBS: Each fuel tank should have an access door(s) to permit inspection, cleaning, and repair of the entire interior surface of the tank and access to fuel components. Door seals should be designed for expected usage including periodic removal and reinstallation.

REQUIREMENT LESSONS LEARNED (3.4.5.6.12)

The size and shape of a flexible tank will determine the size of the access door. The access door size for flexible tanks will generally be greater than required from the human factors standpoint.

E.4.4.5.6.12 Tank access doors.

Tank access will be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.6.12)

Access to fuel tanks should demonstrate maintenance derived requirements.

VERIFICATION GUIDANCE (4.4.5.6.12)

TBS: Tank access should be verified by analysis and demonstration.

VERIFICATION LESSONS LEARNED (4.4.5.6.12)

Verification of access for flexible tanks should be accomplished early in the program by the use of a tank and door mockup.

E.3.4.5.6.13 Crashworthiness.

All fuel tanks, attachments, manifolds, fuel lines, and fittings installed inside the air vehicle shall be crashworthy. Each fuel tank configuration in the air vehicle shall be capable of withstanding, without leakage, __(TBS)__ foot per second impact.

Fuel tanks, attachments, manifolds, fuel lines, and fittings shall be designed to allow relative movement and separation between the tank and structure without fuel spillage during a survivable crash. Crashworthy fuel systems shall adhere to MIL-STD-1290, including all internal, external, and auxiliary fuel tanks.

REQUIREMENT RATIONALE (3.4.5.6.13)

Relative motion between the fuel tank, plumbing, and structure is unavoidable during a survivable crash. Leakage at fittings, valves, or attach points will occur unless specifically designed to prevent leakage.

REQUIREMENT GUIDANCE (3.4.5.6.13)

TBS should be filled in with the maximum survivable impact velocity of a human being. Fuel tanks and systems should be crashworthy in accordance with MIL-STD-1290. If the tanks are to be crashworthy and self sealing, the tanks must comply with MIL-DTL-27422D. USAAVSCOM TR 89-D-22A, Aircraft Crash Survival Design Guide, gives further guidance on the design of crashworthy systems.

Self-sealing break-away couplings should be used to prevent large fuel leaks during hard impact landings and uncontrolled flight landings.

REQUIREMENT LESSONS LEARNED (3.4.5.6.13)

The maximum survivable impact velocity of a human being is currently understood to be approximately 60 ft/sec.

E.4.4.5.6.13 Crashworthiness.

All fuel tanks installed inside the air vehicle shall be crashworthy. Each fuel tank configuration in the air vehicle shall be capable of withstanding, without leakage, a __(TBS 1)__ foot free-fall drop, onto a non-deforming surface when filled to maximum capacity with water for testing. If desired, the test can be performed with a representative portion of air vehicle structure surrounding the tank. The capability of each fuel tank configuration to withstand the free-fall drop test shall be verified by __(TBS 2)__.

VERIFICATION RATIONALE (4.4.5.6.13)

Crashworthiness requirements should be defined early in the design process to ensure sufficient strength is included in the mounts and other components.

VERIFICATION GUIDANCE (4.4.5.6.13)

TBS 1 should be filled in with corresponding vertical height equal to the maximum load expected during a crash.

TBS 2 should be filled in with component test.

VERIFICATION LESSONS LEARNED (4.4.5.6.13)

The production tank with all openings suitably closed should be filled to normal capacity with water and air removed. The fuel tank should be placed upon a platform and raised to a height of 65 feet. A light cord may be used to support the tank in its proper attitude. Tanks installed in air vehicle structure should be raised to a height of 65 feet; no platform should be used. The platform and structure should be released and allowed to drop freely onto a non-deforming surface so that the tank and structure should impact in a horizontal position ±10°. After the drop, there should be no visible leakage.

E.3.4.5.7 Fuel tank inerting and explosion suppression.

Fuel tanks and vent subsystems in which air-fuel vapors may be exposed to ignition sources (such as incendiary gunfire, missile fragments, hot engine fragments, high wall temperatures, electrical failures, and naturally occurring electrical discharges, etc.) shall be equipped so that fires and over pressures from explosions cannot occur in these areas. The inerting and explosion suppression subsystem shall not cause tank pressure in excess of __(TBS)__.

REQUIREMENT RATIONALE (3.4.5.7)

TBS should not exceed tank structural limits, or prevent transfer of fuel as a result of any single failure.

The ullage in a fuel tank contains a combination of fuel vapor and air which may or may not be in a combustible mixture depending on the energy level of potential ignition sources.

REQUIREMENT GUIDANCE (3.4.5.7)

A study should be conducted for all hazardous areas to determine the most efficient method of eliminating the unsafe condition. Combat (survivability) and non-combat (safety, lightning, static, etc.) conditions should be analyzed to determine the hazards to protect against.

The application of a passive means to reduce the explosion hazard, such as filling the tank with explosion suppressant foam, is one of a number of techniques which has proven effective.

There are a number of active systems which are available for explosion prevention. A supply of inert gas, such as nitrogen, constantly piped into the ullage can be an effective means to eliminate the explosion hazard. This can be accomplished by using either a stored source of nitrogen or nitrogen generator like the Onboard Inert Gas Generating System (OBIGGS). These techniques require plumbing, storage bottles, valves and other associated components. Whatever the design choice, it should be judged on its merits to prevent explosions and also for its effect on maintainability, reliability, performance, and reparability.

Fuel lightning hazards. The fuel subsystem should be safe from fire and explosion hazards caused by direct lightning strikes. Lightning strike should be considered in the design of a fuel subsystem to minimize the probability of a fuel fire or explosion and the malfunction of the fuel subsystem components.

Baffle systems. The baffle material should not degrade the performance of the fuel subsystem beyond the limits specified in the fuel system detail specification. The fuel subsystem should meet all performance requirements with or without the baffle material installed, excluding the explosion protection provided by the baffle material. It should be possible to remove the baffle material from the tanks and operate the air vehicle without removing or adding any other hardware. Any components fastened in the tank because of the baffle material, should be sufficiently tested to verify that these components can be retained if the baffle material is removed. The baffle material should be included in all simulator and ground and flight tests.

Nitrogen inerting systems. Nitrogen inerting should be provided for all fuel tanks. The nitrogen inerting system should be completely automatic and should require no attention from the flight crew during flight except for the monitoring of associated caution and advisory lights. The system should prevent explosions and fire by diluting and maintaining the oxygen concentration below 9 percent (9%), in the fuel tank(s) ullage space, without the use of ground equipment. Nitrogen gas should pressurize the ullage and vent spaces during decreases in altitude to maintain a safe differential pressure between the tanks and ambient pressure. The nitrogen inerting system should maintain inert ullage and vent spaces with no electrical power applied for a minimum of 5 minutes with a 10 square inch hole in any one fuel tank.

At no time should the positive or negative pressures in the fuel tanks and vents exceed the design pressure limits of the air vehicle regardless of failure of any component.

REQUIREMENT LESSONS LEARNED (3.4.5.7)

The protection of an air vehicle from lightning should be addressed at the air vehicle system level. The locations of lightning attachments, the magnitude of the lightning strike, and the ignition of fuel within a fuel tank are all probabilistic events. The ignition of fuel is driven by the type of fuel, the mission profile of the air vehicle, the temperature environment during the mission, and the incorporation of other equipment on the air vehicle such as a fuel tank inerting system. All of these parameters must be combined by a Safety Hazard Risk Analysis to quantify the risk to the air vehicle from lightning. The acceptable risk level for fuel tank lightning protection should be consistent with risk levels for all other air vehicle elements such as air vehicle structure failure, engine failure, flight control system failure, hydraulic system failure, and loss of air vehicle from bird strike.

Paramount to the design of fuel subsystem lightning protection is the Lightning Zone designation of the air vehicle and the fuel tank area. After zones of the air vehicle have been designated, MIL-STD-1757 specifies standard test criteria to be used for testing of components and air vehicle tank skin in each zone. MIL-STD-1757 defines Zone 1A as an "initial attachment point with low probability of flash hang-on, such as a leading edge" and Zone 2A as a "swept stroke zone with low probability of flash hang-on, such as a wing mid-span". Items in zone 1A are tested with a component A waveform which has a peak amplitude of 200 KA and an action integral of 2 x $10^{-6} A^2 s$. Items in zone 2A are tested with a component C waveform which has a peak amplitude of 100 KA with an action integral of 0.25 x $10^{-6} A^2 s$. Based on these action integrals, there is an 8-fold increase in energy applied to the test article between zones 2A and 1A. Therefore, the zone designation is the major driver on tank design for lightning strike for composite fuel tanks. The increase in energy transfer does not impact metal tanks as severely due to the inherent capability of metal to conduct current. Overly conservative zoning of the air vehicle has a major impact on the protection required for fuel subsystem.

Direct Effects test procedure. Combustion Vapor Ignition of MIL-STD-1757 lists photography as the preferred technique for detecting sparks. A camera is mounted in a light-tight chamber behind the test article. The shutter of the camera is opened during the lightning strike. Any light on the film indicates a spark and the test sample have failed. This is a simple test to conduct and a simple method to evaluate. This procedure is extremely conservative and does not address the energy content of the spark and the minimum energy necessary to ignite the fuel.

An "ignition criteria" is a less conservative method of evaluating the test success and provides an indication of the energy of any spark that is produced during the test. In this method, an optimum explosive vapor (a fuel mixture slightly richer than a stoichiometric mixture) is placed adjacent to the test article. This optimum mixture can be ignited with a minimum ignition energy. If the explosive vapor does not ignite as a result of the test lightning strike, then the vapor is ignited by a spark plug to verify that an explosive vapor was present in the test chamber.

A propane air and gas mixture has been used as the explosive vapor on several test programs. The correct mixture with propane is easy to obtain and provides repeatable results. With propane, the testing can be performed at room temperature. Air vehicle fuel tests are more difficult to conduct, but a realistic temperature effect on the tank material is tested in the range necessary to obtain the fuel mixture.

The B-2 program conducted skin panel lightning tests to evaluate the improvement in safety afforded by the conversion of the air vehicle to JP-8 as the primary fuel, with JP-4 designated as an emergency fuel only. A "worst case" batch of JP-8 with a flash point of approximately 100°F was obtained for the test. A procedure was developed to provide an optimum mixture for the test chamber. The procedure was developed using a bomb sampler to measure the maximum pressure rise and the pressure rise time. A maximum pressure rise or a minimum rise time both indicate a near optimum mixture. This optimum mixture will ignite at a minimum energy level. It was determined that the near optimum mixture was obtained at a temperature of 150°F for the test fuel. Higher flash point fuel will require a higher optimum mixture temperature. It is estimated that the optimum mixture temperature will occur approximately 50 degrees above the flash point. The prime contractor conducted additional tests to determine the ignition energy of JP-8 as a function of fuel temperature. As the temperature of the fuel is varied from the optimum temperature the energy required to ignite the fuel goes up.

The panel tests were all conducted at the optimum temperature; therefore, this is conservative with respect to the air vehicle fuel tank conditions. The panels were tested in the new condition. The effects of aging were not investigated. The air vehicle will only rarely be at the optimum temperature. Although there was light on several of the test strikes there was only one ignition at the 200 KA test level during the test. The test results were used to define a probability of ignition for use in a hazard analysis model.

Reference Aero Propulsion Laboratory reports, AFWAL-TR-85-2057 and AFAPL-TR-75-70, for information on fuel ignition.

Commercial air vehicle designers use FAA Advisory Circular 20-53 and its associated Manual AC-20-53 for guidance for protection of airplane fuel subsystems from lightning strikes.

E.4.4.5.7 Fuel tank inerting and explosion suppression.

Operation of the fuel tank inerting and explosion suppression subsystem shall be verified by (TBS 1). The effects of the inerting and explosion suppression system shall be verified by (TBS 2).

VERIFICATION RATIONALE (4.4.5.7)

Fuel tank inerting and explosion suppression is important to satisfy safety and mission critical conditions.

VERIFICATION GUIDANCE (4.4.5.7)

TBS 1: Performance of the fuel tank inerting and explosion suppression subsystem should be verified by analysis, component, subsystem, and air vehicle flight tests.

TBS 2: The air vehicle risk from fire and explosion hazard due to lightning should be verified by analysis, component, and subsystem tests as defined by MIL-STD-1757.

VERIFICATION LESSONS LEARNED (4.4.5.7)

The B-2 has operated safely since 1989 using the methods defined in this requirement.

E.3.4.5.8 Refueling and defueling

E.4.4.5.8 Refueling and defueling

E.3.4.5.8.1 Ground refueling rate.

With the air vehicle on the ground and 10 percent fuel onboard, the fuel subsystem shall permit fueling of all tanks, both internal and external, to design capacity in a flow time not to exceed (TBS 1) with (TBS 2) to source.

REQUIREMENT RATIONALE (3.4.5.8.1)

The time allowed to refuel the air vehicle must be specified. The refueling time should be considered in relation to the required turnaround time of the air vehicle and the capability of the interfacing ground equipment.

REQUIREMENT GUIDANCE (3.4.5.8.1)

TBS 1: The allowed refueling time should be derived from JSSG-2000 requirements.

TBS 2: The refueling source(s) should be identified. The pressure and flow rate available will be determined by the equipment identified. Fuel velocity entering the tank and in line fuel velocity should be considered to minimize static charge generation. In general, a maximum of 30 feet per second (ft/sec) should be considered an acceptable fuel line velocity. A maximum of 20 ft/sec is preferred for larger air vehicles. A maximum recommended tank entry velocity is 10 ft/sec.

REQUIREMENT LESSONS LEARNED (3.4.5.8.1)

If a required time has not been specified by the user, the refuel times depicted in table E-IV should be considered the design objective.

TABLE E-IV. Pressure refueling times.

Ground Refueling		
Total Air Vehicle Fuel Weight (Pounds)	No. of Servicing Adapters	Maximum Time* for 90% Load (Minutes)
450,000	4	60
350,000	4	45
250,000	2	32
100,000	2	20
50,000	1	15
25,000	1	10
10,000 less	1	5

*NOTES:

If less, the aerial refueling time has precedence over ground refueling time.

These times are for flow times only and do not include time for positioning the air vehicle or refueling equipment.

The time to refuel is dependent on the time to refuel the slowest or the largest tank on the air vehicle. The flow rate to each tank should be balanced so that all tanks obtain their capacity shut-off point at the same time. This will produce the minimum time to refuel. The 10 percent (10%) initial load should be distributed in tanks which would naturally occur in the pump down of the system.

The refuel rate for air vehicles which incorporate auxiliary tanks should be optimized based upon the auxiliary tanks not being installed. Refueling rate requirements when the auxiliary tanks are installed should be either stated by the procuring activity, or derived from the specific missions requiring the use of auxiliary fuel tanks.

E.4.4.5.8.1 Ground refueling rate.

The flow time to refuel the air vehicle to capacity shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.5.8.1)

The time to refuel the fuel tanks must be verified to ensure the air vehicle can meet its mission requirements.

VERIFICATION GUIDANCE (4.4.5.8.1)

TBS: The time to refuel the air vehicle to capacity should be demonstrated by analysis, test rig, and refueling an actual air vehicle.

VERIFICATION LESSONS LEARNED (4.4.5.8.1)

The starting condition for the refueling must be specified. It is rare that an air vehicle in a service environment will be empty; therefore, a starting condition of 10 percent of maximum fuel weight distributed in a manner resulting from normal use of the system is recommended.

It is difficult to obtain ground refueling equipment that will deliver the exact pressure and flow capacity that is required for the demonstration; therefore, the flow time may be corrected to account for any difference in delivery pressure.

E.3.4.5.8.2 Receiver aerial refueling rate.

Reference appendix F, F.3.4.6.2.1.2, Receiver aerial refueling rate.

REQUIREMENT RATIONALE (3.4.5.8.2)

Reference appendix F, F.3.4.6.2.1.2, Receiver aerial refueling rate.

REQUIREMENT GUIDANCE (3.4.5.8.2)

Reference appendix F, F.3.4.6.2.1.2, Receiver aerial refueling rate.

REQUIREMENT LESSONS LEARNED (3.4.5.8.2)

Reference appendix F, F.3.4.6.2.1.2, Receiver aerial refueling rate.

E.4.4.5.8.2 Receiver aerial refueling rate.

Reference appendix F, F.4.4.6.2.1.2, Receiver aerial refueling rate.

VERIFICATION RATIONALE (4.4.5.8.2)

Reference appendix F, F.4.4.6.2.1.2, Receiver aerial refueling rate.

VERIFICATION GUIDANCE (4.4.5.8.2)

Reference appendix F, F.4.4.6.2.1.2, Receiver aerial refueling rate.

VERIFICATION LESSONS LEARNED (4.4.5.8.2)

Reference appendix F, F.4.4.6.2.1.2, Receiver aerial refueling rate.

E.3.4.5.8.3 Refueling power conditions.

The fuel subsystem shall be able to refuel and automatically shut off under __(TBS)__ power conditions.

REQUIREMENT RATIONALE (3.4.5.8.3)

Refueling systems can be designed which do not require electrical power, which can operate on air vehicle battery power, auxiliary power unit or external power. Restrictions on the application of power, internal or external, for reasons of safety or air vehicle self-sufficiency should be specified.

REQUIREMENT GUIDANCE (3.4.5.8.3)

TBS should be filled in with consideration given to the following: The air vehicle should be capable of being refueled to capacity without external electrical power applied to the air vehicle. The air vehicle should be capable of being refueled to any intermediate level with only internal electrical power applied to the air vehicle. It is possible to design a refuel subsystem which can shut off at the full level by hydromechanical valves. Intermediate fuel levels require some form of electrical power.

REQUIREMENT LESSONS LEARNED (3.4.5.8.3)

Refueling at remote operating locations may be required with the availability of external power.

E.4.4.5.8.3 Refueling power conditions.

Refueling capability under specified power conditions shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.8.3)

Verification of refueling power conditions is necessary to ensure that operational requirements for refueling can be met.

VERIFICATION GUIDANCE (4.4.5.8.3)

TBS: Verification under specified power conditions should be accomplished by analysis and a refueling demonstration.

VERIFICATION LESSONS LEARNED (4.4.5.8.3)

Refueling power conditions should be considered a mission critical requirement.

E.3.4.5.8.4 Pressure refueling.

The air vehicle shall be capable of __(TBS)__. The adapter shall be in accordance with the international pressure fueling connection air vehicle standards of MIL-A-25896.

REQUIREMENT RATIONALE (3.4.5.8.4)

The requirement for pressure refueling should be specified if required.

REQUIREMENT GUIDANCE (3.4.5.8.4)

TBS should be filled in with consideration given to the following:

All air vehicles with a fuel capacity of 600 gallons or greater should incorporate pressure refueling. The ground pressure refueling connection and refueling pressures were standardized by international agreement (NATO STANDARD AASSEP-2 and NATO STANAG 3105). This standard should be used unless special requirements can be justified.

The MS24484 adapter implements international agreements and is compatible with the legacy Military Specification MIL-N-5877 nozzle which is currently installed on USAF pressure refueling equipment. MIL-N-5877 has been replaced by SAE AS5877.

The air vehicle should be capable of pressure refueling at steady state pressures between 20 and 55 psig, measured at the inlet to the air vehicle refueling subsystem.

The refueling adapter should be compatible with pressure fuel servicing nozzles having a straight or 45° inlet. The adapter should be installed with the adapter face as nearly as possible in the vertical plane.

Pressure refueling is accomplished by connecting the ground refueling hose to the air vehicle refueling manifold. Fuel is delivered to each tank under pressure by an air vehicle fuel manifold.

REQUIREMENTS LESSONS LEARNED (3.4.5.8.4)

In addition to ease of refueling provided by pressure refueling, this method is considerably safer than the gravity (over the wing) method. In the gravity method, fuel vapor is expelled through the filler cap opening beside the fuel nozzle. The need for pressurized high flow rate fueling systems as the primary method for refueling military and commercial airplanes has emerged because of the following considerations:

a. Increased fuel capacity of airplanes

b. Faster turnaround time required

c. Less ground handling equipment necessary

d. Safety to operator of single point filling

e. Reduced damage to air vehicle skins due to personnel walking on the air vehicle

f. Reduction of contamination introduction into system

g. Aerial refueling

The 600 gallons size recommendation is an arbitrary dividing point. In general, small air vehicles with only a few tanks to refuel can avoid the complication, weight, and cost of a pressure refueling system. All air vehicles should incorporate a gravity refueling capability at least in each main tank for backup in case the refueling adapter is damaged.

E.4.4.5.8.4 Pressure refueling.

The pressure refueling capability shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.8.4)

Pressure refueling verification should assess mission requirements to determine the level of verification

VERIFICATION GUIDANCE (4.4.5.8.4)

TBS: The pressure refueling capability should be verified by analysis and aircraft test. The type of pressure refueling adapters should be verified by inspection.

VERIFICATION LESSONS LEARNED (4.4.5.8.4)

Pressurized refueling has the potential to create high surge pressures. Valve closure rates should be evaluated to ensure that no pressure transients occur.

E.3.4.5.8.5 Adapter location.

The ground refueling adapter shall be located to safely permit ___(TBS)___ and avoid environmental contamination from entering the fuel system.

REQUIREMENT RATIONALE (3.4.5.8.5)

Some missions require accomplishing other functions while the air vehicle is being refueled. Fighter air vehicles have frequently required ammunition or armament loading during refueling. Cargo air vehicles could require cargo loading during refueling.

REQUIREMENT GUIDANCE (3.4.5.8.5)

TBS should be filled in with operations allowed to take place concurrently with refueling of the air vehicle.

The mission plans should be reviewed to determine what operations are required during refueling. Simultaneous operations during refueling should be identified as early as possible.

REQUIREMENT LESSONS LEARNED (3.4.5.8.5)

Relocating the refueling adapter after the initial design has been approved is very difficult. Good design practice is to locate the adapter so that ground support elevating devices are not required for connecting the nozzle; however, some air vehicle designs such as the B-2 may not have any suitable air vehicle structure which can be reached from ground level for location of the refueling connection. For this situation a support device must be provided.

For air vehicles where hot refueling is required, the adapter should be located compatible with other types of air vehicles. F-15, F-16, and F-22 refuel from the left side.

E.4.4.5.8.5 Adapter location.

The ability to conduct simultaneous operations shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.8.5)

Verification should be accomplished considering all interface and operational requirements.

VERIFICATION GUIDANCE (4.4.5.8.5)

TBS: Simultaneous operations during refueling should be verified by analysis and a ground demonstration.

VERIFICATION LESSONS LEARNED (4.4.5.8.5)

Low observable requirements may create additional interface requirements on where refuel adapters may be located.

E.3.4.5.8.6 Refueling adapter leakage prevention.

The ground refueling adapter installation shall prevent external leakage in the event of adapter poppet leakage.

REQUIREMENT RATIONALE (3.4.5.8.6)

This is a safety requirement and should not be tailored.

REQUIREMENT GUIDANCE (3.4.5.8.6)

Fuel pressure applied to the back side of a damaged ground refueling adapter will result in a fuel leak. The damage to the adapter can go undetected during ground refueling.

Cracked housings, stuck or cocked poppets, and damaged poppet seals have been a common problem with the ground refueling adapters.

Fuel pressure from the fuel transfer subsystem or from aerial refueling should be isolated from the back side of the refueling adapter by the use of a check valve or by a motor operated valve. If a check valve is used, a manual override for the check valve should be considered if the refueling adapter is used for the defueling process.

REQUIREMENT LESSONS LEARNED (3.4.5.8.6)

When employing an isolation valve between the single point receptacle and the fuel system ensure that the isolation valve does not create high pressure transients on closure.

E.4.4.5.8.6 Refueling adapter leakage prevention.

The refueling adapter isolation from fuel pressure during flight shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.8.6)

Refueling adapters provide redundancy to prevent a large fuel spill in the event that the refueling adapter fails.

VERIFICATION GUIDANCE (4.4.5.8.6)

TBS: The isolation of the refueling adapter should be verified by analysis of system design parameters, aircraft tests and by inspection of the air vehicle.

VERIFICATION LESSONS LEARNED (4.4.5.8.6)

Isolation valves can become unstable during high velocity flow and create high pressure transients upon closing.

E.3.4.5.8.7 Gravity refueling.

The fuel subsystem shall provide the capability to __(TBS)__. The gravity refuel interface provisions shall be in accordance with the international standardization agreements STANAG 3212 and STANAG 3294. A grounding receptacle shall be provided for bonding the gravity refuel nozzle to the air vehicle.

REQUIREMENT RATIONALE (3.4.5.8.7)

A requirement for gravity refueling should be specified. Gravity refueling is accomplished by flowing fuel directly into an air vehicle fuel tank(s). Fuel flowing through a gravity nozzle can produce static electricity. Unless the nozzle is bonded to the air vehicle, sparks may be produced at the nozzle and filler opening.

REQUIREMENT GUIDANCE (3.4.5.8.7)

TBS should be filled in with gravity refueling.

All air vehicles should incorporate a gravity refueling capability. A standard grounding receptacle per MIL-DTL-83413/6 should be provided near each gravity filler opening.

The international standard agreements for gravity filling orifices are ASCC AIR STD 25/11 and STANAG 3212. International standards for grounding are covered by STANAG 3632.

REQUIREMENT LESSONS LEARNED (3.4.5.8.7)

A gravity refueling capability is desired in the event of a pressure refueling adapter breakage at a remote site where a replacement part is not available or when an air vehicle must be refueled and pressure refueling equipment is broken or not available. Gravity refueling is considered as an emergency backup capability for large air vehicles and may be the only refueling capability for a small air vehicle.

Some air vehicles have a filler cap on each tank. The current trend has been to incorporate a filler cap on each main tank.

The main tanks can be gravity refueled and then transfer to other air vehicle tanks by the air vehicle transfer system to obtain the desired load.

E.4.4.5.8.7 Gravity refueling.

The gravity refueling capability shall be verified by __(TBS 1)__. The grounding receptacles shall be verified by __(TBS 2)__.

VERIFICATION RATIONALE (4.4.5.8.7)

(TBD)

VERIFICATION GUIDANCE (4.4.5.8.7)

TBS 1: The gravity refueling capability should be verified by a demonstration.

TBS 2: The presence of MIL-DTL-83413/6 grounding receptacles should be verified by inspection. Resistance tests of the receptacle to structure should be made to verify proper bonding of the receptacle.

VERIFICATION LESSONS LEARNED (4.4.5.8.7)

(TBD)

E.3.4.5.8.8 Hot refueling.

The air vehicle shall be capable of being refueled with __(TBS)__ operating.

REQUIREMENT RATIONALE (3.4.5.8.8)

The requirement to refuel with an engine operating (hot refueling) or to use an air vehicle APU to provide electrical power for refueling in lieu of battery power or external power should be identified.

REQUIREMENT GUIDANCE (3.4.5.8.8)

TBS should be filled in with either engine or APU.

The refueling of an air vehicle is a hazardous operation. The operation of an engine or APU during hot refueling increases the hazard. The requirement for hot refueling should be defined early in the program by the using command.

REQUIREMENT LESSONS LEARNED (3.4.5.8.8)

Hot refueling reduces the required ground equipment at a base and improves air vehicle turn around time. Operation of an APU can reduce battery size especially under cold temperature conditions. A requirement for hot refueling has a large impact on the vent outlet location, refueling adapter and controls location, and the required reliability of the refueling system. The vent outlet location in relation to hot brakes and engine or APU exhaust wake should be considered.

E.4.4.5.8.8 Hot refueling.

The capability of being refueled with an engine or APU operating shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.8.8)

(TBD)

VERIFICATION GUIDANCE (4.4.5.8.8)

TBS: The capability to refuel with the engine or APU operating should be verified by a demonstration.

The Using Service should conduct a satisfactory system safety analysis in accordance with that service's policies, procedures and directives prior to performing any hot refueling operations.

VERIFICATION LESSONS LEARNED (4.4.5.8.8)

T.O. 00-25-172 can be used for hot refueling guidance.

E.3.4.5.8.9 Helicopter in flight refueling (HIFR).

If required, rotary wing air vehicles shall be provided with the capability to HIFR. Air vehicle HIFR refueling provision adapter shall be in accordance with MIL-A-25896.

REQUIREMENT RATIONALE (3.4.5.8.9)

Most rotary wing air vehicles require HIFR capability to meet design mission requirements.

REQUIREMENT GUIDANCE (3.4.5.8.9)

The air vehicle HIFR system should be capable of receiving fuel at the flow rates and at the pressures defined in STANAG 1280 and STANAG 3487.

The air vehicle should be configured with HIFR capability which utilizes a Single Point Refueling (SPR) adapter in accordance with NATO STANDARD AASSEP-2, STANAG 3105, and MS24484. The adapter location should allow manual connection of an SPR nozzle in the cabin.

The requirement to monitor for water, and/or removal of water from, the fuel during HIFR should be considered and provisions should be made.

The requirement for HIFR capability should be specified by the procuring activity.

REQUIREMENT LESSONS LEARNED (3.4.5.8.9)

Helicopter in-flight refueling has been a legacy requirement in virtually all naval helicopters. Recent feedback from helicopter operators indicates that HIFR may not be conducted as part of normal operations, or as frequently as it has been on legacy helicopters. Although HIFR may not be part of normal mission operations, it may still be a viable emergency refueling capability for shipboard operations in rough-sea states.

E.4.4.5.8.9 Helicopter in flight refueling (HIFR).

The air vehicle HIFR capability shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.5.8.9)

The ability to HIFR is important to the mission of the helicopter and should be verified to ensure it can be safely accomplished.

VERIFICATION GUIDANCE (4.4.5.8.9)

TBS: Helicopter in in-flight refueling capability should be verified by component test, ground testing, and flight test.

VERIFICATION LESSONS LEARNED (4.4.5.8.9)

(TBD)

E.3.4.5.8.10 Fuel subsystem refueling pre-check.

A pre-check capability shall be provided prior to or during the first minute of refueling.

REQUIREMENT RATIONALE (3.4.5.8.10)

Assurance that the level control valves are operable and will close when each tank reaches the full or preset fuel level is critical during pressure refueling, and a hot refueling exercise when air vehicle engines are turning. New, stringent environmental regulations and reporting procedures for fuel spills make this a highly desirable feature.

REQUIREMENT GUIDANCE (3.4.5.8.10)

This is a safety requirement and should not be tailored. Pre-check should not be implemented prior to aerial refueling, unless failure to shut-off refueling flow can result in a catastrophic failure or an unsafe operating condition. A failed pre-check status will not preclude aerial refueling.

REQUIREMENT LESSONS LEARNED (3.4.5.8.10)

Without a pre-check feature, the first sign of a valve failure could be fuel spilling out of the vent. A pre-check feature is considered to improve the safety of ground refueling. A pre-check system which operates the valves in a normal manner is preferred.

A “float the float” method where fuel is admitted to chamber surrounding the valves control floats has proven very reliable. A fuel bypass line controlled by a solenoid valve permits fuel flow to the chamber. As the chamber fills the control floats will raise thereby activating the valve. When the valves close, a drastically reduced fuel flow on the refueling unit flowmeters will verify that the valves have closed. The chamber will drain when the bypass flow is stopped.

The pre-check can be mechanically or electrically controlled.

E.4.4.5.8.10 Fuel subsystem refueling pre-check.

The pre-check capability shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.5.8.10)

The pre-check mechanisms must work and be verified to ensure the fuel system will meet its safety requirements, not overflow, nor cause a spill.

VERIFICATION GUIDANCE (4.4.5.8.10)

TBS: The presence and operation of the pre-check system should be verified on the fuel test rig and during a ground refueling demonstration.

VERIFICATION LESSONS LEARNED (4.4.5.8.10)

(TBD)

E.3.4.5.8.11 Static discharge in fuel tanks.

The fuel subsystem shall minimize static electricity discharge within the fuel tanks by __(TBS) and system.

REQUIREMENT RATIONALE (3.4.5.8.11)

Each air vehicle must incorporate design principles and features to minimize the possibility of sparks and ignition sources occurring within the fuel tank. The system design must consider fuels having both good conductivity and poor conductivity. A mandatory electrical conductivity additive has been introduced into JP-4 and JP-8 fuels to minimize static electricity buildup; however, good design practices must continue to be incorporated, as the electrical conductivity additive is not required for air vehicle operations should continue to be incorporated. The primary concern for static electricity is with a highly volatile fuel which does not contain the electrical conductivity additive. Most commercial fuels do not contain electrical conductivity additives.

REQUIREMENT GUIDANCE (3.4.5.8.11)

TBS should be filled in with the fuel subsystem will minimize static electricity discharge with consideration given to the following:

The refueling subsystem should prevent sparking or ignition sources occurring within the fuel tanks during ground and aerial refueling by:

a. Electrical bonding of all fuel components to structure with a bond resistance of 10 megohms or less, or until proven safe based on the components capability not to produce the minimum ignition energy of 0.25 millijoule.
b. Limiting fuel velocities within lines to no more than 30 ft/sec (20 ft/sec or less is preferred).
c. Limiting tank entry fuel velocity to no more than 10 ft/sec.

d. Ensure fuel flow enters a tank only at the tank bottom with induced flow circulation along the tank bottom surface.

e. Gravity refuel caps should be manufactured from a material that will not cause an internal arc when lightning attaches to the exterior.

f. Metallic chain lanyards inside the tank should be avoided.

g. The fuel subsystem tubing and components should be electrically bonded to eliminate static charge accumulation, provide controlled current return paths, and provide lightning protection.

REQUIREMENT LESSONS LEARNED (3.4.5.8.11)

These guidance items have been proven beneficial in reducing static build up. Additional information on static electricity is presented in AFAPL-TR-78-56, AFAPL-TR-78-89, and AIR 1662. Ground refueling equipment has been improved to minimize charge generation in the refueling equipment by controlling the type and location of filters in the system, minimizing fuel velocities, and providing charge relaxation capability prior to entering the air vehicle. Insuring good tank surface contact of the incoming fuel and providing fuel circulation as it enters the fuel tank will assist charge relaxation of the fuel. Surface contact and fuel circulation techniques also apply to aerial refueling.

The minimum ignition energy verification is accomplished by measuring the capacitance (C) of the component and then the voltage (V_b) at which electrical discharge occurs. If $E = {}^1/_2 C(V_b)^2$ is less than 0.25 millijoules, the component is safe without bonding. It was determined on the B-2 air vehicle that even though the fuel tanks are of a graphite composite construction the requirements are no different than for a metal tank. The conductivity of the graphite composite material is sufficient that in relation to static electricity any charge generated can be dissipated. The limiting factor was determined to be the conductivity of fuel tank surface coatings.

For electrical bonding, air vehicle applications to date have used MIL-B-5087 and MIL-STD-1818. Different bonding classifications were defined in MIL-B-5087. Class C bonding for current return path of electrical components, Class H for shock hazard, Class L for lightning protection, Class R for radio frequency (rf) potential, and Class S for static charge. For fuel tank installations Class C, L and Class S were of concern. In all cases the concern is for sparks or ignition sources occurring within the fuel tank which can ignite fuel vapors. Each class of bonding must be considered individually for effects on the system. However, the most severe applicable requirement for each component installation must be met for the bonding to be acceptable.

MIL-B-5087B Interim Amendment 3 was the last version of this currently cancelled specification. Amendment 3 attempted to moderate the static bonding requirements and to address the very small metallic items which could be installed inside a fuel tank. Small items are defined as items not large enough to accumulate a charge of sufficient magnitude that when discharged through an optimum point gap will not ignite an optimum fuel-vapor mixture. For small components, Amendment 3 permitted a laboratory test to measure the energy of any discharge which could result. If the spark energy was less than the minimum ignition energy of fuel, 0.25 millijoules, the component did not require bonding.

For static charge dissipation an electrical bond of 10 megohms is sufficient to prevent accumulation of charge on the fuel or fuel subsystem components; however, Amendment 3 retained the requirement for major components to be bonded with a resistance not to exceed one ohm. The one ohm requirement was retained because this level had been easy to obtain when mounting components on metal structures and was easy to measure and verify the required bond resistance.

The conservative 1 ohm bond resistance requirement is difficult to obtain and verify, and costly to maintain for composite structures. Although a 10-megohms bond is sufficient to bleed static charge, it is not known if a major component which is installed with a bond resistance of 10 megohms or slightly less will maintain this resistance for the life of the air vehicle or after the component has been replaced. A resistance value for a new installation must be established which will insure a 10 megohms bond for the life of the air vehicle. The bond resistance chosen must be cost effective during the fabrication and maintenance of the system.

A mandatory conductivity additive has been added to JP-4 and to JP-8. This has greatly relieved the concern for static electricity during ground and aerial refueling of air vehicle. Static during operation of the fuel subsystem has not caused a problem other than that associated with old non-conductive explosion suppression foam. When the additive is present in a fuel, a charge accumulation can not be measured on fuel within the air vehicle. A remaining concern is when ground and aerial refueling occurs with a fuel which does not contain the conductivity additive into a fuel tank which has previously contained a high volatile fuel such as JP-4 or Jet B. Fuels that do not contain a conductivity additive could generate a charge and fuel vapors could remain in the tank from the previous high volatile fuel. When a low volatile fuel without conductivity additive is ground and aerial refueled into a tank which has previously contained low volatile fuel, a hazard can only exist when the fuel temperature inside the fuel tank is above the flash point of the low volatile fuel (above 100°F for Jet A or 140°F for JP-5). For an optimum fuel vapor mixture to exist which will ignite at the minimum ignition energy, the fuel temperature must be approximately 50°F above the actual flash point of the fuel.

E.4.4.5.8.11 Static discharge in fuel tanks.

The freedom from static electricity discharge within fuel tanks shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.8.11)

Static discharge should be eliminated or must be verified to be below the minimum ignition energy.

VERIFICATION GUIDANCE (4.4.5.8.11)

TBS: The freedom from sparks within fuel tanks should be verified by analysis of system design parameters to verify that the design objectives have been met.

Bond resistance of all components installed inside fuel tanks should be measured (verified) during manufacture and after replacement during maintenance.

VERIFICATION LESSONS LEARNED (4.4.5.8.11)

Full scale “static” testing is very difficult, if not impossible, to accomplish. A worst-case scenario of an active fuel without a static additive and with a high charging ground fueling source must be simulated to obtain measurable or detectable results. Air vehicle ground test or fuel subsystem simulator testing should be accomplished to verify the desired fuel velocities have been obtained.

Each component's bond resistance should be measured after installation of the component into the fuel subsystem. Bonding of the fuel subsystem should be verified by inspection of installation records for each component.

E.3.4.5.8.12 Defueling method(s).

The air vehicle shall be capable of being defueled by the following method(s) _(TBS 1)_, under the following normal and failure conditions _(TBS 2)_.

REQUIREMENT RATIONALE (3.4.5.8.12)

Defueling methods should be specified for maintenance and emergency operations.

REQUIREMENT GUIDANCE (3.4.5.8.12)

TBS 1 should be filled in with the methods which could be used to defuel the air vehicle. The external fuel tanks should have the capability of being defueled through the gravity fuel cap.

TBS 2 should be filled in with the normal and failure conditions which the air vehicle would have to be defueled under.

Any restriction on the defueling operations should be specified. If electrical power will not be available to operate air vehicle pumps, then defueling should be accomplished by suction from the defueling equipment, only. The defueling system design should take into consideration that failures can occur which may prevent defueling of the tank.

The required defueling rate should be accomplished by suction from the defueling ground equipment assisted by the air vehicle pumps. It should be possible to defuel each tank with any single failure in the system. The fuel system will be designed to withstand the negative pressures encountered during suction defueling.

REQUIREMENT LESSONS LEARNED (3.4.5.8.12)

In a system using only a boost pump for defueling, a failure of the boost pump would cause great difficulty in defueling the tank to repair the boost pump. This situation could require draining a large quantity of fuel through a water drain valve or removing a tank access door on a tank containing fuel.

E.4.4.5.8.12 Defueling method(s).

The method(s) of defueling shall be verified by __(TBS 1)__. Defueling of each tank of the air vehicle with the specified failures in the system shall be verified by _(TBS 2)_.

VERIFICATION RATIONALE (4.4.5.8.12)

The ability to verify the defueling process is important for aircraft missions, and air vehicle maintenance and operations.

VERIFICATION GUIDANCE (4.4.5.8.12)

TBS 1: The method of defueling should be verified by a demonstration.

TBS 2: Defueling of each tank with specified failures should be verified by analysis.

VERIFICATION LESSONS LEARNED (4.4.5.8.12)

The procedures should specify each type of air vehicle ground equipment to be used and the components in the air vehicle which may be operated during defueling.

E.3.4.5.8.13 Defueling rate.

Defueling of the air vehicle shall be accomplished __(TBS)__. (Value for blank must be derived for each type and capacity air vehicle.)

REQUIREMENT RATIONALE (3.4.5.8.13)

Every tank on an air vehicle must have a defueling capability to permit fuel removal due to a mission change or for maintenance actions. The allowable time for defueling the fuel subsystem should be specified.

REQUIREMENT GUIDANCE (3.4.5.8.13)

TBS should be filled in with the defueling rate for the air vehicle. Specify defueling source. The air vehicle mission should establish limits for defueling in consonance with operation and maintenance plans.

REQUIREMENT LESSONS LEARNED (3.4.5.8.13)

A defuel rate of 200 gallons per minute (gpm) per defueling connection has been specified for several different air vehicles. A defueling time based on this rate for the full load of a large transport could be very long. The required time should be based on a predicted useful function such as the time to defuel the largest tank on the air vehicle or to remove a specified quantity of fuel from the air vehicle. Defueling rates of 200 gpm can usually be accomplished by the defueling ground equipment assisted by the air vehicle transfer or boost pumps. Specifying unrealistic short defuel times requires a high defuel rate which can impose unnecessary weight and cost impacts on the air vehicle.

For air vehicles with a small fuel load, a low defueling rate, such as by gravity drain, would be acceptable. System design should preclude negative pressures in the tanks during the defueling process.

E.4.4.5.8.13 Defueling rate.

Defueling rate shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.8.13)

Verification of defueling rates is important to ensure mission planning can be accomplished in the specified time.

VERIFICATION GUIDANCE (4.4.5.8.13)

TBS: Defueling time should be verified by analysis and a ground demonstration.

VERIFICATION LESSONS LEARNED (4.4.5.8.13)

The test procedures should specify the quantity and distribution of fuel on the air vehicle.

E.3.4.5.8.14 Defueling crashed air vehicle.

In the event of a wheels-up landing, it shall be possible to defuel __(TBS)__.

REQUIREMENT RATIONALE (3.4.5.8.14)

In a crash landing, the defueling adapter could be damaged, preventing defueling. Defueling of crashed air vehicles is desired in order to reduce hazards and to lighten the weight of the air vehicle for removal from the runway.

REQUIREMENT GUIDANCE (3.4.5.8.14)

Access should be provided, preferably into the top, of each fuel tank.

REQUIREMENT LESSONS LEARNED (3.4.5.8.14)

An access hole in the top of each tank will allow emergency defueling of the tank without cutting a hole in the top surface of the tank. The access hole can be any opening such as filler opening, component cover, or access door which will permit insertion of a stiff hose to the bottom of the tank. Many air vehicles have used the gravity filler caps on top of each wing to defuel each tank. The current trend has been to eliminate the gravity filler caps or to install a gravity filler cap for only the main tanks; therefore, the design problem for emergency is much more difficult and should be considered early in the design of the fuel tanks.

E.4.4.5.8.14 Defueling crashed air vehicle.

The capability to defuel each tank under damaged refueling adapter conditions shall be verified by
__(TBS)__.

VERIFICATION RATIONALE (4.4.5.8.14)

Verification of dufueling a crashed air vehicle is important to allow mishap investigation boards to be able to conduct an investigation.

VERIFICATION GUIDANCE (4.4.5.8.14)

TBS: The capability to defuel with a damaged refueling adapter should be verified by analysis.

VERIFICATION LESSONS LEARNED (4.4.5.8.14)

Moving or gaining access to a mishap air vehicle requires safely removing residual fuel.

E.3.4.5.9 Fuel venting.

The fuel venting shall prevent the pressure of each fuel tank from exceeding its tank proof pressure and any negative pressure within the tanks' structural limits. This shall be prevented during: ground refueling, aerial refueling, including any single fuel subsystem component failure throughout the usage envelope. Fuel venting shall prevent siphoning and spillage of fuel except during __(TBS)__ flight maneuvers. The fuel vent shall not ice under any expected ground or flight conditions.

REQUIREMENT RATIONALE (3.4.5.9)

The primary function of a fuel vent is to maintain the fuel tank pressures within the allowable structural limits of the air vehicle.

REQUIREMENT GUIDANCE (3.4.5.9)

The fuel vent subsystem should prevent the pressure of each fuel tank from exceeding the proof pressure of the tank.

TBS: The sensitivity of an air vehicle to an uncommanded fuel transfer through a vent is a function of the air vehicle's fuel tank (size and geometry), plumbing connectivity and general architectural arrangement. The weight and cost of preventing all transfers under extreme attitudes can be high. A quantity which does not adversely affect air vehicle center of gravity or allow excessive overboard spillage may be permitted. Inter-tank transfer through the vent subsystem should be minimized.

Fuel tanks are not constructed to withstand high pressures or any appreciable negative pressure. The design pressure limit for the fuel tanks should be the basis for the vent subsystem sizing.

The vent system configuration should prevent the vent path from being closed under all conditions and attitudes, except for vehicle rollover conditions.

Fuel spillage should be prevented in the event of air vehicle rollover.

REQUIREMENT LESSONS LEARNED (3.4.5.9)

The structural requirements for a fuel tank are a combination of several different loads such as fight loads, gust loads, and pressure loads. The design proof pressure and limit loads for the fuel tanks must be derived in concert with the total structural criteria and identified for the vent subsystem design. The significant operating conditions for which the vent subsystem should be designed and verified are:

a. Maximum desired rate of in-take of air or gas into the fuel tanks due to engine fuel consumption, fuel transfer, and rapid descent, and refueling.

b. Maximum rate of expulsion of air, vapor, or liquid from the fuel tanks. The design must account for failure of a level control valve during ground or aerial refueling.

c. Negative pressure limits for maximum rate defueling and descent.

d. Single failures in refueling sources; such asincluding refuel shutoff valves and failed pressure regulators.

Vent subsystems may be classified according to their function, such as:

a. Dive vent subsystem, which generally ingests air and gas into the fuel tanks.

b. Climb vent subsystem, which generally expels vapor from the fuel tanks.

In addition, vent subsystems may be classified according to their configuration, such as:

a. Open subsystem, where tank pressure is maintained about equal communicated directly to the outside ambient pressure.

b. Closed or pressurized system, where the tank pressure is maintained at a pressure level above ambient by installing a vent relief and control valve in the overboard vent line to regulate the tank pressure in relation to the ambient pressure.

A complete description of vent subsystems and methods of analysis is presented in NAVAIR 06-5-504.

Failure of a level control or refuel shutoff valve during aerial refueling has typically been the most critical failure for causing the maximum fuel tank positive pressure. The proper design and sizing of vent subsystems involves an analysis of all air vehicle operating conditions and failure modes to determine which are the most critical. Vent lines should not be interconnected to perform multiple functions, (fuel transfer, fuel dump). In certain applications interconnected vents may be necessary to reduce weight, space, and system complexity. Vent subsystem arrangements which interconnect tanks with common vent lines should be examined carefully for inter-tank fuel transfer for reasonable extreme attitudes. Definition and agreement for the extreme attitudes to be considered in the design is essential.

All multiple functions of an interconnected vent subsystem arrangement should be identified for all probable air vehicle operating conditions. The design should consider single fuel subsystem component and pressurization component failures to assure the proof pressure of any tank will not be exceeded. The simplest subsystem arrangement is to provide completely independent vent lines for each tank; however, this is the most costly in terms of weight and space. Termination of the vent lines at a common outlet on the air vehicle is generally acceptable. Vent outlets, which perform multiple functions, such as fuel dump and tank venting, should be avoided, unless it is verified that tank pressure requirements are never exceeded when the outlet is performing this multiple function with the most critical single component failure.

The F-15 fuel vent subsystem uses interconnected lines to perform simultaneous functions. The design permits overboard expulsion of fuel during refueling with a failed level control valve, permits overboard expulsion of transfer fuel which may overfill feed tanks during negative "g" operation, and allows overboard expulsion of excessive air flow from the external tanks in the event of external tank valve failure.

In several cases when the system is performing one of its normal functions in an extreme flight envelope condition simultaneously with a single failure requiring another vent subsystem function, a severe fuel tank overpressure condition results. In all of the possible F-15 overpressure cases except one, involving the vent and dump subsystem interaction, either pressurized fuel or pressurized air is entering the internal tanks through the level control valves. A possible method of eliminating tank overpressure due to fuel or air flow through the level control valves would be to provide valves which are both level sensitive (shut off at a prescribed tank fuel level) and internal tank pressure sensitive (shut off when tank pressure relative to ambient exceeds the prescribed limit). This type level control valve capability has not been developed in an integrated single package.

Due to space limitations, which prohibited installation of separate vent subsystem and dump outlets, the F-15 employed the same outlet to perform both functions. The dump line was connected downstream of the vent relief valve. A destructive tank overpressure condition was produced when the pressurization air regulator failed open during fuel dumping operations. Pressurized fuel being dumped overboard blocked the vent relief valve. Excessive air pressure from the failed regulator was not relieved through the vent outlet due to the blocking. Pressure in the tank increased until rupture occurred.

It was also determined on the F-15 that the most critical failure mode of a level control valve was when the failure occurred in the first tank to fill while other tanks were still filling. The failed level control valve allowed pressurized fuel to flow into the vent lines and outlets thus restricting air flow from the other tanks. This combination of conditions can result in a destructive tank overpressure.

It was extremely difficult to correct these F-15 problems and integrate the fixes into the air vehicle.

Fuel will start to boil when the ambient pressure at the liquid surface falls below the true vapor pressure of the fuel. The initiation of boiling, normally called the boiling altitude, for a particular fuel is dependent on the fuel temperature. The boiling altitude is very high for a low vapor pressure fuel such as JP-5 or JP-8 at normal temperatures. For JP-4, with a Reid vapor pressure of 2-3 psia, the boil-off can be significant for high performance air vehicles which use the fuel as a heat sink and then return it to the tank.

A pressurization subsystem may be desired to pressurize fuel tanks to reduce fuel boil-off at high altitude, to prevent transfer boost pump cavitation, to transfer fuel by differential pressure, to transfer fuel from an external tank, or may be necessary in conjunction with an inerting system. The identification of pressurization requirements must be based on the type and mission of the air vehicle and the fuel intended for use. If government furnished external tanks are provided, it may require pressurization for fuel transfer. Pressurization level is determined in relation to tank pressure capability and type of fuel. Pressure level and temperature limitations should be identified during the pressurization subsystem development in relation to modes of operation and failure of associated subsystem components. The pressurization subsystem should not cause tank pressures in excess of proof pressure (positive or negative) as a result of any single failure during any ground or flight condition, or during simultaneous operation of any other fuel subsystem such as fuel dump subsystem, or component or fuel temperatures in excess of 450°F. A thermal study should be conducted to verify that the temperatures of components, tank walls, and ullage space meet the temperature requirements. The temperature survey should account for any temperature rise which may occur as a result of a failed pressure regulator, vent valve, or any other selected component. Extended periods of elevated fuel temperatures will cause an accelerated aging of elastomeric materials in flexible tanks as well as increasing fuel permeability through tank walls. The pressurization subsystem design should avoid a sudden release of pressure (depressurization) to minimize the pop bottle effect and the blowing of fuel out of the vent.

Vent outlet location and the use of flame arrestors in vent lines should be considered in lightning protection.

Every vent subsystem arrangement should be thoroughly analyzed for transfer through the vent subsystem and its effect on fuel balance and fuel spillage. It is extremely difficult to prevent all vent transfer or overboard leakage during flight maneuvers; however, a small quantity can be tolerated. The establishment of an allowable transfer or leakage limit could prevent unnecessary complication of the vent subsystem. Fuel from the vent lines can be collected in a collector tank and then scavenged back into the system.

E.4.4.5.9 Fuel venting.

The ability of fuel venting to limit tank pressure shall be verified by __(TBS 1)__. The limits of vent line fuel transfer shall be verified by __(TBS 2)__.

VERIFICATION RATIONALE (4.4.5.9)

The fuel venting tests should be conducted to determine the following:

a. Adequacy of vent line size during extreme operating conditions
b. Fuel evaporation loss
c. Effectiveness of tank pressure control system
d. Fuel slugging or siphoning losses, if any, during air vehicle taxing, catapult, or arrested landing
e. Climb and dive venting
f. Performance during ground refueling and defueling.

VERIFICATION GUIDANCE (4.4.5.9)

TBS 1: The ability of fuel venting to limit tank pressure should be verified by analysis, development rig tests, and flight tests. Selected conditions should be flight tested to correlate flight test data with fuel subsystem rig test results.

TBS 2: The ability of fuel venting to minimize vent line fuel transfer should be verified by analysis, fuel subsystem rig tests, ground and flight tests. Vent subsystem designs which use inter-tank fuel transfer through the vent lines should be verified during fuel transfer and vent subsystem ground and flight tests.

VERIFICATION LESSONS LEARNED (4.4.5.9)

Verification of fuel venting solely by air vehicle tests is not advised because some extreme conditions could result in excessive pressure and could cause damage to the tank structure.

The vent subsystem should be evaluated under the following conditions and maneuvers:

a. The air vehicle should be flown at maximum rate of climb to its service ceiling followed by a maximum practical rate of descent to minimum safe altitude. The dive should be accomplished with the minimum safe quantity of fuel aboard. Pressure data for each tank should be recorded.

b. With full fuel tanks it should be demonstrated that fuel spillage does not occur as a result of take-off and landing accelerations or a rejected take-off, uncoordinated turns, afterburner and speed brake applications.

c. Air vehicles where design performance includes inverted or negative “g” flights should be flown in this manner for a maximum period as determined by the air vehicle system specification.

d. Prevention of fuel venting from thermal expansion of full tanks that have been refueled with cold fuel then exposed to maximum diurnal cycles should be demonstrated. Large air vehicles can take up to 72 hours to reach thermal equilibrium after being exposed to extreme ambient conditions. (Source: USAF McKinley Climatic Hangar, Eglin AFB, FL)

For air vehicles where the vent system must be blocked during maintenance to pressure check the vent system or tanks, special Aerospace Ground Equipment (AGE) should be designed for plugging the vent lines. The AGE should be so designed that it will not cause damage to the tank skin in the event it is left in the vent system at the conclusion of the maintenance.

E.3.4.5.9.1 Vent leakage.

Overboard fuel leakage through the vents, while the air vehicle is on the ground or shipboard, shall be prevented.

REQUIREMENT RATIONALE (3.4.5.9.1)

Fuel spillage from the vent during ground and shipboard operation, and routine movement of the air vehicle should be preventedis a fire and environmental hazard.

REQUIREMENT GUIDANCE (3.4.5.9.1)

There should be zero leakage when the air vehicle is parked, during ground and aerial refueling, during engine run-ups, during taxiing, or during air vehicle shutdown.

REQUIREMENT LESSONS LEARNED (3.4.5.9.1)

Failed components and leaking valves should be considered for potential overboard leakage. Fuel spillage (“blow out” or discharge) during depressurization of fuel tanks has been a common problem for many air vehicles. Fuel which has been trapped in the vent lines will be discharged out of the vents when the vent valves are opened to relieve fuel tank pressure. This can occur during touch down where the weight on wheels switch results in the fuel tanks being depressurized. If this occurs, a safety concern with hot brakes generally follows. Another common cause of overboard leakage is due to thermal expansion of the fuel.

Although the overboard leakage of high flash point fuel such as JP-8 and JP-5 may not necessarily be a safety problem, this leakage should be prevented due to its ability to damage asphalt aprons and runways.

Fuel spillage is considered a serious environmental hazard and may result in costly hazardous waste management and environmental repair activity.

E.4.4.5.9.1 Vent leakage.

The absence of fuel leakage through the vents shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.9.1)

Verification of the absence of fuel leakage should be considered a safety and environmental hazard.

VERIFICATION GUIDANCE (4.4.5.9.1)

TBS: The absence of leakage through the vents should be verified by analysis, development rig tests, and by a ground refueling demonstration and taxi tests.

VERIFICATION LESSONS LEARNED (4.4.5.9.1)

The C-17 has experienced small quantities of fuel leakages through the vent system caused by the OBIGGS system.

The V-22 has experienced both small and large quantity fuel spillage through the vents system due to unreliable rupture disk performance, vent plumbing (including couplings and joints) being below the normal high level shutoff quantity of the fuel, and high level shutoff failures (during both refueling and normal fuel transfer).

E.3.4.5.9.2 Vent outlet location.

Fuel or fuel vapors that flow out of the vent outlets shall not impinge onto the air vehicle or come in contact with the engine inlet and exhaust system, air vehicle brakes, air inlets or air pressure sensor ports, or other aircraft interfaces that are intolerant of fuel or fuel vapors.

REQUIREMENT RATIONALE (3.4.5.9.2)

A vent outlet location(s) should be selected based on the assumption that fuel will flow out from the vent. Concern for fuel impingement on the air vehicle should be established.

REQUIREMENT GUIDANCE (3.4.5.9.2)

Fuel or vapors discharged from the vent outlets should not blow back onto impinge on the air vehicle or come into contact with the engine exhaust system, air vehicle brakes, or air inlets or air pressure sensor ports. The tank vent outlet should be located so that foreign matter thrown up by the air vehicle wheels will not enter or block the vent outlet. The outlet should be located so that any moisture collecting in the line will drain to the outlet and prevent the entrance of water from entering into the fuel system, or reducing the available flow area through the vent system. The vent outlet location and configuration should prevent the formation of ice which could partially or completely block the outlet. Lightning hazards should be considered when determining the vent outlet location.

REQUIREMENT LESSONS LEARNED (3.4.5.9.2)

To enhance system safety design use flexible hoses at the tank vent outlet connections to allow tank displacement. Another method is to route the vent line inside the tank in a manner that prevents spillage at any air vehicle attitude. The vent valve may use a float to close the vent as fuel reaches it, plus a weight to keep it closed when inverted. The valve should remain open during normal operation.

In the event of air vehicle rollover, fuel spillage should be prevented with internally mounted vent valves.

E.4.4.5.9.2 Vent outlet location.

Absence of fuel impingement during fuel venting shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.9.2)

If any component failure can cause fuel to vent overboard, tests should be conducted to determine if impingement is possible.

VERIFICATION GUIDANCE (4.4.5.9.2)

TBS: Absence of fuel impingement during fuel venting should be verified by analysis, component test (especially for icing), and flight test.

VERIFICATION LESSONS LEARNED (4.4.5.9.2)

Appropriate tests should be conducted, as indicated by the failure analysis and simulator tests. If any component failure can cause fuel to vent overboard, tests should be conducted to determine if impingement is possible. Dyed fuel or pink fuel sensitive "paint" (e.g., LD5) can be used during the testing to mark any fuel venting and impingement on the air vehicle. It is difficult to determine where the leakage fuel flows in flight. The dye on the air vehicle provides visual proof of leakage during post-flight inspections. Typically, the pink fuel sensitive "paint" on the air vehicle changes color (i.e., from pink to red) when exposed to fuel, and provides visual proof of leakage to a chase pilot and during post-flight inspections. A wash coat of material that will be removed by fuel can also be used to mark fuel impingement.

E.3.4.5.10 Fuel dump.

Fuel dump shall be provided to achieve a safe landing weight in __(TBS)__. During fuel dump operations, fuel shall not re-enter the air vehicle when the air vehicle is in any normal flight attitude or an emergency descent attitude. The fuel dump operation shall not in any way adversely affect the controllability of the air vehicle. The dumped fuel shall not impinge on the air vehicle.

REQUIREMENT RATIONALE (3.4.5.10)

A fuel dump subsystem provides means to dump fuel in flight to reduce the air vehicle fuel load rapidly to a lower, safer landing weight. This may be desired due to an air vehicle structural limitation or for an additional safety margin in case of air vehicle failures, battle damage, or due to an air vehicle structural limitation. The dump mast or dump chute should be located so that dumped fuel will not re-enter the air vehicle or cause a hazardous condition.

REQUIREMENT GUIDANCE (3.4.5.10)

TBS: A fuel dump should be provided to off-load a sufficient quantity of fuel to reduce the weight of the air vehicle from the maximum take-off gross weight to a desired landing weight in approximately ten minutes (other times may be used as determined from mission plans or user requirements).

There should be a quantity of fuel, approximately equal to the reserve fuel quantity, in the feed tanks, which cannot be dumped. If no other guidance is provided, OPNAVINST 3710.7T provides a definition of reserve fuel.

For Navy, the air vehicle should achieve carrier landing weight in the time it takes for take-off and immediate recovery aboard ship.

An explicitly stated, minimum average dump rate is also an acceptable method of defining the dump subsystem requirement, in lieu of deriving an operational requirement.

The dumped fuel should not impinge on the air vehicle.

It is imperative that an early assessment (before structural and outer mold-line configurations are finalized) of the fuel dump outlet location be conducted to ensure successful verification of dump.

REQUIREMENT LESSONS LEARNED (3.4.5.10)

A dump rate of one percent per minute of the maximum air vehicle gross weight has been used as a method of for specifying the dump rate. This has produced a reasonably balanced design in relation to pump size. A high dump rate is desired to minimize the time to get down to a safer landing condition; however, the dump rate should not totally solely drive the design in relation to pump requirements. The dump subsystem should be capable of activatingon or stopping during any flight condition. The subsystem should be incapable of dumping fuel below the designated "low fuel warning" level. Some aircraft, such as the X-47, had imposed a specific design requirement not to allow fuel dump from engine feed tanks. An automatic means of terminating dump should be considered.

The actual location and design of the dump mast is influenced by aerodynamic considerations. Dump subsystems are low pressure, high fuel flow systems. The flow rate and flow pattern are significantly affected by basic air vehicle attitude and speed. Avoidance of impingement may not be possible in all flight attitudes, if the proper location is not identified. Areas of the air vehicle, which may be subjected to fuel impingement, should be sealed with fuel resistant materials. Fuel spillage or leakage as a result of failure of the dump valve should be considered for air vehicle ground safety. Controls for the dump subsystem should be protected from accidental activation.

E.4.4.5.10 Fuel dump.

The operation of the fuel dump shall be verified by __(TBS 1)__. Absence of fuel re-entry during normal flight attitude and emergency descent attitude shall be verified by __(TBS 2)__.

VERIFICATION RATIONALE (4.4.5.10)

Fuel dump capability for USAF should be considered a safety critical function since fuel dump is normally commanded during emergency conditions.

Fuel dump capability for USN should be considered a safety critical function since fuel dump is a normal procedure for USN aircraft and it is required.

VERIFICATION GUIDANCE (4.4.5.10)

TBS 1: The operation of the fuel dump for quantity and rate should be verified by analysis, on the fuel subsystem development rig simulator, and by ground or flight test. Fuel dump (jettison) tests should be conducted in flight. Ground tests may be run to indicate capabilities and time required to jettison. The flight effect on the dump duct exit cannot, of course, be duplicated. Since an unobstructed free discharge flow is necessary, water may be used in lieu of fuel provided that the system components are not adversely affected. If fuel is used, it is recommended that means be provided to collect the discharge fuel and pipe it safely to a receiver tank.

TBS 2: Absence of fuel re-entry during normal flight attitude or emergency descent attitudes should be verified by a flight demonstration.

VERIFICATION LESSONS LEARNED (4.4.5.10)

Do not rely on motion pictures only. The air vehicle should be coated with a dye indicator and a chase aircraft should observe the test during the dump demonstration. The chase aircraft can observe where the fuel impinges on the surface by watching the dye indicator during the flight. After the flight, the air vehicle can be inspected for dye indicators which would indicate fuel impingement.

Fuel-reactive paint has been used on the F-35, F/A-18E/F, and MV-22 to verify fuel impingement patterns due to fuel discharged from vent and fuel dump outlets.

E.3.4.5.11 Fuel used as a heat sink.

The fuel system shall be able to operate under the Thermal Management System heat loads (during ground and in flight). When fuel is used as a heat sink, the following interface parameters are required between the fuel subsystem and the subsystems to be cooled: __(TBS)__.

REQUIREMENT RATIONALE (3.4.5.11)

The required interface parameters should be specified.

REQUIREMENT GUIDANCE (3.4.5.11)

TBS should be filled in with the following parameters when fuel is to be used as a heat sink:

a. Physical
    1. Connection type and size
    2. Connector loads
b. Fuel conditions
    1. Pressure (Maximum, Minimum)
    2. Flow rate (Maximum, Minimum)
    3. Fuel temperature, in (Maximum, Minimum)
    4. Fuel temperature, out (Maximum, Minimum)
c. Heat loads
    1. Ground
    2. In-flight
    3. Heat transfer limits
        a) Maximum total heat
        b) Maximum heat transfer rates.

The physical connections as well as the flow and fuel temperature parameters must be identified when fuel is used as a heat sink.

REQUIREMENT LESSONS LEARNED (3.4.5.11)

When fuel is used as a heat sink, generally the fuel subsystem engineer has responsibility for the fuel circulation loop, and the subsystem requiring cooling is responsible for the other fluid loop including prime responsibility for the heat exchanger. Ownership of any interfacing heat exchanger(s) varies depending on the program. The fuel subsystem engineer should ensure that the pressure drop of the fuel path for the heat exchanger satisfies all the fuel flow requirements of the fuel subsystem. The pressure drop of the fuel flow path should include the effects of contamination, any required filters or screens, and installation line losses. The heat exchanger should meet the required pressure drop after the contamination test has been conducted.

As the systems become more integrated, like in the F-22 air vehicle, a critical assessment should be made on how best to handle engine heat loads in terms of heat sink management. The engine, being autonomous of the air vehicle Environmental Control System and Thermal Management System, needs to be evaluated early in the program to assess the best balanced design.

Heat loads on weapons systems continue to increase demands of the fuel subsystem.

E.4.4.5.11 Fuel used as a heat sink.

The interface between the fuel subsystem and another subsystem using fuel as a heat sink shall be verified by __(TBS1)__. The overall air vehicle Fuel Thermal Management System (FTMS) performance shall be verified by _(TBS2)_.

VERIFICATION RATIONALE (4.4.5.11)

Heat transfer from other subsystems to the fuel is safety and mission critical.

VERIFICATION GUIDANCE (4.4.5.11)

TBS1: When fuel is used as a heat sink, the interface should be verified by analyses, component, subsystem level simulators, ground rig, and flight tests.

TBS2: Overall air vehicle fuel thermal management performance should be verified by correlation of the FTMS model to actual flight test data. Flight testing of mission representative flight profiles are necessary to ensure that all air vehicle level thermal management related assumptions are captured in the model analysis. A flight test aircraft should be instrumented for all critical fluid and material temperatures, fluid flows, and pressures for the purpose of correlating the FTMS model. The correlated model can then be used to verify all required mission profiles and extreme environmental operating conditions.

VERIFICATION LESSONS LEARNED (4.4.5.11)

Thermal loads generally increase as weapon systems are modified with new avionics or subsystems. Extra thermal capacity should be included as part of the baseline fuel system design.

An air vehicle's FTMS is often a "system" in name only, and practically speaking is actually a function of the Fuel, Environmental Control, and Engine and Auxilary Power Unit Systems. As such, the hardware that has direct impact on the overall FTMS performance is owned by those individual subsystem Integrated Product Teams (IPTs), and not the FTMS Team. Therefore, it is critical that one of those IPTs be given ownership of and complete responsibility for the FTMS performance. Thermal analysis, in general, and FTMS performance analysis, specifically, requires unique skills separate from basic subsystem design so a dedicated FTMS performance analysis team is required to support FTMS development. However, it is critical that one of the integrated IPTs have ownership of the overall performance to be able to manage the FTMS development and impact hardware configuration effectively.

F/A-18E/F program had a high degree of success in the development of their FTMS by remaining diligent in monitoring and controlling subsystem heat loads through the use of an integrated IPT process of all FTMS impacted subsystems.

A high degree of confidence in the final verification of Hot Day FTMS performance was achieved through the correlation of the FTMS model with actual spec mission flight profiles. Through the use of the correlated model, NAVAIR/Boeing/NGC were able to confirm occurrences of FUEL HOT cautions were due to inoperative fuel/air heat exchangers and successfully replicated the critical fluid temperatures experienced by fleet aircraft with similarly configured aircraft.

E.3.4.5.12 Controls and monitor

E.4.4.5.12 Controls and monitor

E.3.4.5.12.1 Low level fuel warning.

A low level fuel warning indication shall be provided to indicate a sufficient quantity of fuel remains in the feed tank to support __(TBS)__ fuel remaining. The low level fuel warning indication shall be independent of the gauging system or operate through redundant hardware in the gauging system.

REQUIREMENT RATIONALE (3.4.5.12.1)

A positive, independent alert device (or system) is required to warn the pilot that the tank supplying fuel to the engine is not being replenished, and will soon be depleted. The device should inform the pilot that a known increment of time or quantity volume of fuel remains until the main tank is depleted.

REQUIREMENT GUIDANCE (3.4.5.12.1)

TBS: Should be filled in with quantity of fuel that allows 20 to 30 minutes of flight at a best cruise and altitude flight condition, plus at a normal descent and landing, with one missed approach. A range of 20 to 30 minutes of flight time is specified because the quantity of fuel remaining associated with the low level fuel warning should be related to the reserve fuel requirement in OPNAVINST 3710.7. In short, the OPNAVINST requires that 10 percent (10%) of mission fuel or no less than 20 minutes of reserve flight time is required for mission planning purposes. Since the reserve fuel quantity is mission range dependent, it is not desirable to provide a fixed flight time requirement.

To eliminate potential failure modes that can affect mass quantity indications of fuel, it is important that the low level fuel warning indication provide a volumetric indication of fuel remaining in the engine feed tank.

Low fuel level warnings should be provided for each engine feed tank, and a tank empty indication should be provided for all other tanks. Tank empty indications need not be independent from the basic fuel quantity gauging system.

Coordinate the location and presentation display of the low fuel level warning with Crew Systems and Human Factors engineers.

REQUIREMENT LESSONS LEARNED (3.4.5.12.1)

Air vehicles have been lost because the pilot failed to notice the low level light when his attention was outside the cockpit, and he failed to retard throttles to conserve fuel or he failed to transfer all fuel. These devices and their wiring should be independent of the fuel gauging system or should operate after up to any two (2) failures of the fuel gauging system. The low fuel warning(s) normally indicate(s) sufficient fuel remaining for at least 20 minutes flight at best cruise and altitude, a normal descent, and landing with one (1) missed approach. In any air vehicle operated by a single pilot, the warning should be both aural and visual to ensure the warning is not overlooked in the case the pilot's attention is focused outside the cockpit. In some air vehicles, this warning signal has also been used to open transfer valves to ensure all available usable fuel is transferred into the engine feed tank(s). The warning should be damped or time delayed and/or have sufficient persistance associated with the low level fuel condition to prevent premature and cyclic warnings due to fuel sloshing.

Give consideration to the low level fuel indication requirement when determining the size and shape of the feed tank(s). If a feed tank is sized significantly larger than what is required for low level fuel indication requirements, it can have an adverse impact. Since the low level fuel indication in a non-failure mode situation represents the end of the mission, it is reasonable to derive that the full maneuvering and operating envelop (including negative G operations) is not required after the low level fuel indication is annunciated.

E.4.4.5.12.1 Low level fuel warning.

Low fuel level warning shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.12.1)

Low level fuel waning should be considered a safety critical function.

VERIFICATION GUIDANCE (4.4.5.12.1)

TBS: The correct fuel level activation of the low fuel warning device should be verified by analysis, fuel system simulator testing, during fuel calibration tests, and during ground test and flight test. The testing can be accomplished in conjunction with the fuel tank calibration.

The flight time remaining on the indicated fuel level should be verified by analysis.

VERIFICATION LESSONS LEARNED (4.4.5.12.1)

Verification of low level warning has been verified during fuel calibration tests. Comparing fuel calibration data to low level warning has been shown to identify discrepancies.

E.3.4.5.12.2 Fuel temperature indications.

Fuel temperature indication shall be provided for _(TBS)_.

REQUIREMENT RATIONALE (3.4.5.12.2)

Fuels with freezing points in the -46°F to -50°F range, such as Jet-A-1, JP-8 and JP-5, could be used which could impose special operational procedures for low temperature in high altitude and long endurance air vehicles. Greater use is being made of fuel as a heat sink before delivery to the engine or returning it to the fuel tanks. These conditions make it desirable to provide an accurate indication of the fuel temperature in each critical tank.

REQUIREMENT GUIDANCE (3.4.5.12.2)

TBS should be filled in with each fuel tank and each engine feed line.

The bulk fuel temperature and the temperature of the fuel being delivered to the engine are of concern to the pilot during operation at extreme temperature conditions. A temperature indication capability should be provided for each critical fuel tank. Temperature warnings should be provided for both high and low temperature limits.

Coordinate the location and presentation of the fuel temperature indicator with Crew Systems and Human Factors engineers.

REQUIREMENT LESSONS LEARNED (3.4.5.12.2)

Without temperature indicators, standard air chart temperatures and air speeds must be used to estimate fuel temperature. This approach generally results in an over-conservative fuel temperature limit being used which may impose unnecessary restrictions on air vehicle operation.

The location of the temperature sensor should be carefully considered so that a true fuel temperature will be indicated.

E.4.4.5.12.2 Fuel temperature indications.

The operation of fuel temperature indicators shall be verified by _(TBS)_.

VERIFICATION RATIONALE (4.4.5.12.2)

The ability to read the fuel temperature allows more accurate fuel temperature limits to be set, and is critical for air vehicles that incorporate active Thermal Management Systems.

VERIFICATION GUIDANCE (4.4.5.12.2)

TBS: The operation of fuel temperature indicators should be verified by component tests and by ground and flight tests.

VERIFICATION LESSONS LEARNED (4.4.5.12.2)

(TBD)

E.3.4.5.12.3 Low fuel pressure indication.

Low fuel pressure indication shall be provided for each engine feed line.

REQUIREMENT RATIONALE (3.4.5.12.3)

Pressure indicators have proved to be a reliable indicator of failure conditions in the engine fuel feed system.

REQUIREMENT GUIDANCE (3.4.5.12.3)

The necessary engine fuel cannot be maintained when the fuel boost pump is degraded. A low fuel pressure cockpit indication should be provided for each engine feed line.

A low pressure indication may be desirable for a transfer manifold to indicate low performance or lack of performance of transfer pumps.

Coordinate the location and presentation of the low fuel level warning with Crew Systems and Human Factors engineers.

REQUIREMENT LESSONS LEARNED (3.4.5.12.3)

The pressure pick up point should be as close as possible to the engine fuel inlet.

E.4.4.5.12.3 Low fuel pressure indication.

Activation pressure level for low fuel pressure indication devices shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.5.12.3)

Low fuel pressure in the engine feed system can represent a safety of flight condition. Verification by test is required, can be used to indicate a problem in the fuel system.

VERIFICATION GUIDANCE (4.4.5.12.3)

TBS: Low fuel pressure indication devices should be verified by ground tests.

VERIFICATION LESSONS LEARNED (4.4.5.12.3)

(TBD)

E.3.4.5.12.4 Fuel unbalance indication.

A fuel unbalance indication shall be provided.

REQUIREMENT RATIONALE (3.4.5.12.4)

A fuel unbalance warning is needed where air vehicle unbalance may restrict maneuvers. Warnings are especially needed when the pilot's attention is diverted to other critical air vehicle functions such as approach and landing or weapons delivery.

REQUIREMENT GUIDANCE (3.4.5.12.4)

A fuel unbalance warning device should be provided, if a fuel unbalance can occur causing the c.g. to move outside of the allowed limits.

Coordinate the location and presentation of the fuel unbalance warning with Crew Systems and Human Factors engineers.

REQUIREMENT LESSONS LEARNED (3.4.5.12.4)

Many air vehicles have been lost because the crew was not aware of a c.g. problem until the air vehicle departed from normal flight. The lack of awareness has been attributed to faulty or inoperative fuel quantity indications, poor handbook instructions, heads out of the cockpit flying, and other causes.

For fighter air vehicles, the warning should be audible or incorporated into the heads-up-display. The warning system should be independent of the fuel quantity gauge system and must be capable of being checked for proper operation.

E.4.4.5.12.4 Fuel unbalance indication.

The operation of the fuel unbalance indication shall be verified by (TBS) .

VERIFICATION RATIONALE (4.4.5.12.4)

A c.g. problem could cause an aircraft to crash, so an indication of fuel unbalance could warn the pilot of an unsafe condition.

VERIFICATION GUIDANCE (4.4.5.12.4)

TBS: The operation of the c.g. warning system should be verified by analyses and ground tests.

VERIFICATION LESSONS LEARNED (4.4.5.12.4)

(TBD)

E.3.4.5.12.5 Ground refueling controls.

The ground refueling controls shall have the capability _(TBS 1)_. The refueling controls and fuel quantity gauges shall be located _(TBS 2)_.

REQUIREMENT RATIONALE (3.4.5.12.5)

The requirement is for system flexibility in the refueling subsystem. Refueling controls and gauges in the cockpit require that a person be in the cockpit to accomplish refueling. If there is a preference that no one be in the air vehicle during refueling, then this preference should be stated.

REQUIREMENT GUIDANCE (3.4.5.12.5)

TBS 1: The refueling subsystem should have the capability to fill any individual fuel tank including external tanks or to prevent filling one or more tanks while filling the remaining tanks.

TBS 2: The refueling controls and quantity gauges should be located adjacent to the pressure refueling adapter so that the crew chief can operate the refueling nozzle and the refueling controls. If the air vehicle is always to be refueled to the full level, then fuel quantity indicators need not be repeated at the pressure fuel servicing adapter.

REQUIREMENT LESSONS LEARNED (3.4.5.12.5)

Under emergency conditions it is beneficial to have the capability to select individual tanks for filling or to exclude tanks from filling to allow flying of an air vehicle with a battle damaged or leaking fuel tank. If there are two sets of fuel quantity indicators on the air vehicle there could be a slight difference in the indicated values between the two indicators due to system tolerances. For the Airborne Warning And Control System (AWACS) air vehicle, a ground conversion chart was developed to reconcile the difference between the two indicators so that the ground crew could load the correct quantity as read on the ground indicator as requested by the flight crew which would read the quantity on the cockpit indicator. For example, a system with a 2 percent (2%) error could indicate 98K pounds on one indicator and 100K on the other indicator.

Personnel limitations should be identified early in the development so that the design of the system or location of the control panel can be in accordance with the required number of refueling personnel. The air vehicle should be capable of being refueled or defueled by two (2) maintenance personnel, one person being the crew chief located at the refueling nozzle and control panel and the other a free observer to overview the refueling for safety.

E.4.4.5.12.5 Ground refueling controls.

The ability of the refueling subsystem to fill, partially fill, or to avoid filling individually specified tanks shall be verified by __(TBS 1)__. The location of controls and fuel quantity gauges shall be verified by __(TBS 2)__.

VERIFICATION RATIONALE (4.4.5.12.5)

All fuel tanks should be able to be filled on the ground to ensure an aircraft may lift off with full tanks. The ability of the refueling personnel to control the air vehicle refueling operation (including precheck and partial refueling) from the adapter location is a servicing and operational (i.e., combat turnaround) capability driven requirement. The controls and fuel quantity gauges should provide accurate information to ensure all tanks fill, as required. Verification by demonstration is required.

VERIFICATION GUIDANCE (4.4.5.12.5)

TBS 1: The ability of the refueling system to fill individual, partially fill, or to avoid filling tanks should be verified by analysis.

TBS 2: Location of controls and fuel quantity gauges should be verified by inspections.

VERIFICATION LESSONS LEARNED (4.4.5.12.5)

Only in the case of an extremely complex system should a test or demonstration be necessary to substantiate the analysis.

E.5 PACKAGING

E.5.1 Packaging.

For acquisition purposes, the packaging requirements shall be as specified in the contract or order (see 6.2). When packaging of materiel is to be performed by DoD or in-house contractor personnel, these personnel need to contact the responsible packaging activity to ascertain packaging requirements. Packaging requirements are maintained by the Inventory Control Point's packaging activities within the Military Service or Defense Agency, or within the military service's system commands. Packaging data retrieval is available from the managing Military Department's or Defense Agency's automated packaging files, CD-ROM products, or by contacting the responsible packaging activity.

E.6 NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

E.6.1 Intended use.

The fuel subsystem descriptions in this appendix are intended for use in air vehicle systems developed to perform combat and combat-support missions in environments unique to military weapon systems.

E.6.2 Acquisition requirements.

Acquisition documents should specify the following:

a. Title, number, and date of the specification.

E.6.3 Component information

E.6.3.1 Level control.

A level control must operate over a range of flow rates, pressures, and attitudes. During refueling or fuel transfer an air vehicle fuel tank will not always be at a level attitude and fuel pressure at the inlet to the valve will vary over a large range. A range of attitudes, flow rates, and pressures where the level control valves must operate, should be defined. The range of required tank attitudes and fuel flow and pressure for which the level control must operate should be derived from the air vehicle mission profiles, ground refueling sources, aerial refueling tankers, and allowed runway and apron slopes.

In past applications a standard attitude variation of 15° in any direction has been specified by the general specification for level control valves, see MIL-V-38003. The 15° requirement has provided valves which are insensitive to air vehicle attitude and are adequate for the attitude variations which are encountered during refueling. All refueling sources as well as the air vehicle tank to tank transfer capability must be considered to define the range of flow rates and operating pressures. The allowable tank fuel level rise during valve closure, commonly called overshoot, must be recognized as well as the rate of valve closure for the control of surge pressure.

Level control valves may be used in a transfer system of a fighter air vehicle and may be required to function during low and negative "g" flight maneuvers or during vertical upward and downward attitudes. The operation of the valve under any achievable air vehicle attitude where fuel transfer can occur must be defined and the performance of the system controlled to prevent damaging over pressure as a result of this mode of operation.

a. Valve seat leakage. Small leakage past the valve seat could be tolerated and could result in a simpler, more reliable valve seat. This leakage should be differentiated from external leakage. Prohibition of external leakage includes both leakage through the valve casing walls and subassembly gaskets within the tank and leakage external to the tank when the valve incorporates a mounting plate on the tank wall. Undesirability of leakage external to the tank is obvious and leakage through casing walls and gaskets, even though it could be tolerated, indicates poor component quality.

   Some leakage past the valve seat and pilot valve can be tolerated within the fuel tank. A small allowable leakage in these areas can reduce the cost of the valve. The general specification for level control valves has in the past allowed 100 cc per minute for dual pilot valves and 50 cc per minute for single pilot valves. Most fuel subsystems can tolerate this rate of leakage without any noticeable effect.

   Level control valve leakage rate should be verified by component tests.

b. Surge pressure/valve closure rate. Level control valve rate of closure should prevent refueling surge pressures from exceeding proof pressure of the refueling subsystem. The rate of closure of the level control valve is the primary method of control of surge pressure during refueling. The level control valve rate of closure should prevent refueling surge pressure from exceeding the proof pressure of the refueling subsystem.

   A specific rate or type of closure cannot be specified since surge pressure developed is dependent upon the subsystem in which it is installed. The level control valve may also incorporate a feature to reopen, if high pressure is sensed. For a specified closure time a valve closure characteristic which has a rapid reduction of flow area during the initial stage and a slow rate of flow area reduction during the final stage will produce lower surge pressures. The level control valve rate of closure and surge control should be verified by component test. The ability of the valve to limit surge to the specified value should be demonstrated on the fuel subsystem simulator.

E.6.3.2 Boost pumps.

Pump performance. The pump must be capable of providing rated performance with hot or cold fuel at any operational altitude with a fuel level two inches above the pump inlet. A pump must be able to establish and maintain full flow while being taken to altitude as well as being started after taken to altitude. The pump rated output flow and pressure must be established with specified minimum or maximum fuel temperature, at the maximum operational altitude, and with a minimum fuel height above the pump inlet. The pump is to be capable of providing rated performance with a fuel level of two inches above the pump inlet when started under altitude conditions.

All pumps are to be capable of operation with the mounting flange in its normal position and with the air vehicle in any expected flight attitude. Rated pump performance should not depend on a large fuel head in the tank. Also, the pump must continue to function when rotated from its normal position as long as the inlet is covered with fuel. Fuel pumps in auxiliary fuel tanks may be carried to altitude before they are required to operate. These pumps must provide the required flow and pressure in a time interval sufficient to meet the air vehicle engine feed or transfer requirements.

Spar mounted, plug-in boost pumps have been used to obtain easy replacement capability for maintainability; however, this type of installation, which requires a long pump inlet, has a large impact on the pump performance. Typical boost pumps which are mounted on a tank bottom are a “submerged type” and have a very short inlet to the pump impeller. The long inlet of the spar mounted pump introduces a small but significant fuel pressure drop from the tank to the impeller. This pressure drop along with decreasing tank ullage pressure causes the evolution of air from the fuel as the fuel is sucked up the inlet. This is especially detrimental with hot, volatile fuel such as JP-4 or JET B. If the pump is idle during the climb to altitude, air will evolve from the fuel and collect in the inlet. When the pump is turned on at altitude, the collected air will impede the priming of the pump and under some conditions prevent the pump from priming, thus restricting the altitude performance capability of the pump.

Generally, submerged boost pumps have provided very good reliability and performance. The predicted pump life and the impact on maintainability should be critically reviewed before the decision is made to incorporate plug-in pumps.

Dry operation. The pump assembly is to be capable of dry operation for a minimum of five hours. Transfer tank boost pumps can be left operating after the fuel in the tank has been depleted. The pump assembly should be capable of an extended period of dry operation. A minimum period of five hours is recommended, unless a shorter dry run period can be justified.

Dry operation of a boost pump is considered a safety requirement. If the pump does not have a dry operation capability, the pump could over heat and cause a fuel tank ignition. MIL-P-5238 required incorporation of a thermal protector in electrical pumps. Thermal protection is more difficult in hydraulic or pneumatic pumps. Although thermal protection is essential for operation, it does not supersede the need for a dry operation capability. The pump should flow and pressure should be maintained when fuel is replenished to the tank.

Prime. Establishment of fuel flow after a pump has been uncovered is a basic necessity for each pump. A pump can become uncovered by fuel depletion or by extreme altitudes of the air vehicle. Special procedures to prime the pump cannot be tolerated.

The pump should be capable of self prime within a predictable, repeatable time interval following a period of dry operation or when the inlet has uncovered and then re-submerged in fuel. A maximum period of 5 seconds is suggested unless a system performance analysis justifies a longer period.

Pump testing has been guided by MIL-P-5238. Experience indicates that pump performance should be conducted in several phases; pump down, altitude climb performance, and altitude start with non-recirculated, unweathered test fuel, as follows:

a. Pump down. With the pump operating in the test stand, the fuel flow controls should be adjusted to cause the fuel head above the pump to drop at a rate of one inch per minute while maintaining rated flow and pressure. The head, output flow, and pressure should be recorded at intervals of no greater than one-inch change of head. If fuel is returned to the tank in the test setup, it should not impose any additional velocity or turbulence at the pump inlet. This test should be conducted at ground level pressure with fuel at 60°F and to the temperature specified in the detail specification at maximum altitude with fuel at the high temperature. These tests should be repeated with output flow settings at 80 percent (80%), 50 percent (50%), 25 percent (25%), 10 percent (10%), and 5 percent (5%) of rated flow. The data will be the basis for a family of curves to define pump flow capability in relation to fuel head and temperature.

b. Altitude climb performance. Install the pump in an altitude test tank in fresh, unweathered fuel at the high temperature with the fuel flow and head control set for conditions in accordance with the detail specification. With the pump not operating, the rate of climb should be established for the test tank. Power should be applied to the pump within five seconds or less of climb termination. The pump should achieve the required pressure and flow within five seconds and should maintain them for at least five minutes. This test procedure should be repeated at increasing 5,000 feet intervals up to the maximum operational altitude. The Reid vapor pressure of the fuel used in this test should be in accordance with the detail specification. For JP-4, the Reid vapor pressure of the fuel should be no less than 2.5 psia. Blending of a high vapor pressure component(s) may be necessary to obtain the desired vapor pressure. During heating of the fuel, there should be no hot spots on the surface of the heat exchanger, which exceed the maximum fuel temperature by more than 10°F. During the test, variations of output pressure (pump ripple) should be measured using a high response pressure transducer with a response in the order of 5000 Hertz. Ripple in excess of one psi RMS should be examined to determine possible interaction within the system.

c. Dry performance. A dry endurance test should be accomplished on all pumps. The pump should be operated at rated flow and allowed to pump all fuel from the tank. After the fuel has been pumped out of the tank, the discharge valve should be closed to prevent circulation of air through the pump section. Any fuel remaining in the discharge line between the pump outlet and the discharge valve should be drained. In addition, action should be taken to prevent contact of residual fuel with the pump. The pump should continue to be operated in this dry condition. The air vapor in the tank should be maintained at the high temperature ambient. After 5 hours of dry operation, the pump should be stopped and the tank refilled with fuel at room temperature. The above cycles should be accomplished five times at sea level pressure and 15 times at the maximum operational altitude. The instrumentation should locate and record the maximum case temperature.

d. Prime. The pump should be mounted in a test tank so that it can be rotated (or moved) to a position such that the inlet is out of the fuel. The pump output, depth of submersion of the inlet, fuel temperature, and altitude should be established. The pump should then be moved to uncover the inlet(s) for at least 15 seconds. When the pump is again submerged to the original depth, the pump should resume delivery of fuel at the required flow and pressure within 5 seconds. The test should be conducted at least six times (twice at each of three different altitude levels). The altitude levels should be in accordance with the detail specification.

E.6.4 Acronyms.

The following list contains the acronyms/abbreviations contained within this appendix.

AB	Afterburner
AFML	Air Force Material Laboratory
AGE	Aerospace Ground Equipment
ALCM	Air Launched Cruise Missile
AIT	Auto Ignition Temperature
API	Armor Piercing Incendiary
AWACS	Airborne Warning and Control system
cc	Cubic Centimeter
CI/LI	Corrosion Inhibitor/Lubricity Improver
CRC	Coordinating Research Council
ECS/TMS	Environmental Control System / Thermal Management System
EMD	Engineering and Manufacturing Development
EO	Executive Order
ESF	Explosion Suppressant Foam
FSII	Fuel System Icing Inhibitor
FTMS	Fuel Thermal Management System
FMECA	Failure Modes and Effects Criticality Analysis
FSD	Full Scale Development
GPM	Gallons Per Minute
Hg	Mercury
HIFR	Helicopter In-Flight Refueling
ICD	Interface Control Document
JFS	Jet Fuel Starter
LCU	Level Control Unit
NPSH	Net Positive Suction Head
OBIGGS	Onboard Inert Gas Generating System
OBOGGS	Onboard Oxygen Gas Generating System

OEM	Original Equipment Manufacturer
PPM	Parts Per Million
PSIA	Pounds Per Square Inch Approximate
PSIG	Pounds Per Square Inch Graduated
rf	Radio Frequency
SDA	Static Dissipater Additive
SPR	Single Point Refueling
VCMS	Vehicle Control and Management System
V/L	Vapor / Liquid

E.6.5 Subject term (key word) listing.

Adapter

Bladder

Contamination

Defuel

Engine

Flow

Fuel dump

Fuel tank

Gravity refuel

Hot refuel

Leakage

Pressure

Refuel

Relief

Surge

Vent

E.6.6 International standardization agreement implementation.

This specification implements ASCC AIR STD 25/11, Diameters for Aircraft Gravity Filling Orifices; STANAG 1135, Interchangeability of Fuels, Lubricants and Associated Products Used by The Armed Forces of The North Atlantic Treaty Nations; NATO STANDARD AASSEP-2, Pressure Refuelling Connections and Defuelling for Aircraft; STANAG 3105, Pressure Refuelling Connections and Defuelling for Aircraft; STANAG 3212, Diameters for Gravity Filling Orifices; STANAG 3294, Aircraft Fuel Caps and Fuel Cap Access Covers; STANAG 3632, Aircraft and Ground Support Equipment Electrical Connections for Static Groundings; STANAG 3747, Guide Specification (Minimum Quality Standards) for Aviation Turbine Fuels (F-34, F-35, F-40 and F-44); and STANAG 7036, Fuels to be Introduced into and Delivered by The NATO Pipeline System (NPS). When amendment, revision, or cancellation of this specification is proposed, the preparing activity must coordinate the action with the U.S. National Point of Contact for the international standardization agreements, as identified in the ASSIST database at https://assist.dla.mil/online/start.

E.6.7 Responsible engineering office.

The office responsible for the development and technical maintenance of this appendix is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL. Requests for additional information on this appendix can be obtained from AFLCMC/ENRS, BLDG 28 RM 118, 2145 MONAHAN WAY, WPAFB OH 45433-7017 USA; DSN 674-5476; COMMERCIAL (937) 904-5476; ENGINEERING.STANDARDS@US.AF.MIL.

E.6.8 Amendment notations.

The margins of this specification are marked with vertical lines to indicate modifications generated by this amendment. This was done as a convenience only and the Government assumes no liability whatsoever for any inaccuracies in these notations. Bidders and contractors are cautioned to evaluate the requirements of this document based on the entire content irrespective of the marginal notations.

APPENDIX F

AIR VEHICLE AERIAL REFUELING SUBSYSTEM

REQUIREMENTS AND GUIDANCE

F.1 SCOPE

F.1.1 Scope.

This appendix provides the requirements, verifications, tailoring guidance, and background information for the Aerial Refueling Subsystem provided for in Part 1 of this specification. The appendix has been developed and coordinated by technical personnel from the Air Force, Navy, and Army and has been approved as an official guide for use by Government personnel for assistance in tailoring the air vehicle subsystems specification for acquisition and model specifications. This appendix is a mandatory part of the specification. The information contained herein is intended for compliance.

F.1.2 Structure.

The appendix structure replicates the structure of the Air Vehicle Subsystems Specification except it places each corresponding section 3 requirement and section 4 verification together.

F.1.3 Appendix.

This appendix provides tailoring guidance and background information for individual paragraphs of the Air Vehicle Subsystems Specification. Guidance gives recommendations on how to tailor the specification paragraph. Where ___(TBS)___ appears, the guidance paragraph provides recommended values or text that the using service may use to insert in the __(TBS)__. When contractors are expected to complete the _(TBS)__, the Guidance paragraph will so state. The Using Service makes the final decision on whom completes the __(TBS)__ in the specification. Finally, Lessons Learned is provided to give insight to past events that could impact the tailoring of the specification.

F.1.4 Deviations.

Projected designs for given applications which will result in improvement of the system performance, reduced life cycle cost, or reduced developmental cost through deviations from this guidance, or where requirements of the specification results in compromise in operational capability, should be brought to the attention of the using service.

F.1.5 Environmental impact.

Air Vehicle Subsystems will be designed such that their operation, maintenance, and repair may be accomplished without violating the most stringent environmental regulations applicable to locations where subsystems are used or supported. Compliance with environmental regulations will not prevent subsystems from achieving and sustaining mission performance capability. Materials, processes, and environmental control equipment necessary to meet these environmental requirements must currently be available in the Using Service's maintenance and supply system. The design will not use environmentally unsuitable materials such as ozone depleting fluorocarbons, chlorofluorocarbons, and halons, or highly volatile organic compounds in solvents and coatings during development, production, operation, maintenance, or repair. The Environmental Protection Agency maintains an online list of toxic chemicals and hazardous substances on its Ozone Layer Depletion Website at http://www.epa.gov/ozone/snap/ that should be consulted. The Significant New Alternatives Policy (SNAP) Program available thereon identifies substitutes for ozone depleting chemicals.

The contractor will conduct an environmental analysis of air vehicle subsystems.

F.1.6 Responsible engineering office.

The responsible engineering office (REO) for this appendix is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL.

F.2 APPLICABLE DOCUMENTS

F.2.1 General.

The documents listed in this section are specified in sections 3 and 4 of this handbook. This section does not include documents cited in other sections of this guide specification or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3 and 4 of this handbook, whether or not they are listed.

F.2.2 Government documents

F.2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this appendix to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

INTERNATIONAL STANDARDIZATION AGREEMENTS

NORTH ATLANTIC TREATY ORGANIZATION (NATO)

STANAG 3447	Air-to-Air Refuelling Equipment: Probe-Drogue Interface Characteristics
STANAG 3971	Air-to-Air Refuelling – ATP-3.3.4.2(B) – (ATP-56(B))

(Copies of these documents are available at http://quicksearch.dla.mil, http://nso.nato.int, and www.ihs.com to qualified users.)

DEPARTMENT OF DEFENSE SPECIFICATIONS

JSSG-2001	Air Vehicle Joint Service Specification Guide
JSSG-2006	Aircraft Structures Joint Service Specification Guide
MIL-N-25161	Nozzle, Aerial Pressure Refueling, Type MA-2
MIL-T-26561	Tester, Type MA-2 Reception Coupling Break-Away Force, Portable
MIL-PRF-83282	Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Metric, NATO Code Number H-537
MIL-PRF-83323	Tester, Universal Receptacle, Aerial Refueling

(Copies of these documents are available online at http://quicksearch.dla.mil or from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia PA 19111-5094 USA.)

F.2.3 Order of precedence.

Unless otherwise noted herein or in the contract, in the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

F.2.4 Streamlining.

The Air Vehicle Subsystems Specification has been streamlined. The documents listed in this appendix which are required for acquisition have the same status as those referenced directly in section (first tier). All other documents referenced through tiering may be used for guidance and information only.

F.3 REQUIREMENTS

F.4 VERIFICATIONS

F.3.1 Definition

F.4.1 Definition

F.3.2 Characteristics

F.4.2 Characteristics

F.3.3 Design and construction

F.4.3 Design and construction

F.3.4 Subsystem characteristics

F.4.4 Subsystem characteristics

F.3.4.1 Landing subsystem

F.4.4.1 Landing subsystem

F.3.4.2 Hydraulic subsystem

F.4.4.2 Hydraulic subsystem

F.3.4.3 Auxiliary power subsystem

F.4.4.3 Auxiliary power subsystem

F.3.4.4 Environmental control subsystem

F.4.4.4 Environmental control subsystem

F.3.4.5 Fuel subsystem

F.4.4.5 Fuel subsystem

F.3.4.6 Aerial refueling subsystem.

The air vehicle shall be equipped with __(TBS 1)__ aerial refueling subsystem(s) to provide the air vehicle the capability to __(TBS 2)__ under __(TBS 3)__ conditions.

REQUIREMENT RATIONALE (3.4.6)

This is an operational and integration requirement. If the air vehicle requires aerial refueling, the type(s) of subsystem must be specified to ensure that the air vehicle will be compatible with the required tanker and receiver platforms. The function(s) of each subsystem must be specified to ensure that the subsystem(s) is (are) integrated properly into the air vehicle.

REQUIREMENT GUIDANCE (3.4.6)

TBS 1: Specify which type(s) of aerial refueling subsystem is (are) required for the air vehicle; such as, receiver receptacle, receiver probe, tanker boom, tanker drogue, or other.

TBS 2: If TBS 1 identifies receiver subsystem(s), and a "dry" installation is not desired, specify that the subsystem(s) should provide the air vehicle the ability to safely receive fuel from the targeted tanker air vehicle(s) while in flight. If a "dry" installation is required, then specify that the subsystem(s) should permit the air vehicle the ability to safely conduct aerial refueling procedures (less fuel transfer) with the targeted tanker air vehicle(s) while in flight. In either case, the targeted tanker(s) is (are) the list of tanker platforms specified in JSSG-2001, that the air vehicle must be compatible with to aerial refuel. If it is also required to have the air vehicle be able to refuel through the receiver aerial refueling subsystem(s) while the air vehicle is on the ground, then also specify that the subsystem(s) should provide the air vehicle the ability to safely receive fuel from the targeted ground refueling source(s). The targeted ground refueling source(s) is (are) the list of ground refueling sources specified in JSSG-2001, from which the air vehicle must be able to refuel. If a tanker subsystem is identified in TBS 1, as a minimum, specify in TBS 2 that the subsystem should provide the air vehicle the ability to safely transfer fuel to another air vehicle, or multiple air vehicles (if applicable), while in flight. If it is also required to have the air vehicle be able to defuel through the tanker aerial refueling subsystem(s) while the air vehicle is on the ground, then also specify that the subsystem(s) should provide the air vehicle the ability to safely transfer fuel to targeted ground platform(s) while on the ground. The targeted ground platform(s) is (are) the list of ground refueling platform(s) specified in JSSG-2001. If the air vehicle requires tanker and receiver aerial refueling subsystems, specify the appropriate phrases above.

TBS 3: For in-flight operation of the aerial refueling subsystem(s), specify that the capability should be provided under specified environmental conditions. For ground operation of the aerial refueling subsystem(s), specify in what conditions the subsystem(s) should be able to operate.

REQUIREMENT LESSONS LEARNED (3.4.6)

Ground use of receiver and tanker aerial refueling subsystems should be required as it permits ground tests to be conducted to verify tanker and receiver compatibility issues, for example refuel time, refuel rates, refuel delivery pressures, and fuel surge pressures during transfer. The ability to initially examine these compatibility parameters on the ground rather than in flight is very beneficial in controlling any hazard(s) that may occur due to an incompatibility and permitting a broader examination controlled test points. Ground use of the tanker aerial refueling subsystem(s) could also be required when the subsystem(s) is (are) to be used to conduct Forward Area Refueling Point (FARP) or Forward Area Remote Rearming Point (FARRP) operations.

Aerial refueling subsystems have typically interfaced with fuel subsystems, hydraulic subsystems, fire and explosion protection subsystems, electrical subsystems, structures, avionics, and crew subsystems. As such, references have been made within the appropriate aerial refueling subsystem Guidance and Lessons Learned sections to requirements within these other technical disciplines to ensure that the integration of the aerial refueling subsystem(s) onto the air vehicle is properly addressed.

"Dry" receiver installations are typically incorporated into air vehicles for aerial refueling training purposes only.

F.4.4.6 Aerial refueling subsystem.

The ability of each aerial refueling subsystem to provide the air vehicle its specified capability under the identified conditions shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6)

The ability of each aerial refueling subsystem to provide the specified capability must be verified to ensure that the air vehicle can successfully fulfill each of its operational requirements.

VERIFICATION GUIDANCE (4.4.6)

TBS: Specify inspection, analysis, ground demonstration, ground test, flight demonstration, and flight test.

VERIFICATION LESSONS LEARNED (4.4.6)

(TBD)

F.3.4.6.1 General subsystem requirements

F.4.4.6.1 General subsystem requirements

F.3.4.6.1.1 Other subsystem interfaces.

The __(TBS 1)__ aerial refueling subsystem shall interface with the air vehicle's __(TBS 2)__ subsystem(s) in order for it to properly perform its function(s). The aerial refueling subsystem shall not adversely impact the performance capability of this (these) other subsystem(s) while the aerial refueling subsystem is operating properly or when the aerial refueling subsystem experiences a single failure.

REQUIREMENT RATIONALE (3.4.6.1.1)

This is an integration and safety requirement. The interfaces of the aerial refueling subsystem must be identified to ensure that the aerial refueling subsystem is properly integrated into the air vehicle such that the aerial refueling subsystem can successfully and safely perform its function(s) and not impact the proper operation of the other air vehicle subsystems.

REQUIREMENT GUIDANCE (3.4.6.1.1)

TBS 1: Specify the particular aerial refueling subsystem.

TBS 2: Identify the other air vehicle subsystem(s) that the specific aerial refueling subsystem must interface with to perform its function(s).

REQUIREMENT LESSONS LEARNED (3.4.6.1.1)

For aerial refueling subsystems, typical interfaces with other air vehicle subsystems have been:

a. the hydraulic and electrical subsystems for mechanical power requirements
b. the electrical subsystem for lights and other power requirements
c. the fuel subsystem for other power requirements and as a depository for the fuel to be received or transferred
d. the crew subsystems for displays and controls
e. the vehicle management subsystem for fuel management and flight performance calculations
f. automatic flight control subsystems
g. communication subsystems
h. structures for installation

Since the aerial refueling subsystem typically directly interfaces with the air vehicle's fuel subsystem, the impact that the aerial refueling subsystem has on the fuel subsystem's performance capability should be closely evaluated. The operation of the aerial refueling subsystem (with and without a single failure) should not compromise the fuel subsystem's engine feed capability; venting capability; fuel transfer capability for thermal management, center-of-gravity (c.g.), and dump and defuel purposes; and fuel containment capability. For example, a separation of a fuel line that is used to receive or transfer fuel during aerial refueling should not compromise the venting capability of the fuel subsystem's design.

F.4.4.6.1.1 Other subsystem interfaces.

The ability of __(TBS 1)__ to interface with the air vehicle's __(TBS 2)__ subsystem(s) to allow it to perform its function(s) while not adversely impacting the performance capability of this(these) other subsystem(s) shall be verified by __(TBS 3)__.

VERIFICATION RATIONALE (4.4.6.1.1)

The ability of each aerial refueling subsystem to interface properly with other air vehicle subsystems must be verified to ensure that the aerial refueling subsystem is integrated into the air vehicle, such that, it and the other air vehicle subsystems can successfully and safely perform their functions.

VERIFICATION GUIDANCE (4.4.6.1.1)

TBS 1: Specify receiver or tanker.

TBS 2: Identify the appropriate subsystems on the air vehicle that the particular aerial refueling subsystem must interface with to operate properly.

TBS 3: Specify inspection, analysis, ground demonstration, ground test, flight demonstration, flight test or a combination.

VERIFICATION LESSONS LEARNED (4.4.6.1.1)

Each particular aerial refueling subsystem's ability to perform its function(s) should be evaluated with the specified air vehicle subsystem interface(s) providing only its (their) minimum performance requirement(s) to the aerial refueling subsystem.

The impact of the particular aerial refueling subsystem's operation on the performance of the other air vehicle subsystem(s) that it interfaces with must include the impacts when there is a single failure in that aerial refueling subsystem.

F.3.4.6.1.2 Single failures.

With the exception of __(TBS 1)__, no single failures within a tanker aerial refueling subsystem shall preclude the tanker aerial refueling subsystem from being able to perform its function(s). With the exception of __(TBS 2)__, no single failures within a receiver aerial refueling subsystem shall preclude the receiver aerial refueling subsystem from being able to perform its function(s).

REQUIREMENT RATIONALE (3.4.6.1.2)

This is an operational and safety requirement. The ability for the air vehicle to successfully transfer or receive fuel during aerial refueling operations can be operationally and safety critical.

Each aerial refueling subsystem must be able to perform its identified function(s) even under certain single failure conditions within that particular aerial refueling subsystem.

REQUIREMENT GUIDANCE (3.4.6.1.2)

TBS 1: Specify what single failure(s) should be permitted to prevent the tanker aerial refueling subsystem from being able to adequately perform its designated function(s).

TBS 2: Specify what single failure(s) should be permitted to prevent the receiver aerial refueling subsystem from being able to adequately perform its designated function(s). This requirement does not apply to an aerial refueling subsystem that is a "dry" installation design.

REQUIREMENT LESSONS LEARNED (3.4.6.1.2)

Typically, noted exceptions for "allowable" single failures have been fuel line integrity, but not fuel line couplings.

F.4.4.6.1.2 Single failures.

Except for the noted special cases, the ability of the tanker aerial refueling subsystem to successfully perform its function(s) with a single failure shall be verified by __(TBS 1)__. Except for the noted special cases, the ability of the receiver aerial refueling subsystem to successfully perform its function(s) with a single failure in the receiver aerial refueling subsystem shall be verified by __(TBS 2)__.

VERIFICATION RATIONALE (4.4.6.1.2)

The ability of each aerial refueling subsystem to successfully and safely perform its function(s) even under single failure conditions within the aerial refueling subsystem must be verified to ensure that the air vehicle can successfully and safely complete its mission(s).

VERIFICATION GUIDANCE (4.4.6.1.2)

TBS 1: Specify analysis, ground demonstration, ground test, and flight test.

TBS 2: Specify analysis, ground demonstration, ground test, and flight test.

VERIFICATION LESSONS LEARNED (4.4.6.1.2)

Those failures which can not be adequately controlled in flight, or can cause loss of power and control authority to the air vehicle in flight, should not be evaluated in flight test.

F.3.4.6.1.3 Operating fuel pressure.

The aerial refueling subsystem shall be designed for an operating pressure of __(TBS)__.

REQUIREMENT RATIONALE (3.4.6.1.3)

(TBD)

REQUIREMENT GUIDANCE (3.4.6.1.3)

(TBD)

REQUIREMENT LESSONS LEARNED (3.4.6.1.3)

Tanker/receiver aerial refueling subsystem operating pressures must be designed to be compatible with all targeted receiver/tanker aerial refueling systems.

F.4.4.6.1.3 Operating fuel pressure.

The aerial refueling subsystem operating fuel pressure shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.1.3)

(TBD)

VERIFICATION GUIDANCE (4.4.6.1.3)

(TBD)

VERIFICATION LESSONS LEARNED (4.4.6.1.3)

(TBD)

F.3.4.6.1.4 Subsystem isolation.

Each aerial refueling subsystem shall be capable of being isolated from the fuel pressure resulting from the normal operation of the air vehicle's fuel subsystem or any other aerial refueling subsystem. For those designs where manual activation is required to provide the isolation, the manual activation shall be capable of being initiated by __(TBS)__.

REQUIREMENT RATIONALE (3.4.6.1.4)

This is an integration, operational, and safety requirement. Damage or breakage to any aerial refueling subsystem must not interfere with the proper operation of the air vehicle's fuel subsystem and any other aerial refueling subsystem installed on the air vehicle. Fuel pressure resulting from normal operation of the air vehicle's fuel system must be isolated from the aerial refueling subsystem(s). In addition, if the air vehicle incorporates multiple aerial refueling subsystems, they must be isolated from each other so that damage within one subsystem will not prevent the ability to safely use the other subsystem(s) and successfully complete the aerial refueling process.

REQUIREMENT GUIDANCE (3.4.6.1.4)

TBS: Specify which crew member(s) should be provided this capability. In single seat air vehicles, the pilot obviously should be given this capability. If there is a co-pilot in the air vehicle, and the co-pilot is required to perform the aerial refueling process, then this capability should be provided to the co-pilot also, or only. In some installations, only the flight engineer, or some other crew member, should be provided this capability.

REQUIREMENT LESSONS LEARNED (3.4.6.1.4)

Isolation has typically been accomplished by either a check valve or by a motor operated control valve. If a motor operated control valve is used, consideration must be given for a manual override and access to the valve so that a single failure of the valve will not prevent the capability to aerial refuel the air vehicle.

F.4.4.6.1.4 Subsystem isolation.

The ability to isolate each aerial refueling subsystem from the air vehicle's fuel subsystem and any other aerial refueling subsystem shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.1.4)

It should be verified that each aerial refueling subsystem can be isolated from the air vehicle's fuel subsystem and any other aerial refueling subsystem to ensure that no single failure hazards are introduced to the air vehicle, that single failures do not compromise the proper operation of the air vehicle's fuel subsystem, and that single failures do not prevent the air vehicle from safely and successfully aerial refueling from any other aerial refueling subsystem.

VERIFICATION GUIDANCE (4.4.6.1.4)

TBS: Specify ground demonstration and during flight test of each aerial refueling subsystem.

VERIFICATION LESSONS LEARNED (4.4.6.1.4)

The ground demonstration should simulate failures of the various aerial refueling subsystems to verify that one subsystem can be isolated from the other and the air vehicle's fuel subsystem. If manual activation is provided for any isolation feature, that capability should be verified in the flight test along with the adequacy and accessibility of the activation method.

F.3.4.6.1.5 Removed Group B hardware.

The __(TBS)__ aerial refueling subsystem shall not be a source for fuel leaks and shall not adversely impact the performance capability of other air vehicle subsystems when the Group B hardware for that aerial refueling subsystem has been removed from the air vehicle.

REQUIREMENT RATIONALE (3.4.6.1.5)

This is an operational, safety, and integration requirement. The air vehicle may have missions where the Group B hardware of a particular aerial refueling subsystem must be removed. Recognizing this need will properly integrate that particular aerial refueling subsystem into the air vehicle and will ensure that the removal of the Group B hardware does not prevent the proper function of other subsystems or preclude the air vehicle from being able to safely accomplish its other mission(s).

REQUIREMENT GUIDANCE (3.4.6.1.5)

TBS: Identify the specific aerial refueling subsystem; such as, the wing drogue aerial refueling subsystem or the probe aerial refueling subsystem.

REQUIREMENT LESSONS LEARNED (3.4.6.1.5)

This requirement has typically been required for wing drogue aerial refueling subsystems where the Group B hardware is the aerial refueling pods which have to be removed when the air vehicle has a mission that does not require the pods. This requirement has also been applicable for probe aerial refueling subsystems where the Group B hardware is the probe mast which may have to be removed when the air vehicle does not require the probe refueling subsystem on a given mission.

F.4.4.6.1.5 Removed Group B hardware.

The ability of the __(TBS 1)__ aerial refueling subsystem to not leak and to not adversely impact the performance capability of other air vehicle subsystems when the Group B hardware for that aerial refueling subsystem has been removed from the air vehicle shall be verified by _(TBS 2)_.

VERIFICATION RATIONALE (4.4.6.1.5)

It must be verified that it is possible to remove the Group B hardware of a particular aerial refueling subsystem without creating a fire hazard to the air vehicle or without impacting the proper operation of other air vehicle subsystems to ensure that the air vehicle will be able to accomplish all of its missions safely.

VERIFICATION GUIDANCE (4.4.6.1.5)

TBS 1: Identify the specific aerial refueling subsystem; such as, the wing pod aerial refueling subsystem or the probe aerial refueling subsystem.

TBS 2: Specify ground demonstration and during flight test.

VERIFICATION LESSONS LEARNED (4.4.6.1.5)

Flight test should evaluate the performance of the fuel system and other aerial refueling subsystems in the air vehicle when a particular Group B hardware to an aerial refueling subsystem has been removed from the air vehicle. Evaluations should also examine flight control impacts with the particular Group B hardware removed.

F.3.4.6.1.6 Fuel subsystem issues.

The __(TBS 1)__ aerial refueling subsystem(s) shall be designed such that the fuel subsystem requirements specified in appendix E, Fuel Subsystem, paragraph(s) __(TBS 2)__ are met.

REQUIREMENT RATIONALE (3.4.6.1.6)

(TBD)

REQUIREMENT GUIDANCE (3.4.6.1.6)

TBS 1: Identify the specific aerial refueling subsystem(s) on the air vehicle.

TBS 2: Specify the appropriate fuel subsystem requirement paragraphs in the appendix E, Fuel Subsystem.

REQUIREMENT LESSONS LEARNED (3.4.6.1.6)

Some typical fuel subsystem requirements that should be applicable to the design of the aerial refueling subsystem(s) are the following:

a. Fuel Designation

b. Material Fuel Resistance

c. Fuel Contamination
d. Fuel Temperatures
e. Thermal Relief
f. External Fuel Leakage
g. Compartment Drains
h. Electrical Fault and Explosive Atmosphere
i. Fuel Tank Inerting and Explosion Suppression
j. Static Discharge in Fuel Tanks
k. Fuel Vent.

F.4.4.6.1.6 Fuel subsystem issues.

The ability of the aerial refueling subsystem(s) to meet the specified fuel subsystem requirements shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.1.6)

(TBD)

VERIFICATION GUIDANCE (4.4.6.1.6)

TBS: Identify the same verification methods specified for each referenced fuel subsystem requirement.

VERIFICATION LESSONS LEARNED (4.4.6.1.6)

(TBD)

F.3.4.6.1.7 Fire protection considerations.

The __(TBS 1)__ aerial refueling subsystem(s) shall be designed such that the fire protection subsystem requirements specified in appendix G, Fire and Explosion Hazard Protection Subsystem, paragraph(s) __(TBS 2)__ are met.

REQUIREMENT RATIONALE (3.4.6.1.7)

(TBD)

REQUIREMENT GUIDANCE (3.4.6.1.7)

TBS 1: Identify the specific aerial refueling subsystem(s) on the air vehicle.

TBS 2: Specify the appropriate fuel subsystem requirement paragraphs in the appendix G, Fire and Explosion Hazard Protection Subsystem.

REQUIREMENT LESSONS LEARNED (3.4.6.1.7)

(TBD)

F.4.4.6.1.7 Fire protection considerations.

The ability of the aerial refueling subsystem(s) to meet the specified fire protection subsystem requirements shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.1.7)

(TBD)

VERIFICATION GUIDANCE (4.4.6.1.7)

TBS: Identify the same verification methods specified for each referenced fire protection subsystem requirement.

VERIFICATION LESSONS LEARNED (4.4.6.1.7)

(TBD)

F.3.4.6.1.8 Air vehicle center of gravity and flight control and handling qualities.

The aerial refueling subsystem shall be designed such that the air vehicle center-of-gravity is within defined limits and the air vehicle's flying qualities remain acceptable throughout the entire aerial refueling envelope for the air vehicle.

REQUIREMENT RATIONALE (3.4.6.1.8)

(TBD)

REQUIREMENT GUIDANCE (3.4.6.1.8)

(TBD)

REQUIREMENT LESSONS LEARNED (3.4.6.1.8)

(TBD)

F.4.4.6.1.8 Air vehicle center of gravity and flight control and handling qualities.

The air vehicle center-of-gravity and flying qualities shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.1.8)

(TBD)

VERIFICATION GUIDANCE (4.4.6.1.8)

TBS: Specify that the air vehicle center-of-gravity and flying qualities should be verified by modeling, simulation, and flight test throughout the entire flight envelope for the air vehicle.

VERIFICATION LESSONS LEARNED (4.4.6.1.8)

(TBD)

F.3.4.6.1.9 Communication capability.

The communication capability shall be compatible with the aerial refueling procedures defined in ATP-56 (NATO STANAG 3971).

REQUIREMENT RATIONALE (3.4.6.1.9)

(TBD)

REQUIREMENT GUIDANCE (3.4.6.1.9)

ATP-56 (NATO STANAG 3971) defines the general, internationally accepted aerial refueling procedures. If the targeted tanker/receiver(s) or the air vehicle's mission(s) dictate unique communication requirements with respect to the aerial refueling process, these new requirements must be specified.

REQUIREMENT LESSONS LEARNED (3.4.6.1.9)

(TBD)

F.4.4.6.1.9 Communication capability.

The adequacy of the communication capability during aerial refueling operations shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.1.9)

(TBD)

VERIFICATION GUIDANCE (4.4.6.1.9)

TBS: Specify that the communication capability should be verified by demonstration in an operationally-realistic environment.

VERIFICATION LESSONS LEARNED (4.4.6.1.9)

(TBD)

F.3.4.6.1.10 Support equipment interface.

The __(TBS 1)__ aerial refueling subsystem shall interface with __(TBS 2)__ ground support equipment to be able to perform __(TBS 3)__ maintenance actions.

REQUIREMENT RATIONALE (3.4.6.1.10)

This is an operational and safety requirement. Each aerial refueling subsystem must be designed to interface with the appropriate ground support equipment to ensure the necessary maintenance actions can be successfully accomplished. This requirement ensures a properly-functioning aerial refueling subsystem is being fielded, and ideally being made available for operational use in a timely manner.

REQUIREMENT GUIDANCE (3.4.6.1.10)

TBS 1: Specify the appropriate aerial refueling subsystem.

TBS 2: Specify the appropriate ground support equipment. For drogue aerial refueling systems, specify a MIL-T-26561 coupling tester (as a minimum). There are other coupling testers that can perform the same function as the MIL-T-26561 but also have additional checkout functions and a different design from the MIL-T-26561 tester. For receptacle aerial refueling subsystems, specify a MIL-PRF-83323 tester. For boom aerial refueling subsystems, specify an appropriate existing tester(s).

REQUIREMENT LESSONS LEARNED (3.4.6.1.10)

All aerial refueling subsystem support equipment interfaces should be identified based upon the program's Supportability Plan for the air vehicle.

For drogue aerial refueling systems, the MIL-T-26561 coupling tester can verify the proper toggle latching setting in the coupling, thereby assuring the correct break-away force to disengage the probe nozzle from the coupling. There are other coupling testers available that can perform this same function and can also: (1) verify the fuel delivery pressure from the drogue aerial refueling subsystem to the receiver, and (2) permit a single-point refueling hose to be connected which would allow fuel off-loading through the drogue aerial refueling subsystem while the air vehicle is on the ground. For receptacle aerial refueling subsystems, a MIL-PRF-83323 tester exists which can checkout various functions of the receptacle aerial refueling subsystem. This tester can be used to: (1) verify proper function of the interface to the tanker's Through-the-Boom communication system, (2) verify the capability to perform tanker-initiated and receiver-initiated disconnects, (3) verify synchronized advancement of the mode status for the air vehicle's receptacle aerial refueling subsystem and the tanker's boom aerial refueling subsystem, and (4) permit a single-point refueling hose to be connected which would allow ground refueling through the receptacle aerial refueling subsystem.

For boom aerial refueling subsystems, there is a boom nozzle tester that can be used to: (1) verify proper function of the air vehicle's Through-The-Boom communication capability provided in the boom aerial refueling subsystem, (2) verify the capability to perform tanker-initiated and receiver-initiated disconnects, (3) verify synchronized advancement of the mode status for the air vehicle's boom aerial refueling subsystem and the receiver's receptacle aerial refueling subsystem, and (4) permit a single-point refueling hose to be connected which would allow ground defueling through the boom aerial refueling subsystem. In addition, there is another boom nozzle tester that can be used to verify the proper torque required to produce rotation and deflection in the boom nozzle of the boom aerial refueling subsystem. For probe aerial refueling subsystems, there is a GA-2B adapter (Pressure Fuel Servicing Adapter) that connects to the probe nozzle and permits ground refueling through the nozzle. There is a Pull-off Tester that checks the release mechanism of the probe nozzle. There is also a Sleeve Load Tester that checks the spring load of the probe nozzle's sleeve.

F.4.4.6.1.10 Support equipment interface.

The ability of the (TBS 1) aerial refueling subsystem(s) to interface properly with the specified ground support equipment shall be verified by (TBS 2) .

VERIFICATION RATIONALE (4.4.6.1.10)

The ability of each aerial refueling subsystem to interface properly with ground support equipment must be verified to ensure personnel can perform the necessary maintenance actions to assure the air vehicle is being fielded with an aerial refueling subsystem in proper working order.

VERIFICATION GUIDANCE (4.4.6.1.10)

TBS 1: Specify the appropriate aerial refueling subsystem.

TBS 2: Specify ground demonstration.

VERIFICATION LESSONS LEARNED (4.4.6.1.10)

(TBD)

F.3.4.6.2 Receiver aerial refueling subsystems

F.4.4.6.2 Receiver aerial refueling subsystems

F.3.4.6.2.1 General receiver aerial refueling subsystem requirements

F.4.4.6.2.1 General receiver aerial refueling subsystem requirements

F.3.4.6.2.1.1 Tanker compatibility.
The receiver aerial refueling subsystem shall be compatible for refueling, under all environmental operating conditions, with the following tanker aerial refueling subsystem(s): (TBS) .

REQUIREMENT RATIONALE (3.4.6.2.1.1)

(TBD)

REQUIREMENT GUIDANCE (3.4.6.2.1.1)

(TBD)

REQUIREMENT LESSONS LEARNED (3.4.6.2.1.1)

(TBD)

F.4.4.6.2.1.1 Tanker compatibility.
Tanker compatibility shall be verified by (TBS) .

VERIFICATION RATIONALE (4.4.6.2.1.1)

(TBD)

VERIFICATION GUIDANCE (4.4.6.2.1.1)

(TBD)

VERIFICATION LESSONS LEARNED (4.4.6.2.1.1)

(TBD)

F.3.4.6.2.1.2 Receiver aerial refueling rate.

The __(TBS 1)__ receiver aerial refueling subsystem shall be designed so that the receiver air vehicle can be refueled from __(TBS 2)__ to __(TBS 3)__ in __(TBS 4)__ from the targeted tanker (TBS 5)__ aerial refueling subsystem(s).

REQUIREMENT RATIONALE (3.4.6.2.1.2)

This is an operational requirement. The air vehicle's mission should dictate how much time is allowed for the air vehicle to perform aerial refueling operations. In addition to the fuel pumping capacity of the tanker aerial refueling subsystem, the receiver aerial refueling subsystem design will affect how long it will operationally take to fill a receiver from a predetermined fuel quantity to a final fuel quantity.

REQUIREMENT GUIDANCE (3.4.6.2.1.2)

TBS 1: Identify the specific receiver aerial refueling subsystem.

TBS 2: Specify the fuel quantity within the receiver air vehicle at the beginning of the refuel sequence. For example, an initial fuel condition may be 10 percent (10%) fuel in all tanks.

TBS 3: Specify the fuel quantity within the receiver air vehicle at the end of the refuel sequence. Ideally, the final fuel status desired is a complete filling (top-off) of every fuel tank that the aerial refueling subsystem is designed to refuel; however, there are situations due to the lack of system redundancy, proof pressure limitations and structural considerations where refueling to a capacity less than top-off may be required.

TBS 4: Specify the maximum allowable refuel time (minutes).

TBS 5: Specify the appropriate targeted tanker aerial refueling subsystem(s).

REQUIREMENT LESSONS LEARNED (3.4.6.2.1.2)

Generally, air vehicles have been designed for a 90 percent load, that is at the initiation of the refueling process the air vehicle would contain 10 percent of its fuel load evenly distributed in its main tanks. This is considered a maximum transfer requirement. In order to minimize the time of refueling, the receiver can be designed for flow rates greater than the transfer capability of the tanker aerial refueling subsystem. This growth capability is considered desirable and will enable the tanker aerial refueling subsystem to perform at or slightly above its rated fuel transfer performance. Unless mission requirements dictate otherwise, the following values have been used:

Total Air Vehicle Fuel Weight (lb)	Flow Rate – Referenced (GPM)	Time (Minutes) 90% Load
250,000 - 450,000	1500	23 - 42
100,000 - 250,000	1200	12 - 28
50,000 - 100,000	900	8 - 16
25,000 - 50,000	600	6 - 12
10,000 - 25,000	400	4 - 9
UP TO - 10,000	300	≤5

The time required for accomplishing a hookup and the time to transfer the fuel which is burned by the receiver during the refueling must be added to the time of the chart.

F.4.4.6.2.1.2 Receiver aerial refueling rate.

The ability of the __(TBS 1)__ aerial refueling subsystem to permit the air vehicle to be refueled as specified within the defined time shall be verified by __(TBS 2)__.

VERIFICATION RATIONALE (4.4.6.2.1.2)

It must be verified that the air vehicle is able to complete aerial refueling operations from the targeted tanker aerial refueling subsystem(s) within the allotted time to ensure the air vehicle can successfully complete its operational mission(s).

VERIFICATION GUIDANCE (4.4.6.2.1.2)

TBS 1: Identify the specific receiver aerial refueling subsystem.

TBS 2: Specify analysis, ground demonstration, ground test, flight demonstration, flight test or a combination.

VERIFICATION LESSONS LEARNED (4.4.6.2.1.2)

Ground tests should include evaluations on an aerial refueling and fuel subsystem simulator testing and on the actual air vehicle or both. Simulator tests allow close control over fuel flow rate and pressures and monitoring of more subsystem test data than is generally possible on an air vehicle. In ground tests, it is important to assure that the refuel source is able to replicate the fuel transfer rate and pressure that the tanker aerial refueling subsystem is able to provide while aerial refueling. For simulator tests, it is therefore prudent to conduct the evaluations at different fuel delivery pressures as would be experienced from the tanker aerial refueling subsystem. In the past, fuel delivery pressures of 25, 35, 45, and 55 psig have been used. Tanker aerial refueling subsystems that are able perform identically (with regards to fuel delivery rate and pressure) on the ground as they would in flight allow ground tests with the actual receiver air vehicle to be valid evaluations for refuel time. The time required to fill the air vehicle should be determined using the required starting conditions and should be evaluated with each targeted tanker aerial refueling subsystem. The flow rates to the receiver subsystem should be determined for various tank open conditions and for each tank open singularly. Successful completion of the ground test(s) will permit flight testing of the aerial refueling subsystem with minimum risk.

F.3.4.6.2.1.3 Refuel control mode.

The distribution of fuel into the air vehicle when aerial refueling through the __(TBS 1)__ receiver aerial refueling subsystem shall be controlled by __(TBS 2)__.

REQUIREMENT RATIONALE (3.4.6.2.1.3)

This is an operational and integration requirement.

REQUIREMENT GUIDANCE (3.4.6.2.1.3)

TBS 1: Identify the specific receiver aerial refueling subsystem on the air vehicle.

TBS 2: Specify whether the fuel distribution into the air vehicle when aerial refueling through the particular receiver aerial refueling subsystem will be automatically controlled or manually controlled. If manually controlled, also specify which crew member(s) will have this control capability. In single-seat air vehicles, the pilot obviously should be given this capability. When the co-pilot is required to perform the aerial refueling process, the control capability should be provided. In some receptacle installations, only the flight engineer should be provided this capability.

REQUIREMENT LESSONS LEARNED (3.4.6.2.1.3)

(TBD)

F.4.4.6.2.1.3 Refuel control mode.

The ability to control fuel distribution when aerial refueling through the __(TBS 1)__ receiver aerial refueling subsystem shall be verified by __(TBS 2)__.

VERIFICATION RATIONALE (4.4.6.2.1.3)

(TBD)

VERIFICATION GUIDANCE (4.4.6.2.1.3)

TBS 1: identify the specific receiver aerial refueling subsystem on the air vehicle.

TBS 2: specify ground demonstration and flight demonstration .

VERIFICATION LESSONS LEARNED (4.4.6.2.1.3)

(TBD)

F.3.4.6.2.1.4 Fuel parameters.

(TBD)

REQUIREMENT RATIONALE (3.4.6.2.1.4)

(TBD)

REQUIREMENT GUIDANCE (3.4.6.2.1.4)

(TBD)

REQUIREMENT LESSONS LEARNED (3.4.6.2.1.4)

(TBD)

F.4.4.6.2.1.4 Fuel parameters.

(TBD)

VERIFICATION RATIONALE (4.4.6.2.1.4)

(TBD)

VERIFICATION GUIDANCE (4.4.6.2.1.4)

(TBD)

VERIFICATION LESSONS LEARNED (4.4.6.2.1.4)

(TBD)

F.3.4.6.2.1.5 Low Observable (LO) parameters.

The installation and operation of the aerial refueling system shall be compliant with the Low Observable requirements for the air vehicle.

REQUIREMENT RATIONALE (3.4.6.2.1.5)

This is an operational and integration requirement.

REQUIREMENT GUIDANCE (3.4.6.2.1.5)

(TBD)

REQUIREMENT LESSONS LEARNED (3.4.6.2.1.5)

(TBD)

F.4.4.6.2.1.5 Low Observable (LO) parameters.

The impact of the aerial refueling system to the air vehicle's Low Observable performance shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.1.5)

(TBD)

VERIFICATION GUIDANCE (4.4.6.2.1.5)

TBS: Specify that the Low Observable parameters of the aerial refueling installation, and its operation, should be verified by analysis and demonstration.

VERIFICATION LESSONS LEARNED (4.4.6.2.1.5)

(TBD)

F.3.4.6.2.2 Receptacle receiver aerial refueling subsystems

F.4.4.6.2.2 Receptacle receiver aerial refueling subsystems

F.3.4.6.2.2.1 Type of receptacle installation.

The receptacle installation shall be compatible with tanker boom nozzles which comply with figures F-1 through F-5. The receptacle installation shall be __(TBS)__.

REQUIREMENT RATIONALE (3.4.6.2.2.1)

This is an integration and operational interface requirement. The specific type of receptacle installation must be identified to ensure compatibility with the tanker boom system(s) identified for the air vehicle to aerial refuel from operationally and to insure the proper integration with other air vehicle subsystems.

REQUIREMENT GUIDANCE (3.4.6.2.2.1)

TBS: Specify what type of receptacle will be used and specify its interface design requirements. In the past, the installation has required a receptacle with toggle latches, a slipway, a signal system, slipway lights, status indicator lights and controls. As such, the interfaces with other disciplines (fuel, electrical, hydraulic, avionics, structures, and crew subsystems) had to be identified.

REQUIREMENT LESSONS LEARNED (3.4.6.2.2.1)

The Universal Aerial Refueling Receptacle Slipway Installation (UARRSI) can be the best compromise for a receptacle installation in relation to performance, function, volume required, weight, maintenance, and cost. The development and qualification cost have already been amortized. The ENFE Technical Exhibit 77-1 standardized the function of the receptacle and defined all interfaces between the receptacle and the air vehicle. The UARRSI is considered universal because the receptacle can be positioned between 31 degrees and 46 degrees (in

5-degree increments) in the UARRSI box to accommodate the installation of the UARRSI box at different angles or positions on a receiver air vehicle. After the receptacle angle is selected for a particular air vehicle, a close-out plate is installed on the back of the box to hold the receptacle at the selected angle. There are four standard close-out plates for 31 degrees, 36 degrees, 41 degrees, and 46 degrees.

Other design options include rollover installations that roll the receptacle over to change it from the "closed" position to the "open" position. This type of design has been used successfully in air vehicles that had strict LO requirements that had to be maintained when the aerial refueling subsystem was not being used for aerial refueling.

The flying boom receptacle specification MIL-R-27521 also contains valid design requirements for a receptacle to be compatible with boom nozzles which comply with figures F-1 through F-5.

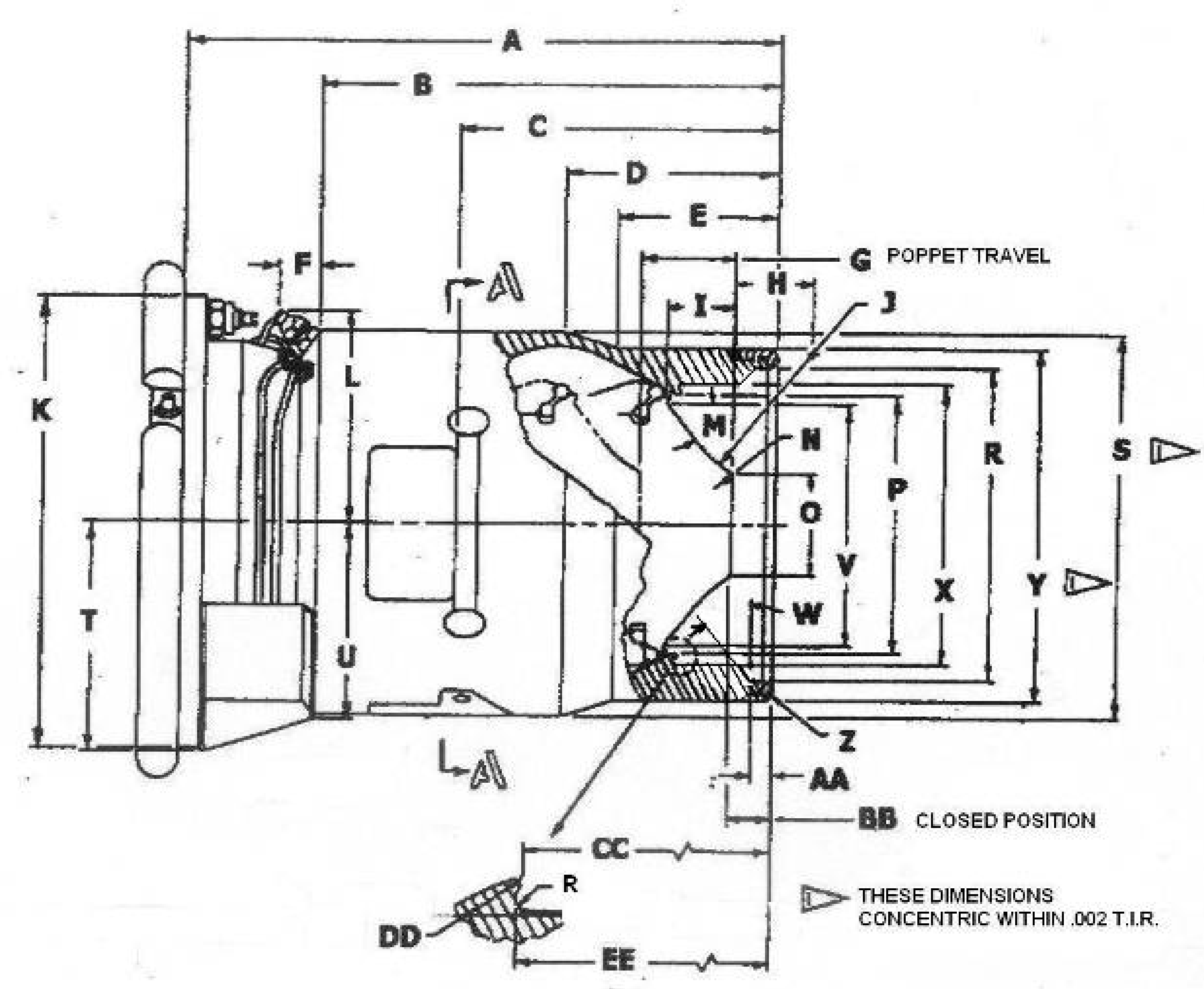

FIGURE F-1. Boom nozzle mating dimensions.

DIM	MAXIMUM in.	MAXIMUM mm	MINIMUM in.	MINIMUM mm	REMARKS
A	8.11	205.99	8.095	205.61	
B	6.245	158.62	6.22	157.99	
C	4.4125	112.08	4.3775	111.19	
D	2.865	72.77	2.84	72.14	
E	2.165	54.99	2.14	54.36	
F	0.5	12.70			
G	1.31	33.27	1.17	29.72	
H	1.08	27.43			
I	0.91	23.11	0.9	22.86	
J	2.05	52.07			radius
K	6.21	157.73	6.19	157.23	
L	2.9	73.66			radius
M	51.5				degrees
N	0.02	0.51			radius
O	1.4	35.56			
P	3.55	90.17	3.53	89.66	
R	4.3	109.22	4.29	108.97	
S	5.25	133.35	5.248	133.30	
T	3.23	82.04			radius
U	2.71	68.83			radius
V	3.31	84.07			
W	50*		45*		degrees
X	3.89	98.81	3.88	98.55	
Y	4.8	121.92	4.798	121.87	
Z	0.125	3.18			radius
AA	0.315	8.00	0.290	7.37	
BB	0.66	16.76	0.61	15.49	
CC	1.345	34.16	1.33	33.78	
DD	0.04	1.02	0.03	0.76	radius
EE	1.375	34.93	1.36	34.54	

* Angle W revised from MS27604, to reduce receptacle seal damage

FIGURE F-1. Boom nozzle mating dimensions – Continued.

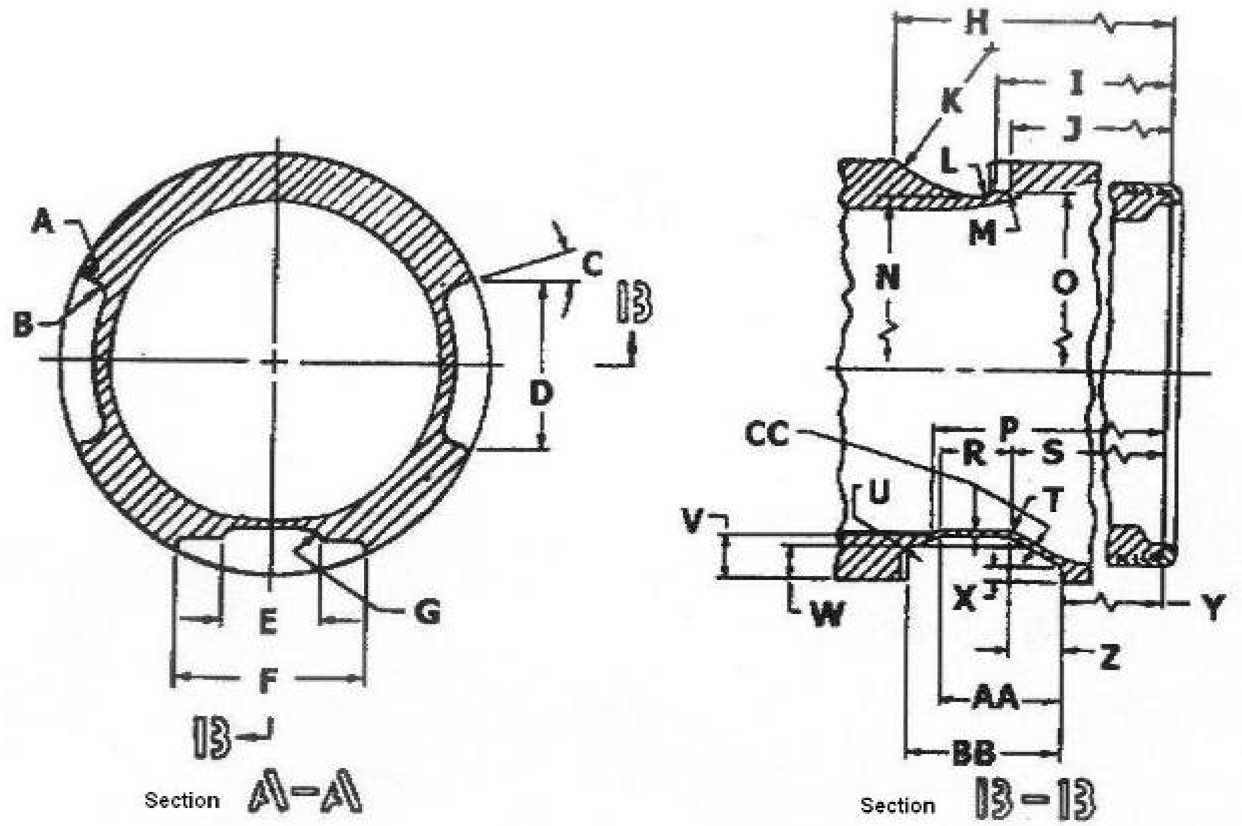

FIGURE F-2. Nozzle latching and voice coil recesses.

DIM	MAXIMUM in.	MAXIMUM mm	MINIMUM in.	MINIMUM mm	REMARKS
A	0.09	2.29	0.06	1.52	radius
B	0.25	6.35			radius
C	18				degrees
D	2.1	53.34			
E	1.315	33.40	1.285	32.64	
F	2.475	62.87	2.445	62.10	
G	0.156	3.96			radius
H	5.58	141.73			
I	4.28	108.71			
J	4.09	103.89			
K	1.88	47.75			radius
L	0.25	6.35			radius
M	0.04	1.02	0.03	0.76	radius
N	4.42	112.27	4.41	112.01	
O	4.56	115.82	4.55	115.57	
P	5.14	130.56			
R	0.98	24.89			
S	4.02	102.11			
T	0.09	2.29	0.03	0.76	radius
U	0.156	3.96			radius
V	0.59	14.99	0.56	14.22	
W	0.45	11.43	0.42	10.67	
X	0.19	4.83	0.16	4.06	
Y	3.39	86.11			
Z	0.675	17.15	0.645	16.38	
AA	1.595	40.51	1.565	39.75	
BB	1.975	50.17	1.945	49.40	
CC			0.054	1.37	See Note 1.

Note 1: Minimum wall thickness is a stress requirement, and may vary depending on the nozzle material. .054 in. is required for an aluminum nozzle.

FIGURE F-2. Nozzle latching and voice coil recesses – Continued.

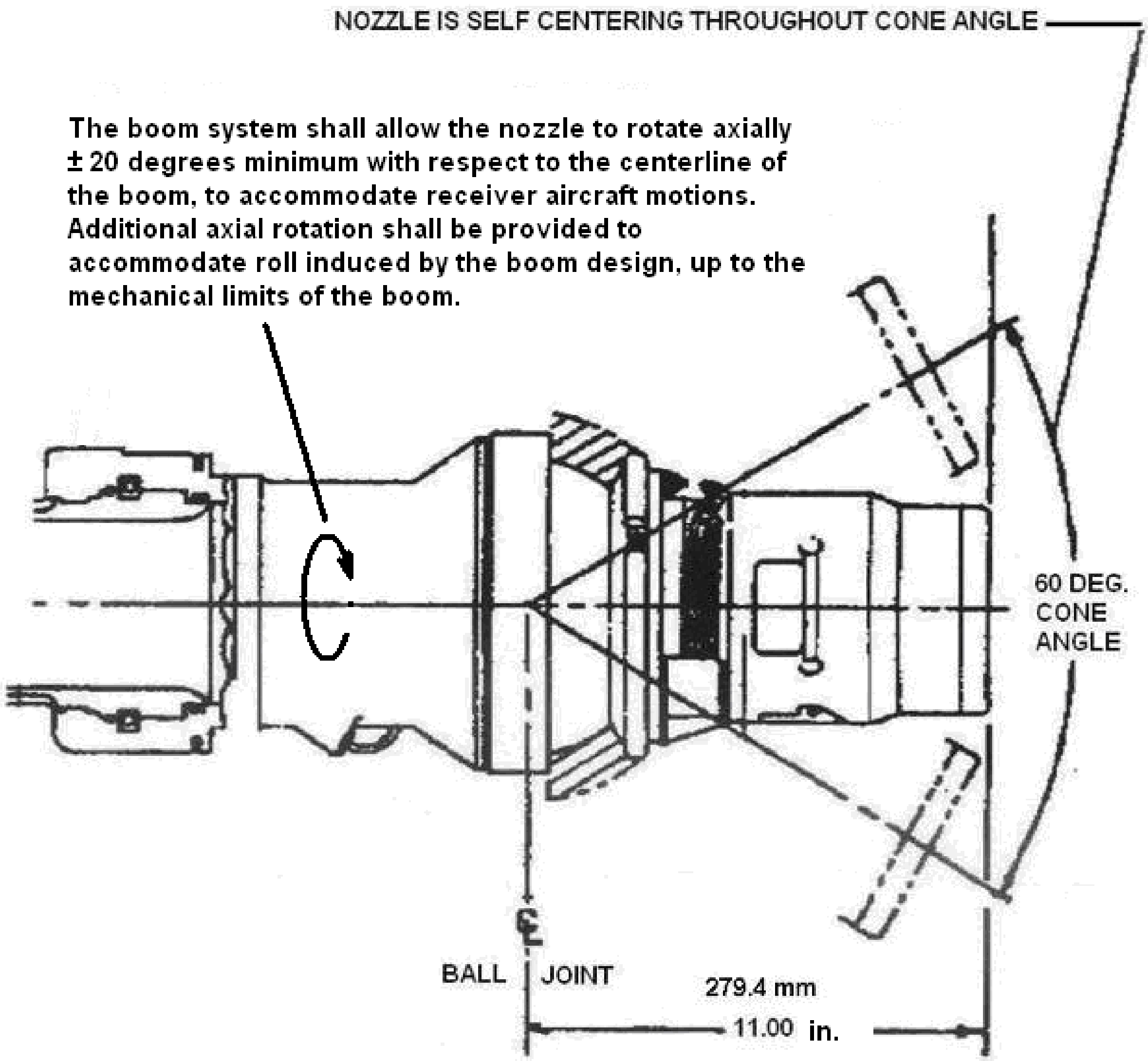

FIGURE F-3. Boom nozzle articulation.

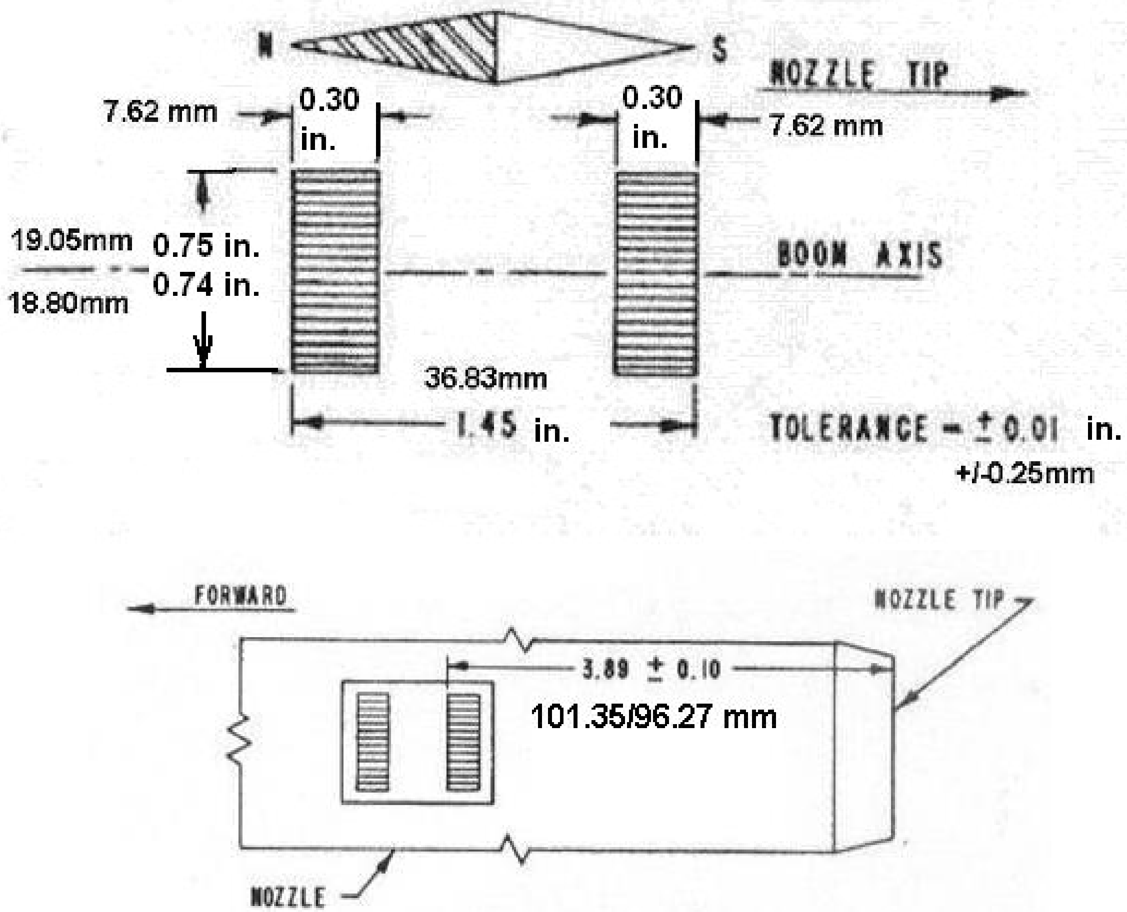

FIGURE F-4. Tanker nozzle induction coil tolerances.

The pole faces shall be positioned from flush with the nozzle surface to minus 0.01 from the outside surface of the nozzle as depicted on figure F-5. The pole faces shall be centered within 0.03 in (0.76 mm) to the left or right of the vertical axis.

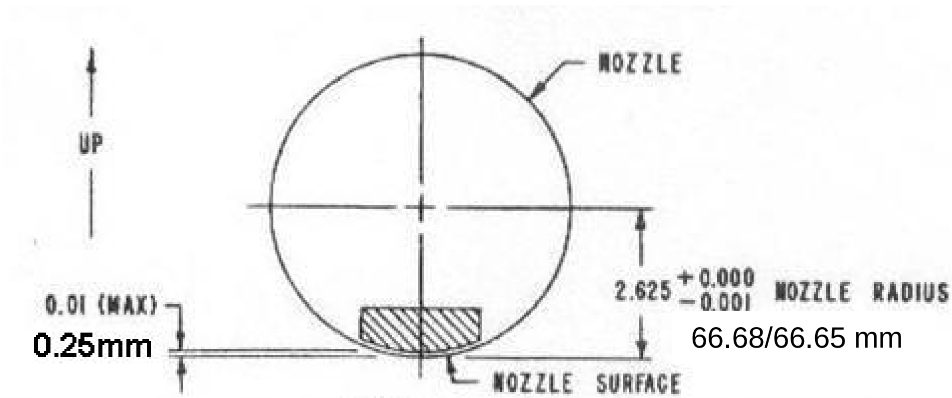

FIGURE F-5. Tanker nozzle induction coil pole face positions.

F.4.4.6.2.2.1 Type of receptacle installation.

The type of receptacle installation shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.2.1)

The type of receptacle installed in the air vehicle must be verified to ensure that the air vehicle can be operationally compatible with the tanker boom system(s) identified for the air vehicle to aerial refuel from and to insure that the installation has been properly integrated into the air vehicle.

VERIFICATION GUIDANCE (4.4.6.2.2.1)

TBS: Specify that the type of receptacle installation on the air vehicle should be verified by inspection, analysis, ground demonstration, and flight or a combination.

VERIFICATION LESSONS LEARNED (4.4.6.2.2.1)

The UARRSI has been completely qualified at the component assembly level. However, the interface with the air vehicle must be verified by inspection and by functional checkout. Receptacle qualification testing is required if a previously qualified unit is not used or being applied in a different environment than previously qualified for. Structural testing of the unit installed in the air vehicle must also be accomplished to verify the structural interface.

The ground demonstration should be conducted using the Universal Receptacle Aerial Refueling Tester, NSN 4920-01-006-5709.

F.3.4.6.2.2.1.1 Receptacle actuation provision(s).

There shall be a primary method to: (a) transition the receptacle installation between the "open" and "closed" positions while in flight and (b) configure the receptacle to accept engagement. If mission and redundancy requirements dictate, a secondary method shall be provided which (TBS)__.

REQUIREMENT RATIONALE (3.4.6.2.2.1.1)

This is an integration, operational and safety requirement. The receptacle aerial refueling subsystem must be able to transition between the "open" and "closed" positions to conduct aerial refueling procedures safely. This capability must not be compromised by a single-failure as the inability to accept fuel from a tanker can impact the air vehicle's mission or jeopardize the safety of the air vehicle.

REQUIREMENT GUIDANCE (3.4.6.2.2.1.1)

(TBD)

REQUIREMENT LESSONS LEARNED (3.4.6.2.2.1.1)

In the past, a direct manually actuated mechanical control has been successfully used as the emergency actuation provision, permitting refueling with an electrical or hydraulic failure to the receptacle installation. The slipway door of the UARRSI will open by spring force with an electrical or hydraulic failure in the system and permit emergency refueling.

The actuation control(s) must be located such they can not be inadvertently bumped during aerial refueling and causing the receptacle installation to try to go to the "closed" position with the tanker boom nozzle engaged in the receptacle. The securing of the actuation control(s) in the "open" position will prevent this type of incident.

An early model of the UARRSI had a problem with moisture freezing on the door control mechanism. This problem has been corrected in the UARRSI; however, the cable mechanism to the UARRSI must also be designed to operate in the presence of moisture and extreme temperature.

Maintenance personnel should be able to operate both actuation mechanisms while the air vehicle is on the ground to permit verification that the proper operation of actuation mechanism.

F.4.4.6.2.2.1.1 Receptacle actuation provision(s).

The receptacle actuation provisions shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.2.1.1)

(TBD)

VERIFICATION GUIDANCE (4.4.6.2.2.1.1)

TBS should be filled in with ground demonstration. The ground demonstration should evaluate the adequacy of the location of the actuation provisions. The suitability of any manually activated mechanisms in relation to the required forces and operation with failures in the air vehicle's subsystems should be accomplished by the ground demonstration. The loads that can be imposed by a crew member under extreme stress on a manually activated mechanism should be considered.

VERIFICATION LESSONS LEARNED (4.4.6.2.2.1.1)

A mechanical cycling device was once used on a receptacle and probe handle design and had successfully completed a qualification endurance test. However, during service, over-torquing of the handle by the pilot caused several failures of the handle bushing. A redesign of the bushing was required.

F.3.4.6.2.2.1.2 Receptacle actuation airspeed and altitude envelope.

The receptacle installation shall be capable of being transitioned between the "open" and "closed" positions by the primary method within an airspeed and altitude envelope of (TBS 1) . When using the secondary method, the receptacle installation shall be capable of being transitioned between the "open" and "closed" positions within an airspeed and altitude envelope of (TBS 2) .

REQUIREMENT RATIONALE (3.4.6.2.2.1.2)

This is an operational requirement. The airspeed and altitude envelope at which the receptacle installation will be able to be actuated must be identified to ensure that the receptacle can be placed in "open" position within an envelope similar to the operational airspeed and envelope of the targeted tanker aerial refueling boom subsystem(s) and can be placed in the "closed" position within that same envelope to permit the air vehicle to depart the aerial refueling track in a "clean" configuration.

REQUIREMENT GUIDANCE (3.4.6.2.2.1.2)

TBS 1 should be filled in with the primary airspeed (Knots Equivalent Airspeed (KEAS)) and altitude (Mean Sea Level (MSL)) envelope of operation.

TBS 2: should be filled in with the secondary airspeed (KEAS) and altitude (MSL) envelope of operation.

The envelopes specified for the above TBS's may be exactly the same or separate with some overlap. Specify the airspeed (KEAS) and altitude (MSL) envelope. The airspeed and altitude envelope should be similar to the operational airspeed and altitude envelope of the targeted tanker aerial refueling boom subsystem(s). Ideally a receptacle installation should be capable of being placed in the "open" and "closed" positions by the primary and emergency methods at all aerial refueling airspeeds up to .9 Mach (M) or 350 KEAS, whichever is lower, and altitudes from 100 feet to 35,000 feet MSL.

REQUIREMENT LESSONS LEARNED (3.4.6.2.2.1.2)

Attention should be given to door and panel airspeed limits to preclude loss of hardware. If the maximum actuation airspeed is less than the placard limits for the air vehicle, then that limit must somehow be communicated to the crew.

F.4.4.6.2.2.1.2 Receptacle actuation airspeed and altitude envelope.

The airspeed and altitude envelope that the receptacle installation can be activated to its "open" and "closed" positions using the primary and emergency activation methods shall be verified by (TBS) .

VERIFICATION RATIONALE (4.4.6.2.2.1.2)

The actuation airspeed and altitude envelope for a receptacle installation must be verified to ensure that the receptacle can be placed in the "open" position within the operational envelope of the targeted tanker aerial refueling boom subsystem(s) and can be placed in the "closed" position within that same envelope to permit the air vehicle to depart the aerial refueling track in a "clean" configuration.

VERIFICATION GUIDANCE (4.4.6.2.2.1.2)

TBS: Specify the airspeed and altitude envelope that should be verified by flight test.

VERIFICATION LESSONS LEARNED (4.4.6.2.2.1.2)

Flight test should evaluate the actuation envelope under both hot and cold temperature conditions using the primary and emergency methods. Any condition of low power (hydraulic, fueldraulic, electrical) being provided to the actuation mechanism of the primary and emergency methods should be examined for the effects on the receptacle installation actuation envelope.

F.3.4.6.2.2.1.3 Receptacle actuation times.

Using the primary actuation mode, the receptacle installation shall transition from the "closed" position to the "open" position, and from the "open" position to the "closed" position, in __(TBS 1) within its specified actuation airspeed and altitude envelope. When using the secondary method for actuation, the receptacle installation shall be able to be transitioned between the "open" and "closed" positions in __(TBS 2)__ within its specified actuation airspeed and altitude envelope.

REQUIREMENT RATIONALE (3.4.6.2.2.1.3)

This is an operational requirement. The allowed time for transitioning between the "closed" and "open" positions must be specified in order for the air vehicle to be refueled within the time dictated by its mission(s).

REQUIREMENT GUIDANCE (3.4.6.2.2.1.3)

TBS 1: Specify the desired time (seconds) for receptacle installation actuation between the "closed" and "open" positions. The receptacle installation should transition from the "closed" position to the "open" position, and from the "open" position to the "closed" position, in 5 to 20 seconds when using its primary mode.

TBS 2: Using its emergency mode, the receptacle installation should transition from the "closed" position to the "open" position, and from the "open" position to the "closed" position, within 30 seconds.

REQUIREMENT LESSONS LEARNED (3.4.6.2.2.1.3)

The receptacle installation must be able to transition between the "closed" and "open" positions in a reasonably rapid period of time. A transition which is too rapid can cause excessive forces within the actuation mechanism while a transition time that is too long can impact the total aerial refueling time for the air vehicle.

F.4.4.6.2.2.1.3 Receptacle actuation times.

The receptacle actuation times shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.2.1.3)

The time required to transition the receptacle installation between the "closed" and "open" positions must be verified to ensure that the air vehicle can be refueled within the time dictated by its operational mission(s).

VERIFICATION GUIDANCE (4.4.6.2.2.1.3)

TBS: Specify that the receptacle actuation times should be verified by ground and flight test.

VERIFICATION LESSONS LEARNED (4.4.6.2.2.1.3)

The actuation times should be measured in flight test after a long period of cold temperature conditions and icing conditions. The test should determine any effect of air speed and altitude on actuation time. Any condition of low power (hydraulic, fueldraulic, electrical) being provided to the actuation mechanism of the primary and emergency methods should be examined for the effects on the receptacle installation actuation time.

F.3.4.6.2.2.1.4 Slipway illumination.

The receptacle installation's slipway (including the top of the slipway door scuff plate and the bore of the receptacle) shall be illuminated, when the receptacle installation is in the "open" position, to assist the boom operator in observing the engagement area for the tanker boom nozzle within the receptacle installation. The slipway illumination shall be oriented such that it does not blind or distract the boom operator or the air vehicle crew member(s) during the aerial refueling process. The slipway illumination shall not be a potential source of ignition of flammable fuels. The aircrew shall be able to control the intensity of the slipway illumination in variable increments from “OFF” to “FULL BRIGHT”.

REQUIREMENT RATIONALE (3.4.6.2.2.1.4)

This is an operational and safety requirement. In boom aerial refueling subsystems that require a boom operator, the entire slipway of the receptacle installation must be illuminated to assist the boom operator in making clean, safe engagements of the tanker boom nozzle with the receptacle installation. This assistance is needed during night, twilight, and dawn aerial refueling operations, and can be required in receptacle installations where the contrast between the receptacle and the surrounding air vehicle structure is hard to discern due to similar colors and installation orientation or both.

Since fuel can spray onto the area in and around the receptacle installation when the boom nozzle disconnects from the receptacle, the slipway illumination provision(s) must not create a fire and explosion hazard to the air vehicle.

REQUIREMENT GUIDANCE (3.4.6.2.2.1.4)

This requirement should not be applicable for boom and receptacle aerial refueling subsystems that feature an automatic engagement capability; for example, when a boom operator is not required to make the tanker boom nozzle connect into the receiver's receptacle.

REQUIREMENT LESSONS LEARNED (3.4.6.2.2.1.4)

This requirement is mandatory for night aerial refueling operations, except for automatic engagement capability.

The light assemblies should not produce bright spots or direct the light toward the tanker boom operator. The light assemblies should not be a source of ignition since fuel spray onto the light assemblies can be expected during the disconnect phase of the aerial refueling process. When operating at maximum intensity and temperature, the assemblies must not fail or fracture when coming into contact with -65^{o}F fuel.

Ideally, the slipway illumination should automatically occur once the receptacle installation has been activated to the "open" position and automatically terminate once the receptacle installation has been activated to the "closed" position.

F.4.4.6.2.2.1.4 Slipway illumination.

The ability to illuminate the slipway shall be verified by __(TBS 1)__. The inability of the slipway illumination to be a potential ignition source for flammable vapors shall be verified by _(TBS 2)_.

VERIFICATION RATIONALE (4.4.6.2.2.1.4)

It must be verified that the provided slipway illumination is adequately installed to ensure that the boom operator can make clean, safe engagements of the tanker boom nozzle with the receptacle installation during aerial refueling procedures. In addition, it must be verified that the slipway illumination feature is properly designed to insure that it does not create a fire and explosion hazard to the air vehicle during the aerial refueling process.

VERIFICATION GUIDANCE (4.4.6.2.2.1.4)

TBS 1: Specify ground test and flight test.

TBS 2: Specify analysis and ground test.

VERIFICATION LESSONS LEARNED (4.4.6.2.2.1.4)

The ground test should evaluate the surface brightness of the slipway illumination at the following locations:

a. Slipway area, forward right-hand corner

b. Slipway area, forward left-hand corner

c. Slipway area, center of forward edge

d. Slipway area, center of aft edge

e. Slipway area, center of scuff plate

f. Center of poppet face (receptacle bore).

F.3.4.6.2.2.2 Location of receptacle installation.

The receptacle installation shall be positioned on the receiver air vehicle to permit both a precision contact and a slipway contact of the boom nozzle with the receptacle.

a. Slipway contact. A smooth contact (no hang-up) shall be accomplished by the boom, within the normal contact envelope of the boom, when a download is applied to the boom nozzle after contact of the boom nozzle has been made with the slipway.

b. Spatial envelope clearance. With the boom nozzle engaged in the receptacle, the boom shall not contact the slipway sides when the receiver exceeds the automatic disconnect envelope of the tanker by five degrees azimuth or boom roll.

c. Disconnect alignment. The receptacle bore axis shall be positioned to provide alignment at disconnect of the tanker boom centerline, in the center of the normal contact envelope for all identified tankers, when the receiver is in the normal disconnect pitch attitude.

d. Airflow characteristics. The receptacle installation shall be located so that airflow around the receptacle installation will not cause boom instability during aerial refueling from precontact of the boom until completion of aerial refueling. The receiver stability and control behind all identified tankers shall not be adversely affected during aerial refueling from the precontact position until the completion of aerial refueling when the boom is close to or coupled to the receiver.

e. Receptacle visibility characteristics. The receptacle installation shall interface with the contour of the air vehicle such that optical illusions of the installation are not created for the boom operator during day or night aerial refueling. The total bore opening of the receptacle shall be visible from each tanker's boom operator's eye position when both the tanker and receiver are in the normal contact position.

REQUIREMENT RATIONALE (3.4.6.2.2.2)

(TBD)

REQUIREMENT GUIDANCE (3.4.6.2.2.2)

(TBD)

REQUIREMENT LESSONS LEARNED (3.4.6.2.2.2)

(TBD)

F.4.4.6.2.2.2 Location of receptacle installation.

The location of the aerial refueling receptacle installation shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.2.2)

(TBD)

VERIFICATION GUIDANCE (4.4.6.2.2.2)

(TBD)

VERIFICATION LESSONS LEARNED (4.4.6.2.2.2)

(TBD)

F.3.4.6.2.2.3 Receptacle installation drainage.

Spilled fuel and rain water shall be removed from the receptacle installation by __(TBS)__.

REQUIREMENT RATIONALE (3.4.6.2.2.3)

This is a safety requirement. Fuel is typically spilled during disconnect of the boom nozzle and can accumulate within the receptacle installation. In addition, water can accumulate in the receptacle installation due to rain and aircraft washings. These fluids must be removed. Trapped fuel can create a fire hazard and freezing water can interfere with the proper function of the operating mechanisms located within the receptacle installation.

REQUIREMENT GUIDANCE (3.4.6.2.2.3)

TBS: Specify the provision(s) for removal of fuel or water. Spilled fuel and water has been removed from the receptacle installation by connecting one, two, or three drain lines to appropriate locations in the cavity below the receptacle. The number of drains connected should be determined by considering all normal ground and flight attitudes of the receiver. The fluids are then either drained overboard or to an on-board collector tank.

REQUIREMENT LESSONS LEARNED (3.4.6.2.2.3)

The drain line exit should be at a negative pressure in relation to the interior of the installation. Unused drain connections must be plugged. This compartment should be drained if the receptacle is installed in a sealed compartment or pressure shroud. Interconnecting fuel drain lines should be avoided as much as possible as this makes it difficult to identify the specific source of the leakage and can also affect proper drainage.

See compartment drains requirements (E.3.4.5.1.10) in appendix E, Fuel Subsystem, for additional information related to this requirement.

See fuel drainage requirements (G.3.4.7.5) in appendix G, Fire and Explosion Hazard Protection Subsystem, for additional Lessons Learned related to this requirement.

F.4.4.6.2.2.3 Receptacle installation drainage.

Receptacle installation drainage shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.2.3)

The adequacy of the drains for the receptacle installation should be verified to ensure a potentially hazardous condition is not created due to fuel accumulation.

VERIFICATION GUIDANCE (4.4.6.2.2.3)

TBS: Specify ground demonstration and/or flight demonstration.

VERIFICATION LESSONS LEARNED (4.4.6.2.2.3)

The ground demonstration can be accomplished by pouring water into the cavity below the receptacle installation and observing the quantity of water retained in the cavity at all normal ground and flight attitudes of the aircraft.

The ground demonstration may require demonstration be conducted with the appropriate compartment pressurization that would be experienced in flight. In transport and bomber air vehicles, where the cavity below the receptacle is typically exposed to cabin pressure, the ground demonstration must include the cabin pressure to ensure such pressurization does not impact drainage capability. Similarly, if the drain line(s) can be exposed to pressurization while in flight, then the appropriate compartment(s) which contain the drain line(s) must also be pressurized during the ground demonstration.

If pressurization of the necessary compartments cannot be accomplished on the ground, then flight demonstrations should be conducted to ensure adequate drain provisions are provided in flight. Flight test can also validate that the drained fluid(s) do not re-enter the air vehicle when drained overboard. Flight testing should also be conducted throughout the entire flight envelope of the air vehicle to ensure pressure differentials along air vehicle's mold line do not prevent drainage from occurring in flight.

F.3.4.6.2.2.4 Receptacle installation sealing and fairing.

The receptacle installation exterior frame shall __(TBS)__.

REQUIREMENT RATIONALE (3.4.6.2.2.4)

This is an integration and safety requirement. The sealing of the receiver installation from the interior of the aircraft must be identified, along with the requirement for a smooth fit with the aircraft skin.

REQUIREMENT GUIDANCE (3.4.6.2.2.4)

TBS: Specify that the receiver installation exterior frame must make a fuel-tight seal with the aircraft skin or be installed in a fuel-tight compartment. The aircraft skin should fair smoothly with the receiver installation edges.

REQUIREMENT LESSONS LEARNED (3.4.6.2.2.4)

The sealing of the edges can be omitted if the receiver installation is installed in a fuel-tight compartment that contains fuel drains. The fairing of the receiver installation edges is desired to reduce drag and to eliminate rough edges.

See JSSG-2006 for additional information regarding fuel sealing in aircraft structures.

F.4.4.6.2.2.4 Receptacle installation sealing and fairing.

Receptacle installation sealing and fairing shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.2.4)

Rough edges and installation defects can best be detected by an inspection prior to flight. Ground water tests can verify the sealing of the unit; however, the aircraft should be inspected for evidence of fuel entering adjacent compartments after each flight test.

VERIFICATION GUIDANCE (4.4.6.2.2.4)

TBS: Specify that the sealing of the receiver installation frame with the aircraft skin and the smoothness of the edges and adjacent skin should be verified by inspection and ground tests.

VERIFICATION LESSONS LEARNED (4.4.6.2.2.4)

(TBD)

F.3.4.6.2.2.5 Structural loads.

The receptacle installation shall withstand the following load conditions: __(TBS)__.

REQUIREMENT RATIONALE (3.4.6.2.2.5)

This is an operational and safety requirement. The receptacle must be designed to the appropriate structural loads to ensure that it is structurally compatible with the targeted tanker boom subsystems and can withstand the loads typically encountered during aerial refueling operations. Structural incompatibility can result in damage to the tanker boom subsystem and the receiver receptacle, or both.

REQUIREMENT GUIDANCE (3.4.6.2.2.5)

TBS: Specify that the receiver's aerial refueling receptacle should be designed for the following loads when contacted by the boom nozzle, during fuel transfer when mated with the boom nozzle, and when disconnected from the mated boom nozzle. These loads should be applied within the respective contact envelope, fuel transfer envelope and disconnect envelope for the given tanker boom subsystem:

a. Tension - An ultimate load of 14,000/(Cos A) lbs. applied to the boom-nozzle ball joint, where the angle A may vary from 0 degrees to 30 degrees.

b. Compression - An ultimate load of 20,000 lbs. applied at the boom-nozzle ball joint anywhere within a 34 degree cone.

c. Tension and compression working load - A limit load of 9,000/(Cos C) lbs. applied at the boom-nozzle ball joint where angle C may vary from 0 degrees to 17 degrees.

Angles A and C should be taken relative to the receptacle axis. Fuel flow pressure should be added to the above loads only when the resulting incremental load is additive. In both cases, use of ailerons to maintain wings level is a major source of load and the abruptness and amount of aileron used is highly pilot dependent.

REQUIREMENT LESSONS LEARNED (3.4.6.2.2.5)

The above load conditions have been historically applied to receptacle installation designs to ensure structural compatibility with the existing tanker boom subsystems. The limit tension values are based on a limit load imposed by the existing KC-135 and KC-10 tanker boom subsystems when a tension disconnect is performed with the receiver at -65^{o}F with a boom nozzle average retract velocity up to 10 feet per second. Operational experience has shown that the above values are adequate in assuring aerial refueling operations with existing tanker boom subsystems can be accomplished safely. Values selected below the recommended loads will compromise the structural integrity of the receptacle installation while values selected above the recommended loads will compromise the structural integrity of the tanker boom systems.

When the UARRSI is selected, ensure the four airframe structural attachment points that are used to mount the UARRSI are able to withstand these loads. The distribution of loads from the UARRSI to the air vehicle's structure is critical to the structural integrity of the UARRSI. The four airframe structural attachment points must be connected by a stiff load path tying the fore and aft attachment points together to prevent tension overloading of the UARRSI side members. If the loads are allowed to be evenly distributed between the four structural attachment points, a structure failure will occur in the UARRSI side member to the forward bulkhead at approximately 100 percent limit load.

See JSSG-2006's handbook for additional Structures Lessons Learned related to this requirement.

F.4.4.6.2.2.5 Structural loads.

The suitability of the receptacle installation in relation to the structural loads that will be encountered during aerial refueling operations shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.2.5)

It must be verified that the receptacle is designed to the appropriate structural loads to ensure that it is structurally compatible with the targeted tanker boom subsystems and can withstand the loads typically encountered during aerial refueling operations.

VERIFICATION GUIDANCE (4.4.6.2.2.5)

TBS: Specify that verification should be accomplished through analysis, ground test, and during flight tests.

VERIFICATION LESSONS LEARNED (4.4.6.2.2.5)

Flight tests for aerial refueling certification of receptacle-equipped receivers include tension disconnects to verify that the loads do not exceed the specified limits. For receptacles where hydraulics is used to control the toggle latches, the tension disconnects will be conducted after the receptacle installation has been adequately "cold-soaked". Flight test experience shows that, for such receptacle designs, the tension disconnect loads are greater when the hydraulic fluid is cold soaked; i.e., when the viscosity is greater. As such, flight test data has revealed that the tension disconnect loads are greater when MIL-PRF-83282 hydraulic fluid is used in the receptacle latching system as compared when MIL-PRF-5606 hydraulic fluid is used. In some receptacle installations which use MIL-PRF-83282 fluid, the tension disconnect loads come very close to exceeding the tension disconnect limit value. Exceeding this limit can result in damage to the tanker's boom structure.

Ground tests can be conducted on the receptacle as installed in the air vehicle or on the receptacle installed in a representative air vehicle structure. The UARRSI side member loading problem was not revealed during component development because the qualification test fixture stiffness was different from the subsequent flight test airframe structure.

F.3.4.6.2.2.6 Receptacle installation maintenance.

The __(TBS 1)__ of the receptacle aerial refueling subsystem shall be capable of being removed and replaced with a like unit and functionally checked in __(TBS 2)__.

REQUIREMENT RATIONALE (3.4.6.2.2.6)

This is an operational requirement. Due to the nature of boom and receptacle aerial refueling procedures, there are certain items in the receptacle aerial refueling subsystem design that will require have to be replaced on a regular basis. To minimize the impact on the availability of the air vehicle to perform its mission(s), these items need to be readily removable and replaceable.

REQUIREMENT GUIDANCE (3.4.6.2.2.6)

TBS 1: Specify the item(s) of the receptacle aerial refueling subsystem that should most likely have to be replaced on a regular basis due to the nature of boom and receptacle aerial refueling procedures and the design of the air vehicle's receptacle aerial refueling subsystem. Typically, this has been those items which are intentionally or inadvertently impacted by the boom nozzle during aerial refueling; such as, the receptacle, the slipway scuff plate, the receptacle sliding valve, and the receptacle slipway doors.

TBS 2: Identify the specific time (minutes and hours) to remove and replace each item and the number of maintenance personnel.

REQUIREMENT LESSONS LEARNED (3.4.6.2.2.6)

Normally, the UARRSI should be capable of being removed and replaced with a like unit and functionally checked in one hour by two maintenance personnel. However, special design cases may dictate different requirements. The removal and replacement of components within the UARRSI is possible without requiring the removal of the total UARRSI from the air vehicle. Maintenance personnel must be provided the appropriate support equipment and access to the back of the UARRSI to remove internal components of the UARRSI. UARRSI installations require access to hydraulic lines, fuel lines, and electrical connections. If the UARRSI is fitted tightly within its pressure box, access to these connections is made difficult even through the close out plate in the back of the UARRSI. Any access through the pressure box may require breaking a fuel tight seal. If sealant is used to seal the pressure box, the removal and replacement of any internal components of the UARRSI may also require surface preparation time, resealing time, cure time, and a cabin pressure leak check as part of the maintenance time.

The removal and replacement of receptacle doors is common in receptacle installations that use the receptacle doors to help guide the boom nozzle into the receptacle and open in such a way that they are commonly impacted by the boom nozzle while trying to make contact with the receptacle.

See JSSG AVSS “maintainability”, for other maintenance requirements that may apply to the removal and replacement of the identified items (such as with chemical and biological gear on, at night with night vision goggles).

F.4.4.6.2.2.6 Receptacle installation maintenance.

The capability to remove and replace the ___(TBS 1)___ of the receptacle aerial refueling subsystem within the defined time with the specified number of maintenance personnel shall be verified by __(TBS 2)__.

VERIFICATION RATIONALE (4.4.6.2.2.6)

To ensure that the air vehicle will be readily available to conduct its mission(s), it must be verified that those items in the receptacle aerial refueling subsystem that commonly become damaged during the aerial refueling process can be removed and replaced by the appropriate number of the maintenance personnel within the allowable time specified.

VERIFICATION GUIDANCE (4.4.6.2.2.6)

TBS 1: Specify the item(s) of the receptacle aerial refueling subsystem that should be removed and replaced by maintenance personnel.

TBS 2: Specify ground demonstration.

VERIFICATION LESSONS LEARNED (4.4.6.2.2.6)

(TBD)

F.3.4.6.2.2.7 Receptacle modes.

The receptacle aerial refueling subsystem shall have the following status modes: __(TBS)__. The receptacle aerial refueling subsystem shall provide the means of displaying functional modes of operation.

REQUIREMENT RATIONALE (3.4.6.2.2.7)

(TBD)

REQUIREMENT GUIDANCE (3.4.6.2.2.7)

(TBD)

REQUIREMENT LESSONS LEARNED (3.4.6.2.2.7)

(TBD)

F.4.4.6.2.2.7 Receptacle modes.

The provision of the specified functional modes for the receptacle aerial refueling subsystem shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.2.7)

(TBD)

VERIFICATION GUIDANCE (4.4.6.2.2.7)

TBS: Specify inspection, ground demonstration or a combination.

VERIFICATION LESSONS LEARNED (4.4.6.2.2.7)

A reasonable evaluation of the suitability of the displays for the functional modes of the receptacle aerial refueling subsystem can be made during the ground demonstration, however, the ground demonstration must consider sun angles for brightness and glare. As such, final validation of the indicators should be made by several pilots under various actual refueling conditions (for example direct sunlight, dawn, dusk, and night with and without night vision goggles, if applicable) throughout the aerial refueling flight test program.

F.3.4.6.2.2.7.1 Disconnect function.

The receptacle aerial refueling subsystem shall be capable of being advanced from the "CONTACT" mode to the "DISCONNECT" mode to permit disengagement of the tanker boom nozzle from the receptacle. Advancing shall be accomplished by __(TBS 1)__ under __(TBS 2)__ conditions.

REQUIREMENT RATIONALE (3.4.6.2.2.7.1)

This is an operational and safety requirement. At the end of the refueling process, the boom nozzle must be able to disconnect from the receptacle. In addition, there can be scenarios where the disconnect must occur prior to the completion of the fuel transfer sequence from the tanker. As such, the receptacle aerial refueling subsystem must have the capability to advance from the "CONTACT" mode to the "DISCONNECT" mode upon command whenever required during the aerial refueling process.

REQUIREMENT GUIDANCE (3.4.6.2.2.7.1)

TBS 1: Specify how the receptacle aerial refueling subsystem should be commanded to advance from the "CONTACT" mode to the "DISCONNECT" mode. From the tanker boom subsystem, advancement should be able to occur when a disconnect signal is sent from the boom nozzle's signal coil to the receptacle's signal coil when the receptacle subsystem is in NORMAL status. This disconnect signal should be sent when activated by the boom operator or should automatically be sent when the tanker's boom envelope limit has been exceeded. Also, the occurrence of a boom float-out should automatically advance the receptacle aerial refueling subsystem from the "CONTACT" mode to the "DISCONNECT" mode.

TBS 2: Defines the conditions under which disconnect may be accomplished.

REQUIREMENT LESSONS LEARNED (3.4.6.2.2.7.1)

From the receiver side, the disconnect function has historically been manually activated by a crewmember and has operated whether the receptacle subsystem is in NORMAL status or in OVERRIDE status. Also, a pressure disconnect switch located in the air vehicle's aerial refueling manifold has been used to advance the receptacle aerial refueling subsystem from the "CONTACT" mode to the "DISCONNECT" mode when steady-state fuel delivery pressures from the tanker exceed the normal range, receptacle subsystem in NORMAL or OVERRIDE status.

Manual advancement from the "CONTACT" mode to the "DISCONNECT" mode must be provided to the appropriate crew member(s)

Ground maintenance personnel should also have this capability when the air vehicle is on the ground while using the Universal Receptacle Aerial Refueling Tester to verify proper operation of the receptacle aerial refueling subsystem.

F.4.4.6.2.2.7.1 Disconnect function.

The ability of the receptacle aerial refueling subsystem to advance from the "CONTACT" mode to the "DISCONNECT" mode, when commanded, to permit the tanker's boom nozzle to disengage from the receptacle under the specified conditions shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.2.7.1)

Operationally, it must be verified that the receptacle aerial refueling subsystem is capable of being advanced from the "CONTACT" mode to the "DISCONNECT" mode when required to ensure that the aerial refueling process can be terminated safely. Verifying that this capability exists while the air vehicle is on the ground ensures that maintenance personnel have the ability to confirm proper operation of the receptacle aerial refueling subsystem.

VERIFICATION GUIDANCE (4.4.6.2.2.7.1)

TBS: Specify that verification should be completed through ground demonstration and during flight demonstration of the subsystem.

VERIFICATION LESSONS LEARNED (4.4.6.2.2.7.1)

The ground demonstration should use the Universal Receptacle Aerial Refueling Tester, NSN 4920-01-006-5709, to verify that the disconnect capability functions properly when commanded. Each method of activation from the "CONTACT" mode to the "DISCONNECT" mode (automatic or manual) should be evaluated with the receptacle subsystem in the NORMAL status and in the OVERRIDE status. Each manual advancement feature that has been provided to a crew member should be individually evaluated. Flight test must also verify the proper operation of each advancement method from the "CONTACT" mode to the "DISCONNECT" mode (automatic or manual) with the receptacle subsystem in the NORMAL status and in the OVERRIDE status. Each manual advancement feature that has been provided to a crew member should also be individually evaluated during flight test.

F.3.4.6.2.2.7.2 Reset function.

Whether in NORMAL status or in OVERRIDE status, the receptacle aerial refueling subsystem shall be capable of being reset from the "DISCONNECT" mode to the "READY" mode after the tanker's boom nozzle has disconnected from the receptacle. Resetting modes from “DISCONNECT” to “READY” shall be accomplished by __(TBS 1)__ under__(TBS 2)__conditions.

REQUIREMENT RATIONALE (3.4.6.2.2.7.2)

This is an operational and safety requirement. After the boom nozzle has disconnected from the receptacle, the receptacle subsystem is in the "DISCONNECT" mode. Any subsequent attempt to reinsert the boom nozzle into the receptacle for another contact will not result in a successful engagement; for example the receptacle toggle latches will not lock into the boom nozzle in the "DISCONNECT" mode. Resetting the receptacle subsystem to the "READY" mode will permit a successful and safe re-engagement with the boom nozzle.

REQUIREMENT GUIDANCE (3.4.6.2.2.7.2)

TBS 1: Specify how the receptacle aerial refueling subsystem should be commanded to reset from the "DISCONNECT" mode to the "READY" mode.

TBS 2: Specify under what conditions the receptacle aerial refueling subsystem should be commanded to reset from the "DISCONNECT" mode to the "READY" mode.

REQUIREMENT LESSONS LEARNED (3.4.6.2.2.7.2)

In one receptacle aerial refueling subsystem installation, an automatic reset feature was incorporated which required an additional switch in the receptacle to determine if the nozzle was seated in the receptacle. This design also required a time delay in the receptacle subsystem so that the subsystem would not disconnect, reset, and then re-latch if the boom nozzle was not cleared away from the receptacle fast enough. The UARRSI control logic does not have provisions for automatic reset.

Ground maintenance personnel should also have this capability when the air vehicle is on the ground while using the Universal Receptacle Aerial Refueling Tester to verify proper operation of the receptacle aerial refueling subsystem.

If reset from the "DISCONNECT" mode to the "READY" mode is to be manually activated, the appropriate crew member(s) must have the capability to reset.

The reset function usually has been manually commanded by the crew but it can be an automatic feature that does not require crew activation.

F.4.4.6.2.2.7.2 Reset function.

The ability of the receptacle aerial refueling subsystem to reset from the "DISCONNECT" mode to the "READY" mode while the subsystem is in NORMAL or OVERRIDE status, when commanded, shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.2.7.2)

It must be verified that the receptacle aerial refueling subsystem is capable of being reset from the "DISCONNECT" mode to the "READY" mode once the tanker's boom nozzle has disconnected from the receptacle to ensure that the receptacle subsystem can operationally permit a subsequent re-engagement of the boom nozzle with the receptacle.

VERIFICATION GUIDANCE (4.4.6.2.2.7.2)

TBS: Specify that the proper operation of the reset function should be verified by a ground demonstration and during flight demonstration of the subsystem.

VERIFICATION LESSONS LEARNED (4.4.6.2.2.7.2)

The ground demonstration should use the Universal Receptacle Aerial Refueling Tester, NSN 4920-01-006-5709, to verify that the reset capability functions properly when commanded. Each method of activation from the "DISCONNECT" mode to the "READY" mode (automatic or manual) should be evaluated. Each manual reset feature that has been provided to a crew member should be individually evaluated. Flight test must also verify the proper operation of each activation method from the "DISCONNECT" mode to the "READY" mode (automatic or manual). All evaluations should be conducted with the receptacle aerial refueling subsystem in the “NORMAL” status and in the “OVERRIDE” status.

F.3.4.6.2.2.7.3 Manual override status.

The receptacle aerial refueling subsystem shall be capable of being placed from the “NORMAL” status to the “OVERRIDE” status and permit the air vehicle to continue safe aerial refueling with the targeted tanker boom subsystem(s). Advancing to "OVERRIDE" status shall be accomplished by __(TBS)__.

REQUIREMENT RATIONALE (3.4.6.2.2.7.3)

This is an operational and safety requirement. In the event of a signal amplifier failure, the receptacle aerial refueling subsystem must still be able to allow the air vehicle to safely conduct aerial refueling procedures with the targeted tanker boom subsystem(s).

REQUIREMENT GUIDANCE (3.4.6.2.2.7.3)

TBS: Specify how the receptacle aerial refueling subsystem should be commanded to the "OVERRIDE" mode.

REQUIREMENT LESSONS LEARNED (3.4.6.2.2.7.3)

In the past, the command to the "OVERRIDE" mode has been manually activated by a crew member.

The UARRSI incorporates an override mode to accommodate a signal amplifier failure. Operational sequencing and intercommunication capability will be unaffected, except the receptacle toggles can only be operated by the receiver crew and the READY light will illuminate when the slipway door is released.

As this requirement will typically require crew member activation to place the receptacle aerial refueling subsystem into the OVERRIDE status, the appropriate crew member(s) must have the capability to select the OVERRIDE status.

F.4.4.6.2.2.7.3 Manual override status.

The ability of the receptacle aerial refueling subsystem to be placed in the “OVERRIDE” status, when activated, to permit the air vehicle to continue to be safely aerial refueled with the targeted tanker boom subsystem(s) shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.2.7.3)

It must be verified that the receptacle aerial refueling subsystem is capable of being be placed in the “OVERRIDE” status when a signal amplifier fails to ensure that the aerial refueling process can still be conducted safely.

VERIFICATION GUIDANCE (4.4.6.2.2.7.3)

TBS: Specify that verification should be completed through ground demonstration and during flight demonstration of the subsystem.

VERIFICATION LESSONS LEARNED (4.4.6.2.2.7.3)

The ground demonstration should use the Universal Receptacle Aerial Refueling Tester, NSN 4920-01-006-5709, to verify that the receptacle aerial refueling subsystem functions properly when placed in “OVERRIDE” status. The ground demonstrations should verify that only receiver initiated disconnects (automatic and manual activated) can disengage the boom nozzle from the receptacle. Each method of activation to the “OVERRIDE” status (automatic or manual) should be evaluated. Each manual advancement feature that has been provided to a crew member should be individually evaluated. Flight demonstration must also verify the proper operation of each advancement method from the "CONTACT" mode to the "DISCONNECT" mode (automatic or manual). Each manual advancement feature that has been provided to a crew member should be individually evaluated in the flight.

F.3.4.6.2.2.8 Through-the-Boom voice intercommunication capability.
The receptacle aerial refueling subsystem shall provide a capability for the receiver crew to clearly and securely voice communicate to the tanker crew via the targeted tanker's Through-the-Boom intercommunication system when the tanker's boom is engaged in the receptacle and when the receptacle installation is in “NORMAL” or “OVERRIDE” status.

REQUIREMENT RATIONALE (3.4.6.2.2.8)

This is an operational and safety requirement. Boom and receptacle operations can require voice communication between the boom operator and the receiver crew in order to accomplish the aerial refueling operation safely. There may be missions where normal radio communications between the tanker and receiver air vehicles are not allowed for security reasons. As such, a clear, secure voice communication capability between the tanker and receiver crews during radio silent conditions would be required.

REQUIREMENT GUIDANCE (3.4.6.2.2.8)

If the capability for the air vehicle's crew to communicate with the tanker during radio silent conditions via the tanker's Through-the-Boom intercommunication system is not required or is not provided in the targeted tanker boom subsystem(s), this requirement should be deleted.

REQUIREMENT LESSONS LEARNED (3.4.6.2.2.8)

The UARRSI and other receptacles have the capability to transmit voice signals when a MIL-S-38449 signal amplifier, or equivalent, is installed.

The Through-the-Boom intercommunication system of the United States Air Force (USAF) KC-10 and KC-135 tankers is provided by a signal coil installed in the boom nozzle and a signal amplifier system. The capability to transmit voice signals occurs when the receptacle's signal coil properly mates with the boom nozzle's signal coil once the boom nozzle is inserted into the receptacle.

Noise has often been a problem with the receptacle subsystem's provision to communicate via the tanker's Through-the-Boom intercommunication system. Noise prevents the ability of the tanker and receiver crews to communicate clearly. Noise has been minimized by using shielded, twisted cables which connect to the air vehicle's intercom subsystem by an on or off switch and by avoiding tying the wiring to the Through-the-Boom intercommunication system with other electrical subsystems.

F.4.4.6.2.2.8 Through-the-Boom voice intercommunication capability.
The ability of the receptacle aerial refueling subsystem, whether in “NORMAL” status or “OVERRIDE” status, to provide the receiver crew member(s) a clear and secure voice communication capability with the tanker crew via the targeted tanker's Through-the-Boom intercommunication system when the tanker's boom is engaged in the receptacle shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.2.8)

The ability of each specified crew member on the receiver air vehicle to clearly communicate via the Through-the-Boom once the boom nozzle is engaged within the receptacle must be verified to ensure a secure voice communication is available between the targeted tanker and the receiver air vehicle during aerial refueling operations which are conducted under radio silent conditions. Verification ensures that any information that must be shared between the targeted tanker and the receiver air vehicle crew to safely conduct aerial refueling is not compromised.

VERIFICATION GUIDANCE (4.4.6.2.2.8)

TBS: Specify that verification should be through ground demonstration and flight demonstration.

VERIFICATION LESSONS LEARNED (4.4.6.2.2.8)

Preliminary evaluations should be made during a ground demonstration with the Universal Receptacle Aerial Refueling Tester, NSN 4920-01-006-5709. However, final validation should be made during flight testing with the targeted tanker boom aerial refueling subsystem(s). Ground demonstrations and flight demonstrations should be conducted with the receptacle aerial refueling subsystem in its “NORMAL” status and in the “OVERRIDE” status.

F.3.4.6.2.2.9 Tanker pressure regulation failures.

The receptacle aerial refueling subsystem shall withstand, or protect itself against, the fuel pressure conditions created during fuel delivery from each targeted tanker boom aerial refueling subsystem when that particular subsystem's pressure regulation capability has failed. Any feature incorporated to provide this protection shall not activate and interfere with the fuel transfer process when fuel pressure transients occur that are normal during the aerial refueling process at properly regulated fuel delivery pressures.

REQUIREMENT RATIONALE (3.4.6.2.2.9)

This is an operational and safety requirement. A failure in the pressure regulation capability of a tanker's boom aerial refueling subsystem will result in fuel delivery pressures to the receiver's receptacle aerial refueling subsystem higher than normally expected. This increase in the fuel delivery pressure can create surge pressures within the receiver's receptacle aerial refueling subsystem higher than what would be experienced if the fuel delivery pressure was properly regulated by the tanker's boom aerial refueling subsystem. If the receiver's receptacle aerial refueling subsystem is not designed to handle a failure in the tanker's boom aerial refueling subsystem pressure regulation capability, the resultant higher surge pressures could possibly damage the receiver's receptacle aerial refueling subsystem; for example, component failures, fuel leaks. Such damage would terminate any further aerial refueling operations and could create a fire and explosion hazard to the air vehicle.

REQUIREMENT GUIDANCE (3.4.6.2.2.9)

(TBD)

REQUIREMENT LESSONS LEARNED (3.4.6.2.2.9)

The typical design approach to this requirement has been to provide an automatic disconnect feature that activates when the delivered fuel pressure in the receptacle aerial refueling subsystem is above the normally expected delivery pressure. Using a sensing switch, a signal is sent to the receptacle signal amplifier, advancing it to "DISCONNECT" mode, when the fuel pressure is above the normally expected value. The boom nozzle is automatically disconnected from the receptacle, thereby terminating fuel flow at the high delivery pressure. With this design approach, care must be taken to insure that normal fuel pressure fluctuations within the receptacle aerial refueling subsystem do not cause inadvertent disconnects. Normal pressure fluctuations that will not activate the automatic pressure disconnect feature would include tanker pump(s) startup surges and surges created by the automatic closure, or manual selected closure, of any valve within the receptacle aerial refueling subsystem. Inadvertent disconnects become an operational nuisance as they add to the aerial refueling time and workload on the receiver crew and the tanker boom operator. With this design approach, the automatic disconnect capability should be removed or locked out when the manual override switch is activated. See "Disconnect Function" and "Manual Override Function" in this appendix.

Another possible design approach to this requirement could be the incorporation of pressure relief valves and accumulators to accommodate the higher surge pressures that would occur with the higher fuel delivery pressure. Another possible design approach to this requirement could be designing the subsystem to a higher proof pressure value, one that assumes an unregulated fuel delivery pressure from the tanker boom aerial refueling subsystem(s). This approach may result in a heavier subsystem design to be able to withstand the higher surge pressures.

F.4.4.6.2.2.9 Tanker pressure regulation failures.

The ability of the receptacle aerial refueling subsystem to withstand the fuel pressure conditions created during fuel delivery from each targeted tanker boom aerial refueling subsystem when that subsystem's pressure regulation has failed, or protect itself only when such a failure condition exists, shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.2.9)

It must be verified that the receptacle aerial refueling subsystem can withstand or protect itself from the fuel pressure conditions created during fuel delivery from each targeted tanker boom aerial refueling subsystem when that subsystem's pressure regulation has failed to ensure damage does not occur to the aerial refueling subsystem.

VERIFICATION GUIDANCE (4.4.6.2.2.9)

TBS: Specify ground and flight test.

VERIFICATION LESSONS LEARNED (4.4.6.2.2.9)

Special test equipment or procedures are required to generate fuel pressures above the normal regulated pressure level. If a pressure disconnect feature is used, tests should verify that normal fuel pressure perturbations within the receptacle aerial refueling subsystem that occur during properly regulated fuel transfer procedures do not activate the pressure disconnect function and result in, inadvertent disconnects.

F.3.4.6.2.2.10 Reverse refueling.

If reverse aerial refueling is a requirement, the receptacle aerial refueling subsystem shall be capable of reverse aerial refueling without exceeding its proof pressure limit and impacting the performance of other air vehicle subsystems. The minimum reverse refueling rate shall be (TBS 1)__ at __(TBS 2)__ fuel pressure.

REQUIREMENT RATIONALE (3.4.6.2.2.10)

This is an operational and safety requirement. If the air vehicle has a mission requirement to be able to reverse refuel a tanker air vehicle due to an in-flight emergency condition on the tanker, that requirement must be defined so that the aerial refueling subsystem can be designed to provide a fuel transfer (pumping) capability back to the tanker that does not compromise safety to the air vehicle or tanker.

REQUIREMENT GUIDANCE (3.4.6.2.2.10)

This requirement is applicable only if mission dictates.

TBS 1: Specify the minimum fuel flow rate (gallons per minute).

TBS 2: Specify the fuel pressure (psig) at the air vehicle's receptacle during flow. The specified fuel pressure should not exceed 60 psig.

REQUIREMENT LESSONS LEARNED (3.4.6.2.2.10)

Reverse refueling should only be considered for large air vehicles. The capability to reverse refuel should not degrade the capability of the receiver's fuel subsystem to perform critical functions to maintain flight and safe control of the air vehicle, such as engine feed and fuel management. When reverse refueling capability has been added to a receptacle subsystem, failures have resulted in the aerial refueling manifold due to fuel pressures that have exceed the proof pressure limit. In reverse aerial refueling operations, the aerial refueling manifold must be designed to withstand the surge pressures that are generated within the air vehicle's aerial refueling subsystem when a flowing disconnect from the tanker occurs.

F.4.4.6.2.2.10 Reverse refueling.

The reverse aerial refueling capability shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.2.10)

The ability to perform reverse aerial refueling should be verified to ensure the air vehicle can conduct all its operational missions safely.

VERIFICATION GUIDANCE (4.4.6.2.2.10)

TBS: Specify that the reverse refueling capability should be verified by inspection and flight test.

VERIFICATION LESSONS LEARNED (4.4.6.2.2.10)

Reverse aerial refueling is usually accomplished by low pressure transfer pumps, therefore, the elevation difference between the tanker and receiver must be duplicated to validate flow rate. This can best be validated in flight. Instrumentation is required to measure surge pressures when a disconnect is made under fuel flow conditions. (Inspections include assuring pumps available to reverse flow and no valves to prevent reverse flow.)

F.3.4.6.2.2.11 Receptacle noise level.

At no time during flight shall the receptacle installation in a closed, open, or transient position cause an increase in the noise level of the air vehicle's crew compartment beyond (TBS) .

REQUIREMENT RATIONALE (3.4.6.2.2.11)

This is a safety and integration requirement. It is possible for a receptacle to cause an objectionable noise level in the crew compartment, particularly when the receptacle is in the open configuration (ready to be contacted by the boom nozzle). As such, a maximum limit for noise resulting from the receptacle installation must be established.

REQUIREMENT GUIDANCE (3.4.6.2.2.11)

TBS: Specify the maximum noise level in decibels (dB).

REQUIREMENT LESSONS LEARNED (3.4.6.2.2.11)

(TBD)

F.4.4.6.2.2.11 Receptacle noise level.

The acceptability of noise generated by the receptacle installation in flight shall be verified by (TBS) .

VERIFICATION RATIONALE (4.4.6.2.2.11)

The level of noise generated by the receptacle installation during flight must be verified to ensure that the crew compartment noise is maintained to a safe level.

VERIFICATION GUIDANCE (4.4.6.2.2.11)

TBS: Specify flight test.

VERIFICATION LESSONS LEARNED (4.4.6.2.2.11)

In the closed position, the flight test should examine noise generation within the entire airspeed and altitude envelope for the air vehicle. In the open position and any position between the closed and open positions, the flight test should examine noise generation within the entire airspeed and altitude envelope that the receptacle installation can be actuated to and maintained in the open position.

F.3.4.6.2.3 Probe receiver aerial refueling

F.4.4.6.2.3 Probe receiver aerial refueling

F.3.4.6.2.3.1 Type of probe installation.

The type of probe installed on the receiver air vehicle shall be __(TBS)__.

REQUIREMENT RATIONALE (3.4.6.2.3.1)

This is an integration requirement. To successfully accomplish total system integration for the receiver air vehicle, the type of probe installation must be identified.

REQUIREMENT GUIDANCE (3.4.6.2.3.1)

TBS: Specify the type of probe installation for the air vehicle, for example, a retractable or fixed (non-retractable) type. A retractable probe includes those that are fully retractable and those that are semi-retractable. The type of probe should be selected based on the mission performance requirements for the air vehicle.

REQUIREMENT LESSONS LEARNED (3.4.6.2.3.1)

Probe selection can possibly impact the overall aerodynamics of the air vehicle and should be analyzed to minimize any effects. The drag penalty associated with a fixed probe will degrade air vehicle performance throughout the receiver's flight envelope. Similarly, if the fixed probe is to be removed on missions not requiring aerial refueling, the drag penalty associated with the "cleaned up configuration" must be considered when choosing a probe type. The effects on air vehicle stability control parameters throughout the receiver's entire flight envelope must be evaluated if a fixed probe is considered (including probe removed configuration if applicable). Fully retractable probes drag impacts are typically only associated within the air vehicle's aerial refueling envelope when the probe would normally be extended. The amount of "retractability" in a semi-retractable probe will determine the level of impact on air vehicle aerodynamics. With fully retractable or semi-retractable probes, if single failure modes can prevent the probe from retracting, impacts on air vehicle aerodynamics should then be considered within the air vehicle's entire flight envelope.

Maintenance concepts should be considered which probe installation best meets weapon system requirements. In general, a fixed probe can be installed into the receiver air vehicle easier than the other types, particularly if the installation is a retrofit effort. Fixed probes are typically more maintainable than the other probe types since there are usually no movable, mechanical parts and can be designed to be easily removed on the ground for missions not requiring aerial refueling.

F.4.4.6.2.3.1 Type of probe installation.

The type of probe installation shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.3.1)

It must be verified that the proper probe design has been installed into the air vehicle to ensure total system integration has been accomplished.

VERIFICATION GUIDANCE (4.4.6.2.3.1)

TBS: The probe type should be verified by inspection.

VERIFICATION LESSONS LEARNED (4.4.6.2.3.1)

(TBD)

F.3.4.6.2.3.1.1 Type of probe nozzle.

The probe nozzle attached to the end of the probe mast shall be a __(TBS)__. The nozzle shall comply with the interface requirements defined in North Atlantic Treaty Organization Standardization Agreement (NATO STANAG) 3447.

REQUIREMENT RATIONALE (3.4.6.2.3.1.1)

This is an operational interface requirement. A specific nozzle must be identified to ensure operational compatibility with the targeted tanker drogue aerial refueling subsystem(s) identified for the air vehicle.

REQUIREMENT GUIDANCE (3.4.6.2.3.1.1)

TBS: Specify that the probe nozzle should be a MIL-N-25161 probe nozzle. A MIL-N-25161 qualified probe nozzle meets NATO STANAG 3447 design requirements but also has other design requirements which make it the most compatible probe nozzle with all of the current tanker drogue aerial refueling subsystems and the aerial refueling couplings used in these subsystems.

REQUIREMENT LESSONS LEARNED (3.4.6.2.3.1.1)

Per US government agreements with the international community, the probe nozzle must comply with NATO STANAG 3447. NATO STANAG 3447 only addresses the mating dimension and latch operation requirements for a probe nozzle. A MIL-N-25161 nozzle meets NATO STANAG 3447 requirements but also has other design features that are required for full operational compatibility with tanker drogue aerial refueling subsystems. For example, MIL-N-25161 requires flexibility of the nozzle poppet. This flexibility reduces the probability of nozzle hang-up on the tanker's drogue and coupling during severe off-center disconnects thereby reducing the chance of probe nozzle damage. This is particularly necessary when aerial refueling with the KC-135's boom-to-drogue adapter (BDA) kit subsystem that has a limited hose envelope. The nozzle specification also does not permit structural weak-link features incorporated into the design. This feature is prevalent in allied nozzle configurations and is incorporated with the intent to restrict any resultant structural damage due to excessive probe loads to the probe nozzle rather than the probe mast structure. Operationally, receiver air vehicles using this type of nozzle have demonstrated a higher propensity for nozzle breakage particularly when aerial refueling from the KC-135 BDA kit system. Damage to a probe nozzle can terminate not only the mission for the receiver (insufficient fuel transferred to complete the mission) but also end it for the tanker. It is not rare for part of the broken nozzle to remain in the tanker aerial refueling subsystem's coupling. For tankers without redundant drogue systems, such a condition renders the tanker incapable of performing any additional aerial refueling tasks. By having a more damage tolerant design, a MIL-N-25161 nozzle is more ideal for probe installations.

F.4.4.6.2.3.1.1 Type of probe nozzle.

The suitability of probe nozzle design shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.3.1.1)

It should be verified that the proper nozzle design has been incorporated into the probe installation to ensure operational compatibility with the specified tanker drogue system(s) can be attained.

VERIFICATION GUIDANCE (4.4.6.2.3.1.1)

TBS: Specify inspection, ground demonstration, ground test, and flight test. The inspection should verify that the nozzle meets NATO STANAG 3447 requirements. If the nozzle is a MIL-N-25161 item, then flight testing should also be used to verify that the selected probe nozzle is adequate. If the nozzle selected is not a MIL-N-25161 qualified component, ground demonstrations and tests should first be performed to initially evaluate physical compatibility with the aerial refueling coupling of each targeted tanker aerial refueling subsystem. Flight testing must then examine compatibility within the entire aerial refueling envelope for each tanker drogue aerial refueling subsystem identified for operational use. The flight tests should ensure that there are no hang-up problems with the probe nozzle on the tanker aerial refueling subsystem's drogue or coupling and confirm that there is no resultant probe nozzle damage.

VERIFICATION LESSONS LEARNED (4.4.6.2.3.1.1)

(TBD)

F.3.4.6.2.3.1.2 Probe actuation provisions.

The primary actuation (extension and retraction) method for a retractable probe shall be __(TBS 1)__. Given a failure of the primary method, the emergency method to extend the retractable probe shall be __(TBS 2)__. Given a failure of the primary method, the emergency method to retract the retractable probe shall be __(TBS 3)__.

REQUIREMENT RATIONALE (3.4.6.2.3.1.2)

This is an operational and an integration requirement, applicable to retractable-type probe designs only. The ability to actuate a retractable probe is required in order to successfully conduct aerial refueling operations. Providing redundant capability to actuate a retractable probe prevents a single failure from allowing the air vehicle's mission to be successfully completed. Identifying how each actuation method is activated and powered addresses air vehicle subsystem integration requirements.

REQUIREMENT GUIDANCE (3.4.6.2.3.1.2)

TBS 1: Specify how the retractable probe should be actuated to and from the "retracted" and "extended" positions; such as, manually, electrically, or hydraulically.

TBS 2: Specify how the retractable probe should be actuated to the"extended" position; such as, manually, electrically, or hydraulically.

TBS 3: Specify how the retractable probe should be actuated to the"retracted" position; such as, manually, electrically, or hydraulically.

REQUIREMENT LESSONS LEARNED (3.4.6.2.3.1.2)

Mission requirements will dictate whether the emergency retract capability is required for the probe subsystem. Recent probe-equipped fighter-type air vehicles did not require the capability to emergency retract the aerial refueling probe.

F.4.4.6.2.3.1.2 Probe actuation provisions.

The ability of the __(TBS 1)__ to use the primary actuation method to transition the retractable probe between the "retracted" and "extended" positions while in flight shall be verified by __(TBS 2)__. The ability of the __(TBS 3)__ to use the emergency actuation method to transition the retractable probe to the "extended" position while in flight shall be verified by __(TBS 4)__. The ability of the __(TBS 5)__ to use the emergency actuation method to transition the retractable probe to the "retracted" position while in flight shall be verified by __(TBS 6)__.

VERIFICATION RATIONALE (4.4.6.2.3.1.2)

It must be verified that the appropriate crew member(s) has(have) the capability to transition a retractable probe installation between the "retracted" and "extended" positions while in flight to ensure that the air vehicle can successfully and safely conduct aerial refueling operations with the targeted tanker drogue aerial refueling subsystems.

VERIFICATION GUIDANCE (4.4.6.2.3.1.2)

The suitability of the probe extension control and location can be adequately verified by a ground demonstration. The testing must consider improper operation, especially if the control is used for more than one function.

The suitability of the probe extension control and location should be adequately verified by a ground demonstration.

TBS 1: Identify the specific crew member(s).

TBS 2: Specify ground demonstration and during flight test of the subsystem.

TBS 3: Identify the specific crew member(s).

TBS 4: Specify ground demonstration, and during flight test of the subsystem. The JSSG-2001 paragraph on “Refuel interfaces” for the air vehicle should specify if ground operation of retractable probe actuation method(s) is required; hence, whether ground demonstration is appropriate here. The ground demonstration, and during flight test of the subsystem, should also evaluate the suitability of the location and accessibility of the primary and emergency probe actuation control(s).

TBS 5: Identify specific crew member(s).

TBS 6: Specify ground demonstration, and during flight test of the subsystem. The JSSG-2001 requirement for “Refuel interfaces” for the air vehicle should specify if ground operation of retractable probe actuation method(s) is required; hence, whether ground demonstration is appropriate here.

VERIFICATION LESSONS LEARNED (4.4.6.2.3.1.2)

(TBD)

F.3.4.6.2.3.1.3 Probe actuation airspeed and altitude envelope.

A retractable probe shall be capable of extension and retraction by its primary method within an airspeed and altitude envelope of __(TBS 1)__. Using its emergency method, a retractable probe shall be capable of extension within an airspeed and altitude envelope of __(TBS 2)__. A retractable probe shall be able to retract within an airspeed and altitude envelope of __(TBS 3) when its emergency method is used.

REQUIREMENT RATIONALE (3.4.6.2.3.1.3)

This is an operational requirement. The airspeed and altitude envelope at which the probe will be able to be actuated must be identified to ensure that the probe can be extended within an envelope similar to the operational airspeed envelope of the targeted tanker aerial refueling drogue subsystem(s) and can be retracted within that same envelope to permit the air vehicle to depart the aerial refueling track in a "clean" configuration.

REQUIREMENT GUIDANCE (3.4.6.2.3.1.3)

TBS 1: Specify the airspeed (KEAS) and altitude (MSL) envelope for primary extension and retraction.

TBS 2: Specify the airspeed (KEAS) and altitude (MSL) envelope for emergency extension.

TBS 3: Specify the airspeed (KEAS) and altitude (MSL) envelope for emergency retraction.

The airspeed and altitude envelope should be similar to the operational airspeed envelope of the targeted tanker aerial refueling drogue subsystem(s). Ideally, a retractable probe should be capable of extension and retraction by the primary and emergency methods at all aerial refueling airspeeds up to .9M or 350 KEAS, whichever is lower, and altitudes from 100 feet to 35,000 feet MSL.

REQUIREMENT LESSONS LEARNED (3.4.6.2.3.1.3)

Attention should be given to door and panel airspeed limits to preclude loss of hardware. Ensure that the maximum actuation airspeed is somehow communicated to the crew. This has typically been accomplished with a placard placed adjacent to the probe actuation handle.

Mission requirements will dictate whether the emergency retract capability is required for the probe subsystem.

F.4.4.6.2.3.1.3 Probe actuation airspeed and altitude envelope.

The airspeed and altitude envelope that the retractable probe can be actuated (extended and retracted) using the primary and emergency methods shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.3.1.3)

The actuation airspeed and altitude envelope for a retractable probe must be verified to ensure that the probe can be extended within the operational envelope of the targeted tanker aerial refueling drogue subsystem(s) and can be retracted within that same envelope to permit the air vehicle to depart the aerial refueling track in a "clean" configuration.

VERIFICATION GUIDANCE (4.4.6.2.3.1.3)

TBS: Specify the airspeed and altitude envelope should be verified by flight test. Flight test should evaluate the actuation envelope under both hot and cold temperature conditions using the primary and emergency methods. Any condition of low power (hydraulic, fueldraulic, electrical) being provided to the actuation mechanism of the primary and emergency methods should be examined for the effects on the probe actuation envelope.

VERIFICATION LESSONS LEARNED (4.4.6.2.3.1.3)

(TBD)

F.3.4.6.2.3.1.4 Probe actuation times.

A retractable probe shall have the capability to extend and lock into the extended position, or retract and lock in the stowed position, in __(TBS 1)__ using the primary mode within its specified actuation airspeed and altitude envelope. Using the emergency method for extension, a retractable probe shall have the capability to extend and lock into the extended position in (TBS 2)__ within its specified actuation airspeed and altitude envelope. Using the emergency method for retraction, a retractable probe shall have the capability to retract and lock into the stowed position in __(TBS 3)__ within its specified actuation airspeed and altitude envelope.

REQUIREMENT RATIONALE (3.4.6.2.3.1.4)

This is an operational requirement. The allowed time for extending or retracting the probe must be specified in order for the air vehicle to be refueled within the time dictated by its mission(s).

REQUIREMENT GUIDANCE (3.4.6.2.3.1.4)

TBS 1: Specify the desired time (seconds) for probe mast extension and retraction, respectively, using primary means. The probe mast should extend and lock into position, or retract and lock into the stowed position, in 5 to 20 seconds under its primary mode.

TBS 2: Specify the desired time (seconds) for probe mast extension using emergency means. Using its emergency mode, the probe mast should extend and lock into position within 30 seconds.

TBS 3: Specify the desired time (seconds) for probe mast retraction using emergency means. Using its emergency mode, the probe mast should retract and lock into the stowed position within 30 seconds.

REQUIREMENT LESSONS LEARNED (3.4.6.2.3.1.4)

The probe must extend and retract into position in a reasonably rapid period of time. An actuation which is too rapid can cause excessive forces within the actuation mechanism while an actuation time that is too long can impact the total aerial refueling time for the air vehicle.

Hydraulic actuators have been used for probe extension on many different systems with good results. Rotary-wing air vehicles have used engine bleed air to extend the probe. This design was complex and resulted in a difficult and costly effort to maintain the probes at an acceptable level of performance.

F.4.4.6.2.3.1.4 Probe actuation times.

The probe actuation (extension and retraction) times shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.3.1.4)

The time required for extending or retracting the retractable type probes must be verified to ensure that the air vehicle can be refueled within the time dictated by its operational mission(s).

VERIFICATION GUIDANCE (4.4.6.2.3.1.4)

TBS: Specify that the probe actuation times should be verified by ground and flight test. The actuation times should be measured in flight tests after a long period of cold temperature conditions and icing conditions. The test should determine any effect of air speed and altitude on actuation time. Any condition of low power (hydraulic, fueldraulic, electrical) being provided to the actuation mechanism of the primary and emergency methods should be examined for the effects on the probe actuation times.

VERIFICATION LESSONS LEARNED (4.4.6.2.3.1.4)

Mission requirements will dictate whether the emergency retract capability is required for the probe subsystem.

F.3.4.6.2.3.2 Probe location.

The probe shall be located such that it is compliant with NATO STANAG 3447 and so that (TBS) .

REQUIREMENT RATIONALE (3.4.6.2.3.2)

This is an integration, operational, and safety requirement. The criteria for probe location must be provided so that the probe aerial refueling subsystem is properly integrated onto the air vehicle and permits the aerial refueling process to be completed successfully and safely. The adequacy of the location of the probe must be verified to ensure that the probe aerial refueling subsystem is properly integrated onto the air vehicle and that aerial refueling can be completed successfully and safely.

REQUIREMENT GUIDANCE (3.4.6.2.3.2)

The US Government has agreed to comply with NATO STANAG 3447 without reservation or exception. Thus, all new probe subsystems must meet NATO STANAG 3447.

TBS: Specify that the probe should be located so that:

a. The air flow field around the probe and the air vehicle does not cause instability of the tanker aerial refueling subsystem's drogue and coupling during the engagement portion of the aerial refueling process.

b. A minimum of 12 inches of the probe mast, measured from the nozzle tip, should be visible to the receiver pilot (and co-pilot, if applicable) for observing the hookup with the drogue and coupling without requiring the receiver pilot (and co-pilot, if applicable) to change his(their) visual reference on the tanker.

c. The probe should not prevent or degrade the pilot's (and co-pilot's, if applicable) vision during landing or other critical flight phases.

d. The probe should not prevent, or degrade the safety of, the ground and in-flight egress or assisted egress of any crew member.

e. The pilot (and co-pilot, if applicable) should have an unobstructed view of each targeted tanker's underbody, its formation references, drogue aerial refueling subsystem status lights, and hose exit area.

f. The probe should not be required to be removed to perform other ground maintenance actions on the air vehicle.

g. The probe should not interfere with the air flow field around the air vehicle such that it adversely affects the proper operation of the engine(s) and air data ports.

h. The fuel spray that typically occurs at disconnect from the tanker aerial refueling subsystem's drogue and coupling should not become ingested into the engine or air data ports.

i. The probe should not interfere with the proper release of offensive weapons, the release of defensive countermeasures, and the jettisoning of external stores.

REQUIREMENT LESSONS LEARNED (3.4.6.2.3.2)

(TBD)

F.4.4.6.2.3.2 Probe location.

The suitability of the probe location shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.3.2)

It must be verified that the location of the probe is properly selected to ensure that the aerial refueling process can be completed successfully and safely with the targeted tanker drogue aerial refueling subsystem(s) and to insure that the other subsystems on the air vehicle are not adversely affected with the selected probe location.

VERIFICATION GUIDANCE (4.4.6.2.3.2)

TBS: Specify inspection, ground demonstration, and flight test.

VERIFICATION LESSONS LEARNED (4.4.6.2.3.2)

The location of the probe in relation to other air vehicle equipment and subsystems can be verified by an inspection and a ground demonstration; however, its suitability in relation to hookup with the targeted tanker aerial refueling subsystem can only be verified by flight test.

F.3.4.6.2.3.2.1 Probe alignment.

The probe, when in the position to make an engagement with the tanker aerial refueling subsystem's drogue coupling, shall be aligned such that a smooth, positive connection can be made with the drogue coupling within the receiver closure speed limitations for each targeted tanker drogue aerial refueling subsystem.

a. The longitudinal axis of the nozzle shall be __(TBS 1)__.

b. The plane of the vertical axis of the nozzle shall be __(TBS 2)__.

REQUIREMENT RATIONALE (3.4.6.2.3.2.1)

This is an operational and safety requirement. The proper alignment of the probe is a pre-requisite to achieving a safe and effective contact with the drogue and coupling of the targeted tanker aerial refueling subsystem(s).

REQUIREMENT GUIDANCE (3.4.6.2.3.2.1)

TBS 1: Specify that the longitudinal axis of the nozzle should be parallel to the line of average pitch angle during refueling.

TBS 2: Specify that the plane of the vertical axis of the nozzle should be parallel to the local air flow field around the probe mast.

REQUIREMENT LESSONS LEARNED (3.4.6.2.3.2.1)

The local air flow around the probe controls the direction of the forces holding the drogue and coupling. If not properly aligned, the forces on the drogue and coupling may not be sufficient to allow a positive contact with the nozzle. The nozzle may push the drogue and coupling and not establish a complete engagement which is required to create an open fuel flow path between the tanker aerial refueling subsystem's coupling and the probe nozzle.

F.4.4.6.2.3.2.1 Probe alignment.

The suitability of probe alignment shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.3.2.1)

It must be verified that the probe installation is properly aligned to ensure the air vehicle can successfully and safely make a positive contact with the drogue coupling of each targeted tanker aerial refueling subsystem.

VERIFICATION GUIDANCE (4.4.6.2.3.2.1)

TBS: Specify flight test. In the flight tests, the ability to make hookups should be evaluated with the hose empty and full of fuel.

VERIFICATION LESSONS LEARNED (4.4.6.2.3.2.1)

An empty hose flies in a different location than a hose full of fuel. Operationally, the first receiver contact on a tanker drogue aerial refueling subsystem in a mission is usually made with the hose empty of fuel. Contacts with an empty hose may be the preferred procedure during training exercises. During the flight test, fuel should be transferred after the contacts to verify that a positive hookup has been accomplished.

F.3.4.6.2.3.2.2 Probe clearance.

The clearance around the probe shall provide an unobstructed path for the drogue coupling of the targeted tanker aerial refueling subsystems to approach and contact the probe nozzle. The probe clearance shall be __(TBS)__.

REQUIREMENT RATIONALE (3.4.6.2.3.2.2)

This is an operational and safety requirement. In order for the aerial refueling process to proceed successfully and safely, adequate clearance around the probe must be provided such that an unobstructed path for the tanker drogue coupling is available as it approaches and contacts the probe nozzle.

REQUIREMENT GUIDANCE (3.4.6.2.3.2.2)

TBS: Specify the clearance around the probe that should be provided to allow the approach and contact of the tanker drogue coupling from each targeted tanker aerial refueling subsystem. As a minimum, the clearance should comply with NATO STANAG 3447. For retractable probes, the clearance specified should apply when the probe has been actuated to its extended position.

REQUIREMENT LESSONS LEARNED (3.4.6.2.3.2.2)

The US Government has agreed to comply with NATO STANAG 3447, without reservation or exception. As such, all new probe subsystems must meet NATO STANAG 3447 with regard to clearance around the probe. Existing special purpose tankers (rotary-wing air vehicles) can have a drogue coupling that is larger than the minimum clearance specified in NATO STANAG 3447. As such, the probe clearance for receivers that must be compatible with these tanker aerial refueling subsystems must provide clearance around the probe that is larger than the size of the drogue coupling on the special purpose tanker's aerial refueling subsystem.

Inadequate probe clearances can result in preventing drogue coupling contact with the probe nozzle, thereby, not permitting fuel transfer to take place from the tanker to the air vehicle. In addition, insufficient probe clearance can damage the tanker's drogue coupling which can render that aerial refueling subsystem of the tanker inoperable for further aerial refueling transfers during that tanker mission. Any damage to the tanker's drogue coupling or the air vehicle due to inadequate clearance around the probe can result in a foreign object damage (FOD) hazard to the air vehicle.

F.4.4.6.2.3.2.2 Probe clearance.

The suitability of the clearance around the probe to permit the approach and contact of each targeted tanker aerial refueling subsystem's drogue coupling with the probe nozzle shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.3.2.2)

The suitability of the clearance provided around the probe must be verified to ensure that the aerial refueling process can be accomplished safely and successfully.

VERIFICATION GUIDANCE (4.4.6.2.3.2.2)

TBS: Specify ground demonstration and flight test. A ground demonstration should verify that the specified basic clearance with the drogue and coupling has been provided. A flight test is required to verify that the actual approach of the drogue coupling to the probe in flight is as predicted and that there are no obstructions which have been overlooked.

VERIFICATION LESSONS LEARNED (4.4.6.2.3.2.2)

(TBD)

F.3.4.6.2.3.3 Probe compartment fluid accumulation.

Probe compartments shall not accumulate fluids which can create a fire and explosion hazard to the air vehicle, or which can impact the proper operation of the actuation mechanism for retractable probes. Fluids within the probe compartment shall be removed by __(TBS)__. If drains are used, the drainage requirements of JSSG-2001, "Fire and Explosion Prevention" shall be met. Fluids within the probe compartment shall not be able to migrate to another compartment within the air vehicle which can create a fire and explosion hazard.

REQUIREMENT RATIONALE (3.4.6.2.3.3)

This is a safety requirement. During aerial refueling operations, the probe nozzle can be damaged or the probe mast broken. This can result in fuel being spilled in the probe compartment, particularly with retractable-type probe installations. Also, the accumulation of rainwater in the compartment must be prevented to avoid the occurrence of icing conditions that could interfere with the proper operation of the actuation mechanism for a retractable probe.

REQUIREMENT GUIDANCE (3.4.6.2.3.3)

TBS: Specify how any fluid spilled in the probe compartment will be removed to preclude accumulation.

REQUIREMENT LESSONS LEARNED (3.4.6.2.3.3)

Typically, probe compartments have been sealed to prevent fluid leakage into other air vehicle compartments. The fluid is then drained overboard to prevent accumulation of the fluid in the probe compartment. The fluids in question have typically been fuel, rainwater, air vehicle cleaning solutions, and hydraulic fluid (from the probe actuation mechanism). Any sealant material used to help prevent the fluids from migrating to another compartment must be compatible with all fluids expected to be encountered.

See fuel drainage requirements (G.3.4.7.5) in appendix G, Fire and Explosion Hazard Protection Subsystem, for additional Lessons Learned related to this requirement.

F.4.4.6.2.3.3 Probe compartment fluid accumulation.

Provisions to prevent the accumulation of fluids in the probe compartment shall be verified by (TBS 1) . The adequacy of the provided method(s) shall be verified by (TBS 2) . The adequacy of the provided method(s) to prevent fluids from migrating into another compartment within the air vehicle shall be verified by (TBS 3) .

VERIFICATION RATIONALE (4.4.6.2.3.3)

The provisions for, and the adequacy of, containing fluids in the probe compartment and then removing those fluids from the probe compartment should be verified to ensure that a safety hazard has not been introduced to the air vehicle and that proper operation of the probe actuation mechanism for retractable probes is not compromised.

VERIFICATION GUIDANCE (4.4.6.2.3.3)

TBS 1: Specify inspection.

TBS 2: Specify ground and flight tests.

TBS 3: Specify ground test. Ground tests verifying the adequacy of the probe compartment provisions for containing any fluid and then removing that fluid from the compartment should evaluate all ground and flight attitudes of the air vehicle.

VERIFICATION LESSONS LEARNED (4.4.6.2.3.3)

Water has typically been the fluid used to evaluate sealing and drainage capability of probe compartments in ground and flight tests. Flight tests have revealed that initial drainage provisions were not adequate due to pressure differentials across the drainage exit location on the air vehicle. Adequate drainage capability should be verified throughout the entire flight envelope for the air vehicle.

F.3.4.6.2.3.4 Probe illumination.

The (TBS) portion of the probe installation, when in the position to make a contact with the tanker aerial refueling subsystem's drogue coupling, shall be illuminated to assist the air vehicle crew member(s) to make the engage with the tanker aerial refueling subsystem's drogue coupling. The probe illumination shall be oriented such that it does not blind or distract the air vehicle's pilot (and co-pilot, if applicable) during the aerial refueling process and any tanker crew member who is required to observe the aerial refueling procedure. The probe illumination shall not be a potential source of ignition of flammable fuels. The aircrew shall be able to control the intensity of the probe illumination in variable increments from “OFF” to “FULL BRIGHT”.

REQUIREMENT RATIONALE (3.4.6.2.3.4)

This is an operational and safety requirement. When night aerial refueling is required for the receiver air vehicle, proper probe illumination is required to permit the aerial refueling process to be successfully and safely completed.

REQUIREMENT GUIDANCE (3.4.6.2.3.4)

TBS: Specify that, in the precontact position for the targeted tanker drogue aerial refueling subsystem, the probe illumination should illuminate a minimum of twelve inches of the probe mast, measured from the probe nozzle tip, and also illuminate the drogue coupling at a distance of fifty yards. Also specify that, after contact is established, the probe illumination should illuminate the refueling hose, the hose attachment point to the tanker, and the underside of the wing or fuselage area of the tanker (depending on the installed location of the drogue aerial refueling subsystem).

REQUIREMENT LESSONS LEARNED (3.4.6.2.3.4)

This requirement is mandatory for night aerial refueling operations.

The light assembly should not produce bright spots or direct the light toward the air vehicle pilot (and co-pilot, if applicable) and any tanker air crew member (if applicable). The light assemblies in close proximity with the probe installation should be explosion-proof since fuel spray onto the light assemblies can be expected during the disconnect phase of the aerial refueling process. When operating at maximum intensity and temperature, the light assemblies must not fail or fracture when coming into contact with -65°F fuel.

Ideally, for retractable probe installations, the probe illumination should automatically occur once the probe installation has been activated to the "extended" position and automatically terminate once the probe installation has been activated to the "retracted" position. For fixed probe installations, the probe illumination feature will require a dedicated means of activation.

The probe lighting requirements from MIL-L-006730; Lighting Equipment, Exterior, Aircraft (General Requirements For), have been used in legacy probes.

F.4.4.6.2.3.4 Probe illumination.

The ability to illuminate the probe and the specified tanker references shall be verified by __(TBS 1)__. The inability of the probe illumination to be a potential ignition source shall be verified by __(TBS 2)__.

VERIFICATION RATIONALE (4.4.6.2.3.4)

It must be verified that the provided probe illumination is adequately installed to ensure that the air vehicle crew can make clean, safe engagements of the probe nozzle with the tanker subsystem's drogue coupling during aerial refueling processes and that the appropriate tanker crew member(s) can properly monitor the aerial refueling procedures, as required. In addition, it must be verified that the probe illumination feature is properly designed to insure that it does not create a fire and explosion hazard to the air vehicle during the aerial refueling process.

VERIFICATION GUIDANCE (4.4.6.2.3.4)

TBS 1: Specify analysis, ground test and flight test.

TBS 2: Specify analysis and ground test.

The analysis should examine the adequacy of the probe illumination for the requirements that apply to the air vehicle and the tanker. The ground test should complete the preliminary examination of the adequacy of the probe illumination for the air vehicle side of the requirements; such as amount of probe mast illumination, impact on air vehicle crew visibility, when the illumination feature is activated. The flight tests should be the final verification of the adequacy of the probe illumination for air vehicle side of the requirements and the final verification of the adequacy of the probe illumination for the performance requirements that impact the tanker. The flight tests should evaluate several different natural night conditions; such as under twilight, new and full moon conditions.

VERIFICATION LESSONS LEARNED (4.4.6.2.3.4)

(TBD)

F.3.4.6.2.3.5 Structural loads.

The probe and the air vehicle attachment and support structure shall withstand loads of __(TBS 1)__. The __(TBS 2)__ area surrounding the probe mast shall withstand inadvertent impact loads of __(TBS 3)__.

REQUIREMENT RATIONALE (3.4.6.2.3.5)

This is an operational and safety requirement. The entire probe and its attachment/support structure must be structurally compatible with each drogue aerial refueling system on the identified targeted tanker(s) to permit the aerial refueling process to be successfully and safely completed. As there are unique loads associated with each different drogue system, the applicable load criteria must be specified for the probe and its attachment structure. In addition, since probe nozzle and drogue/coupling engagements/disengagements are not always precise, the area surrounding the probe must be able to withstand impact loads that can occur due to inadvertent drogue/coupling strikes.

REQUIREMENT GUIDANCE (3.4.6.2.3.5)

TBS 1: Specify the static operating, design limit, and ultimate loads. In addition, include dynamic impact loads encountered when connecting to the coupling of the tanker's drogue aerial refueling subsystem.

When aerial refueling with the KC-135's BDA system, the probe nozzle, probe mast, and air vehicle attachment/support structure must be able to withstand one of the following limit loads criteria upon contact, within the specified fuel transfer envelope while engaged to the BDA kit's coupling and at disconnect throughout the aerial refueling envelope:

a. a 1000-lb. compression load in combination with a 3000-lb. radial load
b. a 1000-lb. tensile load in combination with a 3000-lb. radial load

c. a 2000-lb. tensile load

d. a 2000-lb. compression load,

or the following:

a. a 2500-lb. compression load in combination with a 1500-lb. radial load

b. a 1500-lb. tensile load in combination with a 1500-lb. radial load

c. a 1500-lb. tensile load

d. a 2500-lb. compression load

e. a 1500-lb. radial load.

When aerial refueling from a hose reel drogue system, the probe nozzle, probe mast, and air vehicle attachment/support structure must be able to withstand the following limit loads upon contact, within the specified fuel transfer envelope while engaged to the tanker's drogue coupling and at disconnect throughout the aerial refueling envelope:

a. a 1000-lb. compression load in combination with a 1000-lb. radial load

b. a 1000-lb. tensile load in combination with a 1000-lb. radial load

c. a 2000-lb. tensile load

d. a 2000-lb. compression load.

Operating loads at normal refueling positions within the specified fuel transfer envelope of each drogue system should be maintained within 2/3 of limit load to minimize impact on fatigue life. Ultimate loads should be 133 percent of the limit loads.

The impact loads during engagements should be based upon a drogue/coupling contact velocity up to 10 feet per second and using the drogue drag at the maximum airspeed within the aerial refueling envelope for that particular drogue aerial refueling subsystem.

TBS 2: Specify the applicable area around the probe structure. All structure in front of, beside, and 6 feet aft of the probe nozzle that is located within 2 drogue diameters circumferentially about the probe nozzle axis should be designed for inadvertent drogue/coupling strikes. The drogue diameter to be used must be the largest diameter drogue on the targeted tanker drogue subsystem(s).

TBS 3: Specify the impact loads to be applied to the defined area around the probe structure due to inadvertent drogue/coupling strikes encountered during the engagement/disengagement process. Inadvertent impact loads onto the surrounding structure should be based upon the loads produced by each targeted tanker drogue subsystem. The impact loads from inadvertent drogue/coupling strikes during engagements should be based upon a drogue/coupling contact velocity up to 10 feet per second, using the drogue drag at the maximum airspeed within the aerial refueling envelope for that particular drogue aerial refueling subsystem, and having the drogue system's hose/coupling full of fuel. The impact loads from inadvertent drogue/coupling strikes during disengagements should be based upon a contact velocity of 2 feet per second greater than the maximum extension rate for the targeted tanker drogue subsystem when a receiver is connected to the drogue/coupling.

Reference JSSG-2006, 3.4.1.7.2, for other structural load guidance.

REQUIREMENT LESSONS LEARNED (3.4.6.2.3.5)

Probe nozzles which comply with MIL-N-25161 are designed to the first set of limit load criteria provided above for KC-135 BDA system compatibility. The second set of limit load criteria has been used by the F-35 as a design solution to air vehicle (probe) weight versus probe load capability. The KC-135 BDA system, historically, has been the "worst case" USAF tanker drogue system regarding probe loads. There may be allied/foreign/commercial tanker drogue systems that may require higher load capability to provide adequate compatibility to permit successful and effective aerial refueling operations.

The above loads are in addition to any aerodynamic/gust loads that may be imparted onto the structure of the air vehicle, the probe mast, and the probe nozzle while in flight. Also, when the resultant incremental load is additive, the additional load conditions created by the presence (or lack of) cabin pressure and the presence (or lack of) fuel pressure in the fuel line within the probe mast must be considered. All loading conditions must be applied to the support structure to which the aerial refueling subsystem/interface attaches.

Impact loads onto the probe should be based upon the loads produced by each targeted tanker drogue subsystem. Historically, impact loads have been defined when the probe nozzle contacts the drogue/coupling at angular positions up to 15 degrees off-center of the drogue/coupling centerline and at a probe contact velocity up to 10 feet per second. The impact loads should be based upon the drogue drag at the maximum airspeed within the aerial refueling envelope for that particular drogue aerial refueling subsystem.

JSSG-2001 provides additional guidance on loads for aerial refueling probe subsystems.

F.4.4.6.2.3.5 Structural loads.

The ability of the probe mast and the aircraft attachment and support structure to withstand the required structural loads shall be verified by ___(TBS 1)___. The ability of the defined area surrounding the probe mast to withstand the specified impact loads shall be verified by __(TBS 2)__.

VERIFICATION RATIONALE (4.4.6.2.3.5)

It must be verified that the probe mast, its attachment/support structure, and the area surrounding the probe mast are structurally compatible with the specified tanker drogue systems to ensure that the air vehicle can safely and effectively perform aerial refueling operations.

VERIFICATION GUIDANCE (4.4.6.2.3.5)

TBS 1: Specify ground test. A ground test should verify that the probe mast and the aircraft attachment and support structure can withstand the required loads. No malfunction or deformation to the probe nozzle, probe mast, or attachment/support structure can occur upon application of each ultimate loading condition.

TBS 2: Specify analysis and ground test.

VERIFICATION LESSONS LEARNED (4.4.6.2.3.5)

The attach point to the air vehicle is generally a critical point in relation to probe strength; therefore, an actual probe attached to a realistic air vehicle structure must be used to verify the complete probe installation.

The tensile loads should be applied at the latching shoulder parallel to the axis of the probe nozzle. The radial loads should be applied to the probe nozzle sleeve 3.5 inches from the gage point in the toggle-latching groove. The compression load should be applied at the lip of the probe nozzle sleeve and parallel to the longitudinal axis of the probe nozzle. The most critical direction for the radial test load application should be selected for the test.

F.3.4.6.2.3.6 Probe maintenance.

Removal, replacement, and checkout of fully retractable and semi-retractable probe masts shall be accomplished in __(TBS 1)__. Fixed probes shall be installed or removed in __(TBS 2)__. The probe nozzle shall be replaceable in __(TBS 3)__.

REQUIREMENT RATIONALE (3.4.6.2.3.6)

(TBD)

REQUIREMENT GUIDANCE (3.4.6.2.3.6)

(TBD)

REQUIREMENT LESSONS LEARNED (3.4.6.2.3.6)

(TBD)

F.4.4.6.2.3.6 Probe maintenance.

Probe maintenance shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.3.6)

(TBD)

VERIFICATION GUIDANCE (4.4.6.2.3.6)

(TBD)

VERIFICATION LESSONS LEARNED (4.4.6.2.3.6)

(TBD)

F.3.4.6.2.3.6.1 Fixed probe nozzle cover.

For probe installations that have the probe nozzle continuously exposed to the environment when the air vehicle is on the ground, a probe nozzle cover with an approved streamer flag shall be capable of being installed over the probe nozzle.

REQUIREMENT RATIONALE (3.4.6.2.3.6.1)

This is an operational and safety requirement. Probe nozzles that will be continuously exposed to the environment when the air vehicle is on the ground should be protected from exposure to extend the service life of the probe nozzle and prevent the possible intrusion of contamination into the aerial refueling subsystem.

REQUIREMENT GUIDANCE (3.4.6.2.3.6.1)

If a nozzle cover is not needed, this requirement should be deleted.

REQUIREMENT LESSONS LEARNED (3.4.6.2.3.6.1)

This requirement has typically been applied to fixed probe installations and semi-retractable probe installations that do not retract the probe nozzle into an enclosed compartment on the air vehicle.

F.4.4.6.2.3.6.1 Fixed probe nozzle cover.

The ability to install a probe nozzle cover with an approved streamer flag onto the probe nozzle of a probe installation that has the probe nozzle continuously exposed to the environment when the air vehicle is on the ground shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.3.6.1)

It must be verified that the probe nozzle can be adequately protected from exposure to ensure that the probe nozzle is not damaged or that contamination is introduced into the aerial refueling subsystem.

VERIFICATION GUIDANCE (4.4.6.2.3.6.1)

TBS: Specify inspection and ground demonstration.

VERIFICATION LESSONS LEARNED (4.4.6.2.3.6.1)

(TBD)

F.3.4.6.2.3.6.2 Probe mast protection.

The probe mast, when not installed on the air vehicle, shall be protected from external contamination and damage by __(TBS)__.

REQUIREMENT RATIONALE (3.4.6.2.3.6.2)

This is a safety requirement. A probe mast, when it is removed from the air vehicle, is vulnerable to being exposed to dirt and other foreign objects. A reinstalled probe mast which has been damaged can result in fuel leaks and can affect the proper operation of the aerial refueling subsystem. A reinstalled probe mast which has collected foreign debris can introduce contamination to the aerial refueling, fuel, and propulsions subsystems which can affect the proper operation of these subsystems.

REQUIREMENT GUIDANCE (3.4.6.2.3.6.2)

TBS: Specify how the probe mast should be protected.

REQUIREMENT LESSONS LEARNED (3.4.6.2.3.6.2)

This requirement has typically been applied to probe installations that are removed when aerial refueling is not required for the air vehicle's mission. This application has usually been to fixed probe installations that are required only for ferry missions. This requirement, however, could be applicable to any type of probe when it is removed from the air vehicle for any maintenance action.

Probe masts have been protected by the use of a cap for the open fuel tube and by the use of a case for storing the entire probe mast.

F.4.4.6.2.3.6.2 Probe mast protection.

The capability to protect a probe mast from external contamination and damage when removed from the air vehicle shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.3.6.2)

The ability to protect the probe mast, when it is removed from the air vehicle, from damage or foreign debris must be verified to ensure the proper operation of the aerial refueling subsystem once the probe mast is reinstalled and to insure the aerial refueling, fuel, and propulsion subsystem are not contaminated.

VERIFICATION GUIDANCE (4.4.6.2.3.6.2)

TBS: Specify inspection.

VERIFICATION LESSONS LEARNED (4.4.6.2.3.6.2)

(TBD)

F.3.4.6.2.3.6.3 Air vehicle probe attachment point cover.

When an aerial refueling probe mast is removed from the air vehicle, the air vehicle attachment point for the probe mast fuel tube opening shall be protected from potential damage and foreign object contamination by __(TBS)__.

REQUIREMENT RATIONALE (3.4.6.2.3.6.3)

This is a safety requirement. The probe mast fuel tube opening attachment point on the air vehicle must be protected from potential damage and foreign object contamination whenever the probe mast is removed from the air vehicle for maintenance purposes. Damage to the probe mast attachment point can result in fuel leakage when the probe mast is reinstalled. The accumulation of contaminates can introduce foreign matter into the aerial refueling subsystem which can then make its way into the fuel and propulsion subsystems and possibly affect the proper operation of these subsystems.

REQUIREMENT GUIDANCE (3.4.6.2.3.6.3)

TBS: Specify how the attachment point for the probe mast fuel tube opening will be protected.

REQUIREMENT LESSONS LEARNED (3.4.6.2.3.6.3)

This requirement has typically been applied to probe installations that are removed when aerial refueling is not required for the air vehicle's mission. This application has usually been to fixed probe installations that are required only for ferry missions. This requirement, however, could be applicable to any type of probe when it is removed from the air vehicle for any maintenance action.

Attachment points have been protected in the past by the use of a cap on the probe mast fuel tube opening.

F.4.4.6.2.3.6.3 Air vehicle probe attachment point cover.

The ability to protect the air vehicle attachment point for the probe mast fuel tube opening from potential damage and foreign objects once the probe mast has been removed from the air vehicle shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.3.6.3)

The ability to protect the air vehicle's probe attachment point from damage or foreign debris, when the probe mast is removed from the air vehicle, must be verified to ensure the proper operation of the aerial refueling subsystem once the probe mast is reinstalled and insure the aerial refueling, fuel, and propulsion subsystems are not contaminated once the probe mast is reinstalled.

VERIFICATION GUIDANCE (4.4.6.2.3.6.3)

TBS: If the air vehicle is not required to be able to fly with the probe mast removed, specify inspection and ground demonstration. If the air vehicle is required to be able to fly with the probe mast removed, specify inspection, ground demonstration, ground test, and flight demonstration.

VERIFICATION LESSONS LEARNED (4.4.6.2.3.6.3)

For air vehicles that must be able to fly with the probe mast removed, the ground test must be a pressure test that verifies that the provision(s) to protect the air vehicle attachment point so that the probe mast fuel tube can function properly (no fuel leakage) once the probe mast has been removed from the air vehicle . A flight demonstration is required to verify that the provision(s) will function properly and not impact the air vehicle or the operation of other subsystems during flight .

F.3.4.6.2.3.6.4 Fuel spillage.

It shall be possible to remove a probe mast without the occurrence of uncontrolled fuel spillage.

REQUIREMENT RATIONALE (3.4.6.2.3.6.4)

This is a safety requirement. Uncontrolled fuel spillage during the removal of a probe mast can create hazards to the maintenance personnel and the air vehicle, and can result in environmental violations.

REQUIREMENT GUIDANCE (3.4.6.2.3.6.4)

If the aerial refueling subsystem design prevents the accumulation of residual fuel in the probe, then this requirement can be deleted.

REQUIREMENT LESSONS LEARNED (3.4.6.2.3.6.4)

This requirement has typically been applied to probe installations that are removed when aerial refueling is not required for the air vehicle's mission. This application has usually been to fixed probe installations that are required only for ferry missions. This requirement, however, should be applicable to any type of probe as damage to the probe mast can be encountered during aerial refueling operations and require the removal of the probe mast from the air vehicle for repair maintenance. A drain plug has proven to be an effective method to remove residual fuel from the probe so that removal of the probe mast does not result in fuel spillage.

F.4.4.6.2.3.6.4 Fuel spillage.

The ability to remove the probe mast without the occurrence of uncontrolled fuel spillage shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.6.2.3.6.4)

The ability to remove the probe mast without the occurrence of uncontrolled fuel spillage must be verified to ensure that maintenance actions on the probe mast can be performed safely and not create environmental hazards.

VERIFICATION GUIDANCE (4.4.6.2.3.6.4)

TBS: Specify ground demonstration. As part of the ground demonstration, during the removal of the probe mast, any fuel spillage should be captured and measured and any fuel remaining in the probe mast should be collected and measured.

VERIFICATION LESSONS LEARNED (4.4.6.2.3.6.4)

(TBD)

F.3.4.6.2.3.7 Probe noise level.

At no time during flight shall the probe cause an increase in the noise level of the air vehicle's crew compartment beyond __(TBS)__.

REQUIREMENT RATIONALE (3.4.6.2.3.7)

This is a safety and integration requirement. A probe can cause an objectionable noise level in the crew compartment when it is installed on the air vehicle (fixed and semi-retractable types) or when commanded into its extended position (semi-retractable and fully retractable types). As such, a maximum limit for noise resulting from the probe must be established.

REQUIREMENT GUIDANCE (3.4.6.2.3.7)

TBS: Specify the maximum noise level in decibels (dB).

Fixed probes and semi-retractable (retracted position) should not increase crew compartment noise levels beyond the limit specified by the human factor requirements for all airspeeds. Semi-retractable (actuated and extended positions) and fully retractable probes should not increase crew compartment noise levels beyond the limit specified by the human factor requirements during all airspeeds that the probe can be extended and retracted.

REQUIREMENT LESSONS LEARNED (3.4.6.2.3.7)

On the F-5E air vehicle, the fixed probe design intended for ferry missions was used by one foreign operator on a day-by-day basis. At higher airspeeds, the probe caused an objectionable noise and some loss of control authority, due to the increased drag on one side of the air vehicle.

F.4.4.6.2.3.7 Probe noise level.

The acceptability of noise generated by the probe installation during flight shall be verified by (TBS) .

VERIFICATION RATIONALE (4.4.6.2.3.7)

The level of noise generated by the probe during flight must be verified to ensure the crew compartment noise is maintained at a safe level.

VERIFICATION GUIDANCE (4.4.6.2.3.7)

TBS: Specify flight test.

VERIFICATION LESSONS LEARNED (4.4.6.2.3.7)

For fixed and semi-retractable probes (retracted position), the flight test should examine noise generation within the entire airspeed and altitude envelope for the air vehicle. For semi-retractable (actuated and extended positions) and fully retractable (actuated and extended positions) probes, the flight test should examine noise generation within the entire probe actuation airspeed and altitude envelope.

F.5 PACKAGING

F.5.1 Packaging.

For acquisition purposes, the packaging requirements shall be as specified in the contract or order (see 6.2). When packaging of materiel is to be performed by DoD or in-house contractor personnel, these personnel need to contact the responsible packaging activity to ascertain packaging requirements. Packaging requirements are maintained by the Inventory Control Point's packaging activities within the Military Service or Defense Agency, or within the military service's system commands. Packaging data retrieval is available from the managing Military Department's or Defense Agency's automated packaging files, CD-ROM products, or by contacting the responsible packaging activity.

F.6 NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

F.6.1 Intended use.

The aerial refueling subsystem descriptions in this appendix are intended for use in air vehicle systems developed to perform combat and combat-support missions in environments unique to military weapon systems.

F.6.2 Acquisition requirements.

Acquisition documents should specify the following:

a. Title, number, and date of the specification.

F.6.3 Definitions.

Group B Hardware: This is hardware which is regularly removed and replaced from the air vehicle by maintenance crews. This includes pylons, tip tanks, and external fuel tanks.

F.6.4 Acronyms.

The following list contains the acronyms/abbreviations contained within this appendix.

AFFTC	Air Force Flight Test Center
BDA	Boom-to-drogue Adapter
FARP	Forward Area Refueling Point
FARRP	Forward Area Remote Rearming Point
FC/HQ	Flight Control / Handling Qualities
FOD	Foreign Object Damage
GPM	Gallons Per Minute
KCAS	Knots Calibrated Airspeed
KEAS	Knots Equivalent Airspeed
LO	Low Observable
M	Mach
MSL	Mean Sea-level
UARRSI	Universal Aerial Refueling Receptacle Slipway Installation
USAF	United States Air Force

F.6.5 Subject term (key word) listing.

Boom

Drogue

Fluid

Fuel

Mast

Nozzle

Probe

Receiver

Receptacle

Slipway

Spillage

Tanker

F.6.6 International standardization agreement implementation.

This specification implements NATO STANAG 3447, Aerial Refueling Equipment Dimensional and Functional Characteristics; and NATO STANAG 3971, Air-to-Air Refuelling – (ATP-56). When amendment, revision, or cancellation of this specification is proposed, the preparing activity must coordinate the action with the U.S. National Point of Contact for the international standardization agreements, as identified in the ASSIST database at https://assist.dla.mil.

F.6.7 Responsible engineering office.

The office responsible for the development and technical maintenance of this appendix is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL. Requests for additional information on this appendix can be obtained from AFLCMC/ENRS, BLDG 28 RM 118, 2145 MONAHAN WAY, WPAFB OH 45433-7017 USA; DSN 674-5476; COMMERCIAL (937) 904-5476; ENGINEERING.STANDARDS@US.AF.MIL.

F.6.8 Amendment notations.

The margins of this specification are marked with vertical lines to indicate modifications generated by this amendment. This was done as a convenience only and the Government assumes no liability whatsoever for any inaccuracies in these notations. Bidders and contractors are cautioned to evaluate the requirements of this document based on the entire content irrespective of the marginal notations.

APPENDIX G

AIR VEHICLE FIRE AND EXPLOSION HAZARD PROTECTION SUBSYSTEM

REQUIREMENTS AND GUIDANCE

G.1 SCOPE

G.1.1 Scope.

This appendix provides the requirements, verifications, tailoring guidance, and background information for the Fire and Explosion Hazard Protection Subsystem provided for in Part 1 of this specification. The appendix has been developed and coordinated by technical personnel from the Air Force, Navy, and Army and has been approved as an official guide for use by Government personnel for assistance in tailoring the air vehicle subsystems specification for acquisition and model specifications. This appendix is a mandatory part of the specification. The information contained herein is intended for compliance.

G.1.2 Structure.

The appendix structure replicates the structure of the Air Vehicle Subsystems Specification except it places each corresponding section 3 requirement and section 4 verification together.

G.1.3 Appendix.

This appendix provides tailoring guidance and background information for individual paragraphs of the Air Vehicle Subsystems Specification. Guidance gives recommendations on how to tailor the specification paragraph. Where ___(TBS)___ appears, the guidance paragraph provides recommended values or text that the Using Service may use to insert in the __(TBS)__. When contractors are expected to complete the _(TBS)__, the Guidance paragraph will so state. The Using Service makes the final decision on whom completes the __(TBS)__ in the specification. Finally, Lessons Learned are provided to give insight to past events that could impact the tailoring of the specification.

G.1.4 Deviations.

Projected designs for given applications which will result in improvement of the system performance, reduced life cycle cost, or reduced developmental cost through deviations from this guidance, or where requirements of the specification results in compromise in operational capability, should be brought to the attention of the Using Service.

G.1.5 Environmental impact.

Air Vehicle Subsystems will be designed such that their operation, maintenance, and repair may be accomplished without violating the most stringent environmental regulations applicable to locations where subsystems are used or supported. Compliance with environmental regulations will not prevent subsystems from achieving and sustaining mission performance capability. Materials, processes, and environmental control equipment necessary to meet these environmental requirements must currently be available in the Using Service's maintenance and supply system. The design will not use environmentally unsuitable materials such as ozone depleting fluorocarbons, chlorofluorocarbons, and halons, or highly volatile organic compounds in solvents and coatings during development, production, operation, maintenance, or repair. The Environmental Protection Agency maintains an online list of toxic chemicals and hazardous substances on its Ozone Layer Depletion Website at http://www.epa.gov/ozone/snap/ that should be consulted. The Significant New Alternatives Policy (SNAP) Program available thereon identifies substitutes for ozone depleting chemicals.

The contractor will conduct an environmental analysis of air vehicle subsystems.

G.1.6 Responsible engineering office.

The responsible engineering office (REO) for this appendix is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL.

G.2 APPLICABLE DOCUMENTS

G.2.1 General.

The documents listed in this section are specified in sections 3 and 4 of this handbook. This section does not include documents cited in other sections of this guide specification or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3 and 4 of this handbook, whether or not they are listed.

G.2.2 Government documents

G.2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this appendix to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

INTERNATIONAL STANDARDIZATION AGREEMENT

Advisory Group for Aerospace Research And Development (AGARD) Conference Proceeding

AGARD CP-84-71	Ignition of Fuels by a Hot Projectile

(Requests for copies of this document may be directed to the NATO Research & Technology Organisation, http://nso.nato.int; and are also available from the NASA Center for AeroSpace Information (CASI), 7115 Standard Drive, Hanover MD 21076-1320 USA; help@sti.nasa.gov; and the National Technical Information Service, http://www.ntis.gov.)

FEDERAL SPECIFICATION

BB-E-2879	Extinguisher, Fire, Carbon Dioxide (CO2), Portable, with Mounting Bracket, for Aviation Use

COMMERICAL ITEM DESCRIPTIONS

A-A-59503	Nitrogen, Technical
A-A-59155	Nitrogen, High Purity, Special Purpose

DEPARTMENT OF DEFENSE SPECIFICATIONS

MIL-PRF-87260	Foam Material, Explosion Suppression, Inherently Electrostatically Conductive, for Aircraft Fuel Tanks

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-411	Aircrew Station Alerting Systems
MIL-STD-464	Electromagnetic Environmental Effects Requirements for Systems

(Copies of these documents are available online at http://quicksearch.dla.mil or from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia PA 19111-5094 USA.)

G.2.2.2 Other Government documents, drawings, and publications.

The following other Government documents, drawings, and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

AIR FORCE SYSTEMS COMMAND DESIGN HANDBOOKS

AFSC DH 1-6	System Safety
AFSC DH 2-2	Crew Station and Passenger Accommodations
AFSC DH 2-3	Propulsion and Power

(Copies of these legacy documents are available to qualified users. Contact AFLCMC/ENRS, BLDG 28 RM 118, 2145 MONAHAN WAY, WPAFB OH 45433-7017 USA; DSN 674-5476; COMMERCIAL (937) 904-5476; ENGINEERING.STANDARDS@US.AF.MIL.)

U.S. ARMY, U.S. NAVY, AND U.S. AIR FORCE TECHNICAL REPORTS

USAAVLABS-TR-65-18	Rapid Gelling of Aircraft Fuel Accession Number AD0629765
USAAMRDL-TR-71-22	Crash Survival Design Guide
USARTL-TR-79-22E	Aircraft Crash Survival Design Guide, Volume V – Aircraft Postcrash Survival
AFWAL-TR-80-2031	Flame Tube and Ballistic Evaluation of EXPLOSAFE Aluminum Foil for Aircraft Fuel Tank Explosion Protection
AFWAL-TR-80-2043	Evaluation of EXPLOSAFE Explosion Suppression System for Aircraft Fuel Tank Protection
WL-TR-95-3039 SURVIAC TR-95-010	Halon Replacement Program for Aviation, Dry Bay Application, Phase I—Operational Parameter Study
WL-TR-95-3077 SURVIAC TR-95-011	Halon Replacement Program for Aviation, Aircraft Engine Nacelle Application, Phase I—Operational Parameters Study
AFRL-VA-WP-TR-1999-3068 WL-TR-97-SURVIAC-97-028	Aircraft Engine APU Fire Extinguishing System Design Model (HFC-125)
WL-TR-97-3066 SURVIAC TR-97-029	Aircraft Engine/APU and Dry Bay Fire Extinguishing System Design Model (HFC-125)

FEDERAL AVIATION AGENCY TECHNICAL REPORT

FAA ADS - 24	Crashworthy Design Principles

(Copies of these documents are available at www.dtic.mil and https://www.dtic.mil to qualified users; Defense Technical Information Center, 8725 John J. Kingman Rd., Suite 0944, Ft. Belvoir VA 22060-6218 USA.)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION TECHNICAL REPORTS

NACA TN 2996	Appraisal of Hazards to Human Survival in Airplane Crash Fires
NACA TN 4024	Appraisal of the Hazards of Friction-Spark Ignition of Aircraft Crash Fires

(Contact the NASA STI Information Desk about availability of these documents at http://www.sti.nasa.gov/find-sti/; NASA STI Information Desk, Mail Stop 148, NASA Langley Research Center, Hampton VA 23681-2199 USA.)

G.2.3 Non-Government publications.

The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

ASTM INTERNATIONAL

ASTM D5632/D5632M	Standard Specification for Halon 1301, Bromotrifluoromethane (CF_3Br)

(Copies of this document are available from www.astm.org; ASTM International, 100 Barr Harbor Drive, West Conshohocken PA 19428-2959 USA; and from www.ihs.com to qualified users.)

SAE INTERNATIONAL

SAE AS1055	Fire Testing of Flexible Hose, Tube Assemblies, Coils, Fittings, and Similar System Components

(Copies of this document are available from www.sae.org; SAE International, 400 Commonwealth Drive, Warrendale PA 15096-0001 USA; and from www.ihs.com to qualified users.)

G.2.4 Order of precedence.

Unless otherwise noted herein or in the contract, in the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

G.2.5 Streamlining.

The Air Vehicle Subsystems Specification has been streamlined. The documents listed in this appendix which are required for acquisition have the same status as those referenced directly in section 2 (first tier). All other documents referenced through tiering may be used for guidance and information only.

G.3 REQUIREMENTS

G.4 VERIFICATIONS

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G.4.1 Definition

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G.4.4 Subsystem characteristics

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G.4.4.2 Hydraulic subsystem

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G.4.4.3 Auxiliary power subsystem

G.3.4.4 Environmental control subsystem

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G.3.4.5 Fuel subsystem

G.4.4.5 Fuel subsystem

G.3.4.6 Aerial refueling subsystem

G.4.4.6 Aerial refueling subsystem

G.3.4.7 Fire and explosion hazard protection subsystem.

Fire and explosion hazard protection shall be designed into the air vehicle to ensure the safety of the crew and passengers and to provide for the safe recovery of the air vehicle. This protection shall be adequate for all combat and non-combat operating conditions. As a first priority, methods, both inherent and added to the air vehicle design shall be used to prevent the occurrence of fire and explosion. When prevention cannot be adequately or feasibly achieved, methods of detecting and controlling the hazardous effects of fire and explosion shall also be included in the air vehicle design. The methods used and the locations within the air vehicle shall be as stated herein.

REQUIREMENT RATIONALE (3.4.7)

The dangers of fire and explosion on board an air vehicle are among the most serious hazards that can occur. Huge fuel loads, a multiplicity of ignition sources, compromise placement of components and lines, exotic fuels for ancillary units, and the nature of the mission can combine to produce extremely severe hazards to the safety of the crew and the air vehicle resulting in compromise of mission completion. The most effective method of obtaining maximum protection for minimum system penalty is to include fire protection in the designing of the air vehicle. The prevention of fire and explosion is the preferred method of providing protection. This will not always be feasible, so fire and explosion detection and control subsystems will also have to be designed into the air vehicle.

The provision of fire and explosion hazard protection may be based on basic fire safety, or survivability and vulnerability, or both. Therefore, the design, performance, development, compatibility, and verification requirements for fire and explosion hazard protection should be consistent to ensure that all provided protection is compatible. The scope of this document applies the performance requirements herein to all fire and explosion hazard protection provided on air vehicles. The requirement herein to provide protection is limited to non-combat (natural) conditions (basic fire safety) since the requirement to provide protection for combat conditions is additional to basic fire safety, has a different basis, and rightly derives from survivability and vulnerability criteria.

REQUIREMENT GUIDANCE (3.4.7)

The requirement to design fire and explosion hazard protection into the air vehicle is a most important one. It requires that this problem be addressed during all phases of a development program. This, in turn, requires that consideration be given to the fact that the provision of fire (and explosion) safety is an interrelated, two-part effort. One part (basic fire safety) is the provision of protection adequate to eliminate or control all hazards shown by hazard analyses to be inherent to the air vehicle design or resultant to air vehicle systems operation (functioning) are adequate for all non-combat conditions. The other part is the additional protection determined through survivability and vulnerability analyses to be necessary for the elimination or control of hazards resulting from operation of the air vehicle in man-made hostile (combat) environments.

Because of the great difference in the basis to provide protection for non-combat and combat conditions, the requirements to do so are stated in separate documents. This specification requires the provision of protection for non-combat conditions, while the requirements to provide protection for combat conditions are derived from specific weapon system threat requirements.

Designing fire and explosion hazard protection requires that the design, performance, development, compatibility, and verification requirements for fire and explosion hazard protection should be consistent to ensure that all provided protection is compatible. The requirements are to be applied to all fire and explosion hazard protection provided on air vehicles.

The following potential fire zones should be considered for monitoring:

a. power sections and accessory sections of reciprocating engine compartments
b. compressor, burner, tailpipe (if applicable), and afterburner compartments of the turbine engine installations
c. accessory sections of turbine engines, if flammable fluid system components and sources of ignition are both present
d. engine compartments of rocket engine installations
e. auxiliary power plant compartments if not normally occupied
f. compartments containing electrical or electronic equipment in the vicinity of combustibles where such compartments are not normally occupied
g. bay or pods that contain flares for explosives squibs.

Include fuels, flammable fluids, ignition sources, component failure modes and effects, operating environment, mission profile (spectrum), air vehicle complexity, electrical systems, electro-magnetic interference, crew stations, material selection, protective finishes, production processes, maintenance accessibility, maintenance overhaul skills, non-destructive inspection methods, and operating life (air vehicle fleet).

REQUIREMENT LESSONS LEARNED (3.4.7)

Protection design. Basic fire protection safety responsibility for an air vehicle should be inherent with each system design. Each engineer concerned with the design of a system or component should realize its potential to all other affiliated and adjacent items and to the air vehicle as a whole. The work done in the initial stages of design will determine the final degree of fire and explosion hazard protection inherent in a new air vehicle or air vehicle modification; therefore, considerable foresight as to the eventual installation details is necessary. A lack of perception as to the relationship between a source of ignition and combustible materials or flammable fluids may result in a combination which no amount of subsequent redesigning can ever completely remedy. The inevitable design conflicts and the resultant trade-offs and compromises which arise on any new air vehicle should always consider the potential for fire and explosion in order to obtain a sensible balance. For this reason, emphasis should be kept on the thought of fire and explosion hazard protection during preliminary design work. Each engineer responsible for the design of a component of an air vehicle can contribute most satisfactorily to the basic safety of the air vehicle if he has a thorough knowledge of the air vehicle fire and explosion hazard protection problem. The work of the detail designer trying to protect any particular section of the air vehicle from fire and explosion is greatly simplified by considering fire and explosion hazard protection in the preliminary design. Each air vehicle is an individual problem and it should be realized that many factors will affect the decisions in its design.

The basic design concept to be applied consists of, first, minimizing the occurrence of fire and explosion and, second, minimizing the seriousness of those effects of fire or explosion that do occur. This means that the achievement of effective fire and explosion hazard protection entails the critical assessment of the probability of occurrence of events such as a combustible and an ignition source coming together (that is, potential fire and explosion hazards inherent in the air vehicle design), the application of preventive techniques (fire and explosion hazard prevention) in the design of the air vehicle to minimize the occurrence of such events, and the incorporation into the design of the air vehicle of appropriate surveillance techniques (fire and explosion hazard detection) and control techniques (fire and explosion hazard control) to counteract those resultant fire and explosion hazards that do occur.

Knowledge of hazards. Of the three basic elements of fire or explosion (fuel, igniter and oxidizer), two are in or may be in combination throughout the air vehicle. In the normal (non-hazard) situation, each element or double element combination is present under controlled conditions which exclude the remaining element(s) except at the point of use. However, due to malfunction or accident, a given element, or combination, may escape the control conditions. Such uncontrolled presence of basic elements is a hazard that has the potential to result in fire or explosion. Actual fire or explosion can produce any of several resultant hazards, such as heat, flame, overpressure, smoke and toxic fumes. Added to the problem is the necessity for weight limitation. Maximum safety for minimum weight penalty is obtained by designing fire and explosion hazard protection into the air vehicle.

In order to apply fire and explosion hazard protection properly to the air vehicle in the most practical and meaningful manner, each designer should have or acquire knowledge about the physical phenomena of air, other oxidizers or reducing agents, fuels, and ignition sources and their interrelation which lead to ignition. If he does not have the necessary knowledge at his command, he may end up with an unsafe air vehicle or he may be forced to be overly cautious at the expense of performance and cost. The many variable parameters involved in the area of flammability may make it necessary to resort to specially tailored tests for many applications. In order to make these tests meaningful and to arrive at the desired result with the least expense, knowledge of the state-of-the-art is a prerequisite.

Approaches. From the standpoint of overall air vehicle fire and explosion hazard protection, the most important information will be obtained from a fire and explosion hazard analysis (FEHA) which should be developed by the airframe contractor during the design phase. It is important that these analyses be initiated early in the design phase and that they be updated as required during the various other phases of air vehicle development. The contractor in performing a fire and explosion hazard analysis of the air vehicle should carefully evaluate each compartment and determine the potential hazards that may occur. Naturally, fuel and other flammable fluid or vapor leakage should be considered. Oxidizer or reducing agent fluid or vapor leakage may be a consideration on air vehicle having exotic fueled systems. The oxidizer and reducing agents have a greater capability of enhancing a combustion process or ignition source than the natural presence of air. Some oxidizers and reducing agents may combine directly with air vehicle materials. Areas where the above noted fluids and vapors may accumulate in hazardous concentrations should be identified. The presence of ignition sources or the possibility of their occurrence should be identified.

After all potential hazards and their locations have been identified, the contractor should then determine the potential for fire or explosion at each location; that is, the conditions necessary to cause the uncontrolled combined presence of all three basic elements. The air vehicle may then be compartmentalized into various type hazard zones.

a. Normally, two basic types of hazard zones have been defined. They are commonly described as follows:

   1. Fire zones: Fire zones are zones where a single failure of a component such as a flammable fluid line break can result in the potential for fire or explosion (if not the actual event). These zones include compartments wherein separation or elimination of potential ignition sources and flammable fluid and vapor components is not practicable and absolute assurance from ignition cannot be achieved due to proximity with combustion processes, high temperature surfaces, high temperature gas leakage or other unpreventable ignition sources. Fire zones contain sufficient hazards to require fire detection systems and fire control methods, such as fire walls and fire extinguishing systems. Typical fire zones are engine compartments and auxiliary power unit (APU) compartments.

   2. Potential fire zones: Potential fire zones are zones where two failures must occur to result in the potential for fire or explosion. These zones may be further defined according to the basic elements that may be present by design (controlled) and that may be present through malfunction or accident (uncontrolled).

b. Three possible further definitions are as follow:

   1. Flammable leakage and combustible zones. These are zones where flammable fluid or vapor leakage may occur from contained or adjacent lines and equipment or directly adjacent fuel tanks (including oxidizer and reducing agents) and zones in which combustible materials are located. Ignition sources are not contained within these zones. The two failures necessary to cause the potential for fire or explosion may consist of combinations that result in ignition source introduction to the zone or flammable fluid or vapor leakage in the zone. Such zones should be provided with adequate means to minimize the presence of the above noted fluids and vapors, to prevent the spread of these fluids and vapors to other compartments, to prevent the introduction of sources of ignition into these zones, and to prevent the spread of any resultant fire or explosion to other compartments. Examples of these compartments are wheel wells, weapon bays, actuator compartments, wing leading and trailing edge compartments, fuel bladder cell bays, dry bays adjacent to integral fuel tanks, cargo and emergency power unit (EPU) compartments. Where mixtures too rich to burn can be maintained in these compartments throughout all flight regimes, prevention of air circulation rather than ventilation may be employed.

   2. Flammable zones. These are zones within which a flammable mixture may exist during normal operation, as within fuel tanks. Ignition sources are not contained within these zones. The two failures necessary to cause the potential for fire or explosion are both related to introduction or an ignition source into this zone.

Explosion prevention systems are the desired means of protection. However, other fire and explosion hazard protection means should be included in case the explosion prevention system becomes inoperative. Also, other means may be deemed to be sufficient protection, dependent on the intended mission of the air vehicle.

3. Ignition zones. These zones are air vehicle compartments which contain equipment, components, or subsystems which experience has shown should be considered ignition sources during normal operating conditions or which may become ignition sources due to malfunction and, also, regions of the air vehicle which, as a result of normal operation, malfunction, or failure, may be the source of high temperature. Flammable fluid or vapor carrying lines or equipment are not normally contained within these zones. Flexible couplings should be shrouded and drained to a safe location outside of the ignition zone. The two failures necessary to cause the potential for fire or explosion are related to flammable fluid and vapor leakage into this zone. Fire and explosion hazard protection that will prevent flammable fluids or vapors from entering these zones should be used. Another consideration is means that will reduce the presence of these fluids and vapors in these zones to a minimum and contain any fire or explosion that may occur. Those zones where high temperature is the problem should be provided with a means of controlling the high temperature and, if overheating is the problem, also with means of detecting this condition. Air cooled electronic bays, electrical bays and potential arcing sources are examples of normal operating ignition potentials. Crew compartments are ignition zones due to food preparation equipment, crew smoking, defogging devices, heaters and high potential electronic equipment. Examples where high temperature can occur are hot air ducts and engine turbine and afterburner sections.

Note that the common descriptions above do not refer to oxidizer or reducing agent leakage. The above descriptions should be modified on an individual basis for those air vehicle that contain oxidizer or reducing agent systems.

To determine the classification of each hazard zone, the contractor should employ an iterative process, whereby protection measures are added and the hazard classification reevaluated until the most acceptable balance of hazard level and required protection is achieved. Where potential fire zones are recognized by a contractor but are not covered in the air vehicle detail specification, appropriate recommendations should be made to the procuring activity.

G.4.4.7 Fire and explosion hazard protection subsystem.

The adequacy of the basic air vehicle design and the integration and proper location of fire protection subsystems to prevent, detect and control fire and explosion hazards and their effects during all non-combat operating conditions shall be determined by a fire hazards analysis. It shall be verified that all hazards and their locations have been determined. The fire hazards analysis should include the following: ___(TBS)___.

VERIFICATION RATIONALE (4.4.7)

The acceptability of the basic air vehicle design to prevent and control the effects of fire and explosion in all areas of the air vehicle should be based on a fire hazards analysis. This analysis will be used to determine the need for and location of fire protection subsystems such as fire detector systems, fire extinguishing systems, and firewalls, and the adequacy of the overall fire protection scheme for the air vehicle.

VERIFICATION GUIDANCE (4.4.7)

TBS: This analysis should be conducted during the design portion of the program so that costly redesigns and modifications are avoided. The type of analysis, its detail and complexity should be appropriate to the phase of the program. In the early phase of a program a preliminary hazard analysis of a general nature would be appropriate. As the program progresses and the design becomes more defined, subsystem hazard analysis, failure modes and effects analysis (FMECA) and system hazards analysis would be appropriate to ensure that unforeseen fire hazards are not overlooked. Review of these analyses should be accomplished during the appropriate program review.

VERIFICATION LESSONS LEARNED (4.4.7)

It should be ensured, early in the program, that the contractor has established a program which will adequately address the problem of fire and explosion hazards. The program should include tasks which identify potential hazards and follow-up procedures which ensure that the identified hazards are eliminated or controlled. Examination, review and analysis of the air vehicle, the air vehicle mockup (if available), and appropriate contractor performed analyses, inspections, tests and demonstrations are essential to ensuring that the requirements of this specification have been met by the contractor. The procuring activity should review the FEHA compartment classification to ensure that the criteria are properly applied and examine available data, analyses and mockups to substantiate classification of the compartments. Procuring activity inspections should be scheduled at least at the mockup inspection and at the completion of the first complete experimental air vehicle. Depending on the complexity of the required protection, additional inspections may be appropriate.

The ideal implementation of this specification is that the procuring activity receives full compliance with no compromises and no deviations. However, in actuality, the procuring activity is restricted by two fundamental situations:

a. Many of the systems are air vehicles that come from other sources (such as the Army, Navy, and commercial off-the-shelf (COTS)) where FAA regulations are the controlling documents. In these cases, the procuring activity is not in control at the critical design point and as a rule, it is too late to make major design changes because of their significant effect upon air vehicle schedules and cost. Many times a decision has to be made to accept the risks involved. Coordination with the System Safety Organization is important.

b. Where a weapon system is under the control of the procuring activity, the fire prevention engineers can have a strong voice in the initial design of the air vehicle and verification can be provided through inspections at various points in the development cycle. Many times, it is found that tradeoff decisions have to be made where some other parameter rules against the fulfillment of a specific design requirement because of weight, cost, or prior design success.

G.3.4.7.1 Hazard resistance.

The exposure of a fire and explosion hazard protection subsystem to its related hazard and to any other hazard which may be assumed to occur at its functional location or along its installation routing shall not disable the subsystem's capability to perform its intended function.

REQUIREMENT RATIONALE (3.4.7.1)

Fire protection subsystems should be designed so that exposure to the related hazard or other hazards which could exist at the functional location or along its installation routing will not disable the subsystem to the extent that it cannot perform its necessary functions. The subsystem should include the action components (detectors, agent dispensers), interconnecting wiring, and all necessary components which can be exposed to the hazard(s). Review Navy comments.

REQUIREMENT GUIDANCE (3.4.7.1)

All potential hazards which could occur at the functional location and along the installation routing should be identified and the capability of a subsystem to operate after exposure to these hazards should be verified by test. Usually, the hazards involved are fire and overheat conditions. A 2000°F flame as described in SAE AS1055 has been used successfully in the past to verify the capability of systems and components to withstand fire hazards. It is not anticipated that this requirement will be achievable or practical for all systems; however, the intent can be achieved by the use of redundant components so that, for example, if a portion of a detection system is disabled by a fire, the remainder of the system can detect the hazard.

Potential fire zones with high airflows which are equipped with fire extinguishing systems should be devoid of sheltered areas in the lower quarter of the installations. The use of smooth fireproof inner liners in these areas should be considered. Where a liner is used, the edges should be sealed so that burning fluid cannot penetrate under the liner.

Include flame temperature, time, and air temperature.

REQUIREMENT LESSONS LEARNED (3.4.7.1)

The wiring for the F-111 engine bay fire detection systems is not fireproof in the wheel well area. Fires in the wheel well area have caused false alarms with the engine bay system and have disabled the engine bay systems so that if an engine bay fire did occur, it could not have been detected. Related reports also indicate that fuel shutoff valve wiring external to the F-111 engine bay firewall has been damaged by engine bay fires causing loss of fuel shutoff capability.

Stainless steel or other materials with equivalent fire barrier characteristics have proven to be useful for all portions of fire extinguishing systems within and close to potential fire zones, with the exception of discharge tubing in cargo and baggage compartments, which may be made of aluminum alloy, and valve seals, which may be made of elastomeric materials

The following measures are recommended to prevent the fire extinguishing system from being disabled due to an electrical failure:

a. Complete electrical circuits should be insured by providing direct ground contact for all electrical components such as agent containers, solenoids, and directional valves.

b. Relays should be avoided, if possible, but if relays must be used, two independent relays should be used in such a way that failure of one relay does not cause malfunction of the system.

c. Where practicable, when the discharge triggering device is electrically operated (squib or solenoid), two such devices with two separate and independent electrical circuits from the circuit breaker outward should be provided.

d. A single circuit with single relay is acceptable for protection of equipment which is used on the ground only.

e. Electrical control systems should be designed so that accidental grounding of the circuit through a discharged squib does not cause malfunction of other circuits of the system.

f. Care should be taken to make certain the power supply is not affected by these firefighting control procedures.

The reliability of grounding through tubing or support structure is poor, because the anodized fittings offer considerable electrical resistance

A pressurized fire extinguisher container should be furnished with a safety outlet incorporating a frangible-disc-type diaphragm in order to relieve excessive pressure that may occur in the container. The blowout pressure of the disc should be equal to the container pressure at the maximum ambient temperature plus 50°F, but not less than 210°F. The fusible plug relief setting should be 50°F in excess of the maximum ambient temperature, but not less than 210°F.

G.4.4.7.1 Hazard resistance.

It should be verified by ___(TBS)___ that the fire and explosion hazard protection subsystem shall not be rendered incapable of performing its intended function after exposure to the hazards which could exist at the functional location and along its installation routing. The hazards that could be present should be determined by a fire hazard analysis.

VERIFICATION RATIONALE (4.4.7.1)

To ensure a fire protection system can perform its required function (detection, extinguishing), it should be verified that the related or other assumed hazards will not disable the system.

VERIFICATION GUIDANCE (4.4.7.1)

TBS: Any required analysis and inspection should be done as part of the fire and explosion hazard analysis to determine the protection required for the total air vehicle. The most practical means of verifying a fire protection system's hazard resistance is by laboratory test. Fire protection subsystems and components should be designed to withstand a 2000°F flame per SAE AS1055 for 5 to 15 minutes depending on the subsystem or component location and particulars of the subsystem design (redundant components, for example). Other suitable verification tests should be used for lesser hazards.

VERIFICATION LESSONS LEARNED (4.4.7.1)

A single failure in circuit board for an engine fire control panel resulted in loss of all engines on an operational aircraft.

G.3.4.7.2 Fire and explosion hazard prevention.

Prevention designs intended to preclude or reduce the occurrence of fire and explosion shall be provided in all locations (areas) where potential hazards can exist or result, either directly or indirectly, due to a single failure.

REQUIREMENT RATIONALE (3.4.7.2)

As noted previously, fire and explosion hazard prevention is the preferred method of providing fire and explosion safety. The intent of this requirement is to ensure that prevention designs are applied to all locations within the air vehicle where potential hazards can result, either directly or indirectly, due to a single failure. The need for fire and explosion hazard detection and control will be minimized, reducing the complexity of the total fire and explosion hazard protection required.

REQUIREMENT GUIDANCE (3.4.7.2)

Fire and explosion hazard prevention should not allow the simultaneous uncontrolled presence of the three basic elements of fire and explosion at any given location. Prevention designs are most easily applied to the elements of fuel and ignition. The recommended prevention designs may be generically described as combustible materials hazards reduction, installation hazards reduction, isolation, separation, ventilation, cooling, drainage, electrical bonding, and lightning protection. These are described in the following sections.

Explosions in potential fire zones due to the presence of flammable vapors should be prevented by either adequate drainage or and ventilation. However, explosions in potential fire zones happen occasionally, and precaution should be taken to restrain the consequences of this hazard to the greatest practical extent. For this reason, the compartment walls should be strong enough to withstand a pressure differential of 5 psi. Quick-opening relief holes in the outside wall should be considered to prevent a pressure rise of over 5 psi, if natural relief is not provided. Ducts inside the potential fire zones should be designed to prevent a failure caused by an explosion, such as collapse of an intake duct or an exhaust pipe, to the extent that a safety-of-flight hazard is prevented.

Provisions should be made to the fullest extent practicable, such that carry-on combustibles necessary for the mission of the air vehicle and the comfort of the crew should not present a fire hazard. A thorough application of fire protection to an air vehicle should consider the combustibles that may be carried on by the crew. Provide storage areas in habitable compartments as necessary for stowage of items such as blankets, pillows, maps, manuals, magazines, newspapers, and other similar combustibles. Provide suitable storage areas in galleys for food packages. Design these areas so that ignition of the contents cannot occur from light bulbs, matches, smoking materials, or other heat sources. Provide closed, fire resistant containers for waste materials. Provide smoking facilities in the form of an adequate number of fire-proof, self-contained, removable ash receptacles with covers. If compartments without smoking facilities are desired, these compartments should be placarded against smoking.

REQUIREMENT LESSONS LEARNED (3.4.7.2)

Low observable (LO) design criteria which minimize outer mold line penetrations have negatively impacted capability to provide ventilation and drainage.

G.4.4.7.2 Fire and explosion hazard prevention.

Fire and explosion hazard prevention shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.7.2)

The provision of prevention designs in all required locations is of greatest importance to the provision of adequate fire and explosion hazard protection on the air vehicle. The need for a prevention design in a given location is dependent on the probability of occurrence of the uncontrolled presence of two of the three basic elements of fire and explosion in that location.

VERIFICATION GUIDANCE (4.4.7.2)

TBS should be filled in with analysis and inspection.

During the appropriate system design review, it should be determined by analysis and inspection that all necessary locations are provided with prevention designs. This analysis and inspection should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle.

VERIFICATION LESSONS LEARNED (4.4.7.2)

Verification of fire and explosion hazard prevention should be considered safety critical.

G.3.4.7.3 Isolation and separation of combustibles and ignition sources.

Separation designs shall be used to the fullest practical extent to prevent occurrences of fire and explosion due to the uncontrolled presence of combustibles and ignition sources.

REQUIREMENT RATIONALE (3.4.7.3)

Separation is an effective method of preventing the occurrence of fire and explosion.

REQUIREMENT GUIDANCE (3.4.7.3)

The general concept of isolation and separation is to require two independent failures to occur before a fire or explosion takes place. Separation is normally used together with one or more of the other designs listed in this paragraph. Separation designs have been applied to combustible materials, flammable fluids and vapors, ignition sources, and oxidizer and reducing agents. It is therefore mandatory that the greatest possible separation between flammable fluid components and ignition sources be accomplished when components are involved which are safety-of-flight items.

a. One separation design is locating lines and equipment to minimize the possibility of leaking fluid coming into contact with ignition sources through either the effect of gravity, airflow, or internal line pressure. All flammable fluid lines are best routed below electrical equipment and lines. Do not route flammable fluid lines through air inlet ducts or plenums and do not route electrical wiring through drain lines. Fuel lines should not be routed through personnel, baggage, or cargo compartments; however, in some instances, an occupied portion of the air vehicle is the only space available for routing of an aerial refueling line or a ferry tank fuel line. In this situation, fuel lines should be double walled and couplings should be shrouded and drained to a safe location. Means to inspect these lines and couplings should be provided so the primary failure mode can be inspected and repaired.

    1. Avoid routing flammable fluid equipment, lines, and joints through inhabited areas, unless: they are enclosed in a fluid- and vapor-tight shroud which is drained and ventilated overboard, or they do not incorporate fittings and are sufficiently well-protected against damage, or the joints in the lines are held to a minimum, and the joints are shrouded and drained. Avoid routing wiring and flammable fluid lines in baggage and cargo compartments, unless such wiring and lines are installed as to be protected from damage by cargo being loaded, carried or shifted. The conduits or covers for lines which have connectors within the cargo area should be drained overboard.

    2. Do not locate sources of fuel leakage, such as joint couplings, in the vicinity of materials or conditions that will permit ignition of fuel. This separation design may also apply to fuel tanks by not locating fuel tanks over personnel compartments. Fuel tanks should not be located in personnel or cargo compartments on a permanent basis. Fuel tanks used on a temporary basis (e.g., cargo tanks or weapons bay fuel tanks) should employ the same design criteria as permanent tanks. Double walls with ventilated and drained spaces between the tanks are applicable.

    3. Design the fuel vent system to prevent spillage of fuel. During the fuel system venting operation, the fuel and fuel vapor should clear all parts of the air vehicle so that no fire or explosion hazard results. Ensure that fuel or fuel vapor does not impinge upon or reenter any part of the air vehicle. The inclusion of hot refueling in the air vehicle mission is an important consideration in locating fuel vent and dump provisions.

b. Another separation design is to prohibit equipment, components, or lines in a fire zone unless they are required for the operation or functioning of equipment contained in this zone. Specifically, do not allow flammable fluid lines, including vent lines, to penetrate any engine compartments except the ones they feed. Apply the separation design noted in paragraph a., above, and position flammable fluid lines relative to engine components and engine bleed air ducts in a manner that will minimize the fire hazards associated with fluid leakage through normal and accidental means. Route plumbing and wiring such that no lines pass unnecessarily close to high temperature components. Also in this separation design is the use of an engine-driven accessory gearbox which is separated from the engine by a liquid- and vapor-tight fire barrier (see G.3.4.7.20). Special consideration of power transmission shaft penetration through the fire barrier shall be considered to ensure a safe design.

This use of separation will reduce the potential for fire or explosions and improve the effectiveness of extinguishing agents. This design uses engine mounted accessories only where these accessories are directly necessary to the operation of the engine; that is, the fuel pump, oil pump, and ignition equipment. All other accessories, such as the hydraulic pump and generator, are mounted on a gearbox and damage to any of these accessories or the gearbox does not affect the operation of the engine. With proper installation design, this system is well adapted to power plant quick change and fire extinguishing in the necessary section.

These separation designs may be applied to oxidizer and reducing agent lines and systems to reduce the possibility of severe or difficult fires or explosions. This is done by separating oxygen lines from fuel, vapor (vent) and electrical lines, and hot surfaces and by separation of exotic fueled ancillary units (EPU, APU), which is best effected by compartmentation. These types of units have been placed in compartments that completely separate the unit from the rest of the air vehicle.

Separation design consideration should be given to the location of flammable fluid carrying lines and accessories to minimize the likelihood of perforation by high energy fragments from an uncontained rotor failure. Potential sources of such fragments include the secondary effect of compressor failures, starter rotors, and other high speed rotating parts. In particular, separation designs are appropriate to: avoid circumferential routing of flammable fluid carrying lines in the plane of a high speed rotor; minimize or group flammable fluid carrying lines that cross planes of a high speed rotor; and, whenever possible, locate such lines and accessories remote to the starter or other components with high speed rotating parts.

A fire and explosion hazard will exist if pathways exist for flammable fluids or vapors to reach ignition sources or for burning fluids or vapors to travel to other parts of the air vehicle. Liquid proof and vapor proof barriers are the best means of providing this isolation. This design is applicable to the flammable fluid tanks, engine compartments and the air vehicle proper. The intent is to restrict the spread of flammable fluids and vapors from controlled to uncontrolled places within the air vehicle. Flammable fluid tanks located adjacent to personnel, cargo, engine, electrical equipment, ammunition and ordnance compartments should be separated from such compartments by a second liquid proof and vapor proof barrier, in addition to the barrier provided by the fluid and vapor storage compartment. This will reduce the fire hazard from flammable fluid leaks caused by normal means or accidents. This precaution may be applied to bomb bays which contain flammable fluid tanks that can be jettisoned.

The engine installations of all air vehicles, regardless of the number or relative position of the engines, should incorporate a liquid and vapor barrier which separates the accessory and compressor areas or that section of the compartment which contains the greater part of the flammable fluid lines and accessories from any engine surface which exceeds a temperature of 700°F. The intent of this barrier is to prevent flammable fluid and vapor contact with the hot sections of the engine. If it is not practical to isolate engine surfaces which exceed temperatures of 700°F, the accessories and drives should be remotely located and isolated from the engine compartment. Isolate flammable fluid system components from electrical equipment that may produce arcing either normally or accidentally in order to minimize the possibility of flammable fluid ignition.

Separation design has been extended to baggage and storage compartment lighting. Locate these lights or protect them so that they will not be an ignition hazard to material placed in these compartments. Apply separation to plumbing, wiring and component supports. Never use flammable fluid, flammable vapor, or oxidizer or reducing agent lines to support these or any other item. Another design is to separate items which have high surface temperatures from combustible materials through the use of insulation. This design may be extended to cover conditions that may result from accident or damage. These designs can consist of fire shields and insulation wraps or blankets and have been applied to items such as bleed air lines and monopropellant emergency power units (MEPU). The material used should be suitable for extended use at the expected maximum temperatures. Another isolation design is the use of explosion proof electrical equipment. This design should be applied to electrical equipment located in potential flammable fluid leakage areas except for flammable zones (i.e., fuel tanks) where containment methods should be used for components located within the fuel tank. Explosionproof aeronautical equipment is designed to prevent ignition of a flammable mixture within the equipment when operated or to prevent an internal explosion from propagating to the exterior atmosphere under operational environmental conditions as defined in the air vehicle model specification.

The requirements for fuel tank isolation, drainage, and ventilation should be applied to fuel tanks in weapons bays, cargo bays, or other locations where temporary fuel tanks are located.

REQUIREMENT LESSONS LEARNED (3.4.7.3)

Burning fluids will occasionally run out the end of exhaust pipes. Positive provisions should be made either to let this fluid run free and clear of the air vehicle to the ground, or to trap and drain it within the adjacent structure.

Aluminum oil coolers and other heat exchangers for flammable fluids, and their air intakes, should be separated from the engine compartment by stainless steel, titanium sheet metal not less than 0.015 inch thick, or other vapor- and liquid-proof materials. Oil coolers and other heat exchangers for flammable fluids should be located as low as practical in a power plant installation so that fluid cannot enter the air intake system in case of a failure. Oil coolers should not be located in the hot engine section.

Engines arranged in close proximity to each other should be separated by a firewall.

Drain openings should be provided and arranged to prevent any potential leakage of flammable fluid from passing through the shaft seal and entering an electrical actuator in the position of installation. Such leakage should not impinge on or otherwise contact an ignition source. Electrical actuators should be explosion-proof.

No lines and equipment carrying flammable fluid should be located in the plane of the turbine wheels, or aft and close to the fuel injection nozzles, except that lines may cross these areas in a longitudinal direction when necessary.

Hot bleed air ducts and other hot gas ducts and components which can be an ignition source, due to high surface temperatures or to leaking hot air or gas, should not be located in compartments containing flammable fluid components with potential leakage, in compartments adjacent to fuel tanks, or in compartments into which leakage of flammable vapor from other compartments is likely.

Portions of heating air ducts passing through regions in the air vehicle where flammable fluid systems are located should be so constructed or isolated from such systems that failure or malfunction of the flammable fluid system components cannot introduce flammable fluids or vapors into the heating airstream.

Locate exhaust systems as high in a compartment and in the air vehicle as practical. Flammable fluid equipment, tanks, and lines should be kept remote from exhaust systems.

Where shrouds cannot be used for the separation of exhaust systems from flammable fluid components, sandwich-type or other suitable insulation blankets may be used for covering the hot exhaust surfaces. They should be designed and installed so that all surfaces, edges, cutouts, and seams are effectively sealed to prevent the entrance of flammable fluids and should be vented and drained at their lowest point. The vent and drain holes should be shielded, if required, to prevent entrance of liquids. The insulation material should be "non-packing" under service conditions. Insulation should be attached to the exhaust system so that a "single failure" of an attachment will not cause an ignition hazard.

As flight altitude increases, turbine engine exhaust wake fans out to a wider effective area, so caution should be taken that exhaust does not impinge on unprotected surfaces or create a hazard by coming close to flammable fluid and vapor drain, vent, and dump outlets.

Discharge of exhaust should not impinge on unprotected surfaces, on the skin of integral tanks, or other places where a hazard may result during normal operation, or when a failure occurs. Exhaust should not pass over access doors and filler wells, and it should be remote enough from flammable fluid and vapor vents and ventilation and fuel jettison outlets to avoid a hazard. Drain discharge should not create a hazardous condition when in contact with exhaust gases under any condition of air vehicle maneuvering.

G.4.4.7.3 Isolation and separation of combustibles and ignition sources.

Isolation and separation of combustibles and ignition sources shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.7.3)

The use of this prevention design to the fullest extent practicable is necessary in reducing the need for detection and control provisions. The adequacy of the provided designs should be verified to eliminate poor designs and avoid costly retrofits.

VERIFICATION GUIDANCE (4.4.7.3)

TBS should be filled in with analysis, inspection, component tests, on-aircraft tests, or demonstrations.

The required analysis and inspection should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle. Laboratory, component, ground and flight tests, and demonstrations may be used to verify the provided separation designs.

VERIFICATION LESSONS LEARNED (4.4.7.3)

Aerial refueling receptacle bays may contain fuel from receptacle leakage. Wiring and electrical components need to consider isolation methods.

G.3.4.7.4 Cooling and ventilation.

Ventilation designs shall be used to the fullest extent practicable to prevent the occurrence of fire and explosion due to the uncontrolled presence of combustibles and ignition sources.

REQUIREMENT RATIONALE (3.4.7.4)

Ventilation is an effective method of preventing the occurrence of fire and explosion.

REQUIREMENT GUIDANCE (3.4.7.4)

Ventilation is commonly used in combination with cooling and drainage and is normally used together with one or more of the other designs listed herein. Ventilation designs have been applied to flammable fluids and vapors, and oxidizer and reducing agents. Ventilation uses airflow to prevent the accumulation of flammable, reactive, or corrosive vapors and explosive vapor-air mixtures within air vehicle compartments. This design is applicable to all compartments in the air vehicle where hazardous fluid or vapor leakage can occur.

a. Incorporate ventilation provisions adequate to remove all hazardous vapors to a safe location outside of the air vehicle during all expected flight and ground conditions. The ventilation should be designed to lean out flammable mixtures below the lower limits of flammability, minimize dwell time of flammable fluid and vapor on hot surfaces and reduce environmental temperatures. One to three air changes per minute have proven to be adequate, whereby the lower value applies to compartments with only low leakage rates are expected and the higher values apply to compartments with potential high leakage rates, which can be the case in power plant accessory sections.

b. Consider leakage from normal means as well as accidental damage when sizing and locating ventilating provisions. Locate ventilating air intakes so that flammable, reactive or corrosive liquids and vapors and engine exhaust gases cannot enter the system.

c. Do not permit system flow reversals or no flow conditions during any ground or flight condition; provide unidirectional airflow under all conditions.

d. Ensure that vapors that are removed from the air vehicle do not come in contact with the engine exhaust gas wake or wheel brakes or impinge on or reenter the air vehicle under any operating condition and cause an unsafe condition. The one exception to this is that engine compartment ventilation, may, of necessity, have to contact the exhaust gas wake.

e. The air intake(s) location should not be susceptible to ice accretion. If ice formation is critical to an extent that airflow is adversely affected, ensure that the intake has suitable ice protection.

f. In compartments divided by liquid and vapor barriers, provide separate air intakes for each compartment and ensure that there is no air exchange between these compartments.

g. Air from other ventilation systems may discharge into fire zone compartment(s) provided the air temperature is 200°F or less and cannot be contaminated with flammable, reactive, or corrosion vapors which may result from any form of leakage throughout any flight attitude or engine operating mode. Ensure that airflow used to ventilate any fire zone compartment or exotic fueled ancillary power unit (APU, EPU, or SPU) compartment is discharged overboard and is not discharged into any other ventilation system.

h. The ventilation provided for dry bay spaces around the fuel tanks and enclosing flammable fluid lines and equipment is a useful means, along with drainage, for checking the integrity of the primary flammable fluid and vapor barrier. Normally, these dry bays are closed compartments and the primary barrier cannot be viewed. The presence of vapors at the ventilation exit is an indicator that the primary barrier has failed. This use of ventilation is especially important in the case of fuel tanks located over engine compartments or other fire zones.

i. Ventilation of auxiliary power plant compartments should be provided in flight, regardless of the power plant being used or not in flight. If an exhaust ejector is used to provide ventilation for an auxiliary power plant compartment, protection should be provided against ignition of flammable fluids and vapors by the exhaust or exhaust pipes, or by the hot turbine after shutdown.

j. Cooling is commonly used in combination with ventilation and is normally used together with one or more other designs. This design is applicable to all compartments and other areas of the air vehicle where hot surfaces can exist and present ignition hazards. The cooling provided should be of sufficient capacity to ensure that all established temperature limits within the air vehicle are not exceeded under any operating condition. This includes the temperature of the installed item, any accessory equipment, the supporting structure and the compartment itself. Engine and power unit compartments and nacelles are a main area of application of cooling designs. Compartments with electronic, electrical installations and equipment, and those with armament installations are areas of concern. Consider hot surfaces caused by normal means as well as accidental damage when sizing and locating cooling provisions. Locate the cooling air intakes so that flammable, reactive or corrosive liquids and vapors and engine exhaust gases cannot enter the system. Do not take cooling air from the engine air inlet duct or plenum except engine fan ducts. Air from fan ducts has been used to cool engine components. Provide for unidirectional airflow under all ground and flight conditions. Do not permit system flow reversals or no flow conditions during any ground or flight condition. Ensure that flammable, reactive or corrosive vapors removed from the air vehicle with the cooling air do not come in contact with the engine exhaust gas wake or wheel brakes or impinge on or reenter the air vehicle under any operating condition and cause an unsafe condition. The one exception to this is that engine compartment cooling air, may, of necessity, have to contact the exhaust gas wake.

k. Ensure airflow used to cool any fire zone compartment, or compartments housing equipment such as oil coolers, generators, inverters, electric motors or exotic fueled power units is discharged overboard and is not discharged into any other cooling system.

REQUIREMENT LESSONS LEARNED (3.4.7.4)

All compartments containing flammable fluid components with potential leakage, compartments adjacent to fuel tanks, and compartments into which flammable vapor can enter from other compartments should be ventilated if these compartments also contain potential ignition sources such as electrical equipment.

Exhaust ejectors have been used successfully for the cooling of exhaust pipes and the ventilation of compartments. This method is particularly suitable for helicopters and auxiliary power plants where ram air is not available in all flight and ground phases. When exhaust ejectors are used which draw the cooling air from compartments containing flammable fluid components with potential leakage, protection should be provided against ignition of flammable fluids and vapors by the exhaust or exhaust pipes, or by the hot turbine wheel after shutdown.

Ventilation inlets should be so located that flames cannot enter from other zones. Ventilation inlets to potential fire zones and to other compartments containing potential ignition sources should be located so that flammable fluids and vapors cannot enter. The inlet air to these compartments should not pass over or through any device containing flammable fluid, such as heat exchangers. The inlet air, under condition of failure, should not contain flammable fluid or vapor. Ventilation air inlets to a potential fire zone should have fire shutoff valves, if the airflow from a single inlet is higher than 5 cu.ft./min, and if fire extinguishing is provided for the zone.

Ventilation discharge from potential fire zones should not impinge on surfaces of integral tanks, on critical structure, or on equipment, if such impingement can cause an additional hazard in case of fire. Ventilation discharge from potential fire zones should not enter any other compartment or re-enter the air vehicle through openings downstream of the discharge. Ventilation discharge from compartments containing flammable fluid components and from compartments adjacent to fuel tanks should not discharge or re-enter into compartments with potential ignition sources.

The ventilating airflow should be distributed as evenly as practicable throughout the compartment with emphasis on high airflows at areas of potential flammable fluid leakage.

Openings should be provided in engine compartments which provide natural convection ventilation during ground operation. Ground support equipment or fans may be required to ensure safe ventilation during maintenance in rotary wing air vehicles. Ventilation by ram air cannot be accomplished for all flight conditions. Ventilation by artificial means such as exhaust or bleed air ejectors, or engine or electric motor driven fans should be applied. Ventilation airflow through two or more compartments, which can carry a hazard from one compartment to another, should be avoided. Such interconnection is prohibited from passing through fire barriers which isolate potential fire zones from the rest of the airplane.

G.4.4.7.4 Cooling and ventilation.

Cooling and ventilation shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.7.4)

The use of this prevention design to the fullest extent practicable is necessary to reduce the need for detection and control provisions. The adequacy of the provided designs should be verified to eliminate poor designs and avoid costly retrofits.

VERIFICATION GUIDANCE (4.4.7.4)

TBS should be filled in with analysis, inspection, and ground and flight tests.

The required analysis and inspection should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle. Laboratory, component, ground and flight tests, and demonstrations may be used to verify the adequacy of the provided ventilation designs.

Demonstration is the best means of verifying that none of the exhausted vapors reenter any portion of the air vehicle or cause any other unsafe condition.

VERIFICATION LESSONS LEARNED (4.4.7.4)

It is important that the maximum ambient temperature environment to which each item (engine, equipment, structure) in a hot surface location may be exposed be determined for all periods of air vehicle flight operation, ground operation and after engine shut down. The manufacturer's temperature limitations for the engine, and equipment should be complied with. In establishing post-shutdown temperature limitations, consider that a gas turbine engine together with its usual installation orientation does not lend itself to pronounced convective circulation of cooling air. Post-shutdown cooling may be further restricted due to adverse operating conditions such as blowing dust or salt spray which will require that all openings in the air vehicle be covered as soon as possible after engine shutdown. Post-shutdown temperature limits should be satisfied without the use of auxiliary ground cooling equipment since such may not always be available or its use may not be practicable.

Ventilation and cooling tests have been conducted in the past in accordance with legacy Military Specification MIL-T-25920 procedures.

G.3.4.7.5 Drainage.

Drainage designs shall be used to the fullest extent practicable to prevent the occurrence of fire and explosion due to the uncontrolled presence of combustibles and ignition sources.

REQUIREMENT RATIONALE (3.4.7.5)

Drainage is an effective method of preventing the occurrence of fire and explosion.

REQUIREMENT GUIDANCE (3.4.7.5)

Drainage is useful for eliminating combustible, conductive, reactive or corrosive fluid leakage build-up and will assist in preventing the accumulation of flammable, reactive or corrosive vapors within the air vehicle compartments. It is often used in conjunction with a companion design, ventilation, and is normally used together with one or more of the other designs. This design is applicable to all compartments in the air vehicle where hazardous fluid leakage can occur. Incorporate drainage provisions adequate to remove all hazardous fluid leakage to a safe location outside of the air vehicle during all expected flight and ground conditions. Places that have historically required drainage are engine compartments, particularly the accessory section and the afterburner ducts during non-operation of the engine; ancillary power units; bladder tank cavities; dry bay spaces around fuel tanks and enclosing fuel, oil, and hydraulic lines and equipment; sheet metal pockets and traps; and other similar places. Drainage is an inherent part of rapid shutoff and purge systems such as those used for fuel at engine manifolds. Drainage is a positive solution to quick engine shutoff, if the risk of self-ignition is not serious.

Consider leakage from normal means as well as accidental damage when sizing and locating drainage provisions. Provide a sufficient number of drain holes in pylons, bulkheads, stiffeners and skin that should permit the normal flow of leakage to collect at low points and exit from the bottom of the fuselage, nacelle, wing or pylon. Locate the drain openings in areas where the local air streams are such that drained fluids should exit freely and should not be driven back into the drained compartment or any other compartment during any ground or flight condition. A rear scoop may be necessary on drains to ensure that back flow of air should not occur and carry the drained liquids or their vapors back into the compartment. All drains should be located so that scavenging suction is produced in flight. Insure that drains are installed so that no drainage should come into contact with a potential ignition source (such as APU or EPU exhaust, the engine exhaust gas wake or wheel brakes) or impinge on or reenter the air vehicle under any operating condition and cause an unsafe condition. The minimum ventilating air flow in fuel tank compartments with potential ignition sources should be one air change per minute.

The minimum recommended internal diameter for drain holes and lines is 9.5 millimeter (mm) ($^{3}/_{8}$ inch). Smaller sizes have a tendency to clog. When single drain holes are used for an entire compartment, the size should be increased accordingly. For example, when a single drain opening is used for the entire engine accessory section drain system, it should be sized to accommodate all leakage including that resulting from equipment failure. The minimum recommended size in this case is 13 square centimeters (cm^2) (2 square inch (in^2)) free area. Drain size openings may need to include LO design requirements.

Do not permit drain lines to be interconnected where return of any fluid or vapor may create a fire hazard or damage any interconnected components. Specifically, engine combustor drains, pressurizing and dump valve drains, and afterburner or tailpipe drains should not be connected with each other or any other drain.

Do not interconnect fuel drains with component seal drains or with drain lines for electrical accessories which drain oil, hydraulic fluid, or water-alcohol. However, drain lines for each particular type of fluid may be joined at the overboard point provided it can be shown that there is no feedback from one to another. These drains may be interconnected if line sizes are made adequate to ensure proper drainage. Therefore, it is permissible to run all normal drains from fuel pumps through one drain, enlarging it to maintain the minimum 13 cm^2 (2 in^2) free area.

The drainage provided for dry bay spaces around fuel tanks and enclosing combustible fluid lines and equipment is a useful means, along with ventilation, of checking the integrity of the primary flammable fluid and vapor barrier. Normally, these dry bays are closed compartments and the primary barrier cannot be viewed. Leakage of the contained fluid appearing at the drain is an indicator that the primary barrier has failed. This use of drainage is especially important in the case of fuel tanks located over engine compartments or other fire zones.

The function of drains should be assessed for all operating conditions including static ground, taxi, and all inflight conditions. Ensure delta pressure from inside the aircraft to the outside ambient conditions is in the right direction to ensure efficacy of drains.

REQUIREMENT LESSONS LEARNED (3.4.7.5)

Minimum drain angles should be greater than 5° throughout the normal range of flight and ground attitudes. All drain lines should be free of traps. Drainage provisions should be designed so that pressure differentials and correlative airflows across the drainage paths do not alter the gravity flow and prevent proper function of the drainage provisions. No drain lines should be manifolded together except at the point of overboard discharge. In cases where manifolding is necessary, pressure differentials in drained compartments or equipment cavities and their possible cause of a fire or explosion, and the ability to identify drained fluids should be carefully considered. Drained fluids which are manifolded should be compatible. Minimum diameter of drain lines and drain holes should be 3/8 inch inner diameter for gravity flow.

For fixed wing Navy air vehicles, a container should be provided for collecting fuel drainage. The container should be designed and located so that flammable vapors from the container cannot enter an engine compartment or any other compartment which contains potential ignition sources, and that the fluid in the container cannot be ignited. If the possibility of ignition in the container cannot be eliminated, the drainage system should be designed to contain a fire without causing a hazard to drained components.

All compartments containing flammable fluid components should be drained, unless leakage from these components is extremely unlikely. All areas surrounding fuel tanks should be drained. All drains should be so arranged so that no trapped fluid can accumulate at any place in the compartment. Cavities in flammable fluid components should be drained if leakage into these cavities is possible and this leakage can cause an ignition hazard, as in components in which separation of flammable fluids from electric equipment is accomplished by seals or bellows. All filler unit scuppers which can collect spilled fuel should be provided with drains.

G.4.4.7.5 Drainage.

Drainage shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.7.5)

The use of this prevention is necessary to reduce the need for detection and control provisions. The adequacy of the prevention designs should be verified to eliminate poor designs and avoid costly retrofits.

VERIFICATION GUIDANCE (4.4.7.5)

TBS should be filled in with analysis, inspection, and component and flight testing.

The required analysis and inspection should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle. Laboratory, component, ground and flight tests and demonstrations may be used to verify the adequacy of the provided drainage designs.

Drains which appear questionable where adequate drainage is concerned, should be subjected to drainage tests. Consider the drain's configuration, location, type, and quantity of fluid drained. Drainage tests conducted with dyed fluids should be used to verify that the performance of all questionable and potentially hazardous drains is acceptable at all applicable air vehicle ground and inflight operating attitudes and conditions. The drains which will require testing and the associated test procedures can be identified from the system analysis. Demonstrate that no fuel or fumes impinge on or enter any portion of the air vehicle or cause any other unsafe conditions under all possible conditions which may be encountered in service. Inspect the air vehicle for the presence of the dyed fluid to insure that there was no impingement. Record data, including movies, during selected operating conditions.

VERIFICATION LESSONS LEARNED (4.4.7.5)

Low observable requirements have influenced the design of drain restricting the type of design that can be used. These conflicting requirements have resulted in poor performance of LO type drains. Ensure LO requirements are considered early in the design phase, and drain types are tested for drain performance and LO requirements.

G.3.4.7.6 Electrical bonding and lightning protection.

Electrical bonding and lightning protection designs shall be used to the fullest extent practicable to prevent the occurrence of fire and explosion due to the uncontrolled presence of combustibles and sources of ignition.

REQUIREMENT RATIONALE (3.4.7.6)

Electrical bonding and lightning protection are effective methods of preventing the occurrence of fire and explosion.

REQUIREMENT GUIDANCE (3.4.7.6)

Electrical bonding and lightning protection are normally used together with one or more of the other designs listed herein.

Electrical bonding should be used to prevent fires and explosions caused by uncontrolled presence of ignition sources from electrical equipment, wiring and static electricity generation.

Electrical bonding methods should be in accordance with the "Electrical interface" requirements defined in JSSG-2001.

REQUIREMENT LESSONS LEARNED (3.4.7.6)

The shell of an air vehicle generally provides satisfactory protection against lightning strikes causing ignition within this shell. There are a few exceptions, however, where precautions must be taken in design to prevent penetration of fuel tank walls, arcing within fuel tanks, and flame propagation through vent lines into fuel tanks.

Some areas on the air vehicle, primarily extremities, have been found to be prone to frequent direct lightning strikes of the type which penetrate air vehicle skins. If fuel must be stored in any of these areas, for justifiable reasons, the following means of protection should be evaluated:

a. The tank skin thickness should be sufficient to carry the electrical current surge of lightning at the points of potential entrance to and exit from the skin, without causing skin penetration due to resistance heating. Skin thicknesses of 0.08 inches seems to give satisfactory safeguard against skin penetration for most lightning strikes.

b. A composite skin structure consisting of the load-carrying skin, a fiberglass cloth layer and an aluminum sheet bonded together. The resistance of such a composite structure to lightning penetration has been demonstrated to be considerably better than for a single aluminum sheet of the same total thickness.

c. Lightning diverters. Lightning current traveling through the fuel tank skin on its path from the point of entrance to the air vehicle to the point of exit, should not cause electric arcs within fuel tanks with the possible consequence of vapor ignition. The use of electrically-conducting gaskets or seals should be considered for all access doors, flanges of filler units, quantity gages, and pumps, in the plane of the skin to ensure a direct and omnidirectional path for the current. If other current bridges are incorporated across openings in the skin, the tendency of inductive current to follow a straight path and the necessity to make the function of the bridge independent of potential maintenance omissions should be considered. The load-carrying capacity of the bridge should not be less than the equivalent of a bonding jumper consisting of tinned copper-stranded cable with a cross-sectional area of 20,000 circular mils. Materials and surface treatments should be selected at joints in the bridge which prevent current-resistant corrosion deposits at the surfaces of contact. Chains or other spark-producing metallic links should not be used for securing filler caps against their loss. Some areas on the air vehicle have been found to be prone to frequent direct or swept lightning strikes which have sufficient energy to ignite fuel vapors emanating from a fuel tank vent line under certain conditions. Fuel tank vent discharge openings should therefore be avoided in the following areas:

1. In the wing plan form area closer than twelve inches to the wing leading and trailing edges, and in the area at the wing tip, and not closer than twelve inches from the wing tip.
2. Within a zone extending behind a propeller which is thirty-six inches wider than the diameter of the propeller.
3. In extremities and protrusions of the air vehicle and in the wake of such extremities and protrusions.
4. Close to any sharp corners, or in the wake of such corners, in vent masts, or in the proximity of static discharge wicks.

If required, flame arrestors of a proven design should be installed in fuel tank vent discharge openings. The flame arrestors should be installed so that the exteriors of the flame arrestors are flushed by the ambient airstream to prevent flames from clinging to sheltered pockets.

If location of fuel vent discharge openings per subparagraphs 1. through 4., above, is not practical; or vent masts must be used; present-day flame arrestors are sufficient protection. A configuration with the vent outlets shielded against direct lightning strikes has proven to be successful in simulated lightning tests where simple flame arrestors failed. Lightning diverters in combination with present-day flame arrestors may also give satisfactory protection, whereby the diverters prevent direct hits to the vent opening, and the flame arrestors protect against potential swept strikes and heat radiation.

Lightning diverters, when used as suggested in the previous paragraphs, should be arranged strategically so that the critical areas or points are shielded from all directions of potential lightning approach. The diverters should be resistant to erosion and to airstream loads, and should carry the current through the diverter base without skin puncture. The tendency of a lightning stroke to be swept away from a lightning diverter by the airflow, or to seek a shortcut, make the design of an effective diverter difficult and testing of every new arrangement almost mandatory.

Under certain conditions lightning discharges have sufficiently steep rates of current rise to produce an inductive potential sufficient to not only cause arcing across fuel tank discontinuities, but also to induce voltages into fuel capacitance gage wiring and into the probes within the tanks. The latter can easily be caused by a strike to a wing tip light or an antenna, if its wiring is contained in the same bundle as the fuel capacitance gage probe. Such induced voltages also can cause inadvertent discharge of a fire extinguisher, or can trigger ordnance equipment. Circuitry prone to lightning strikes should be routed away from other electrical wiring, or should be shielded.

Antenna lead-in wires should incorporate lightning arrestors if they are not sufficiently shielded against lightning by the air vehicle shell.

Pressure fueling inlets to fuel tanks should be sized and designed to minimize fuel splashing. Splashing is an important contributing factor to electrostatic charging of the fuel and can lead to sparking in the tank vapor space.

Fuel dipsticks should be designed to prevent arc-over from a dipstick to tank structure during gaging.

Electric ground receptacles for grounding pressure and gravity fueling nozzles should be provided.

G.4.4.7.6 Electrical bonding and lightning protection.

Electrical bonding and lightening protection shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.7.6)

The use of these prevention designs to the fullest extent practicable is necessary to reduce the need for detection and control provisions. The adequacy of the provided designs should be verified to eliminate poor designs and avoid costly retrofits.

VERIFICATION GUIDANCE (4.4.7.6)

TBS should be filled in with analysis and inspection.

Analysis, laboratory, component and ground tests and demonstrations may be used to verify the adequacy of the provided electrical bonding and lightning protection designs. This should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle.

VERIFICATION LESSONS LEARNED (4.4.7.6)

MIL-STD-464 can be used as a reference for electrical bonding requirements.

G.3.4.7.7 Post-crash fire prevention.

The following shall be applied to the fullest extent practicable to prevent the occurrence of post-crash fire and explosion hazards.

a. Flammable fluid containment features.

b. Ignition source reduction features.

REQUIREMENT RATIONALE (3.4.7.7)

The prevention of post-crash fire is another primary concern in designing-in fire and explosion hazard protection. Records show the casualty rate in generally survivable crashes involving fire is much higher than in those where fire does not result.

REQUIREMENT GUIDANCE (3.4.7.7)

Under crash conditions the fuel onboard an air vehicle is the greatest fire hazard. It is subject to spillage and vaporization and is therefore vulnerable to sources of ignition. These sources are varied and include hot engine compartments, sparks struck from metal impact, and sparks from broken electrical components and circuits. The highly volatile nature of the fuel causes rapid burning, making fire control difficult and casualties likely. Prevention of fuel burning can be accomplished by several methods, such as elimination of ignition source, fuel containment, and alteration of fuel characteristics. The last method, involves changing the characteristics of the fuel to modify its dispersion properties and consequently reducing its susceptibility to ignition and sustained burning during the initial impact and deceleration phase. The following should be considered to minimize post-crash fire and explosion hazards:

a. The air vehicle should be designed to prevent fire and flammable fluid leakage during a wheels up landing.

b. Flammable fluid components should not be located in areas that could be damage during a wheels up landing.

c. Integral fuel tanks in and close to the wing roots are exposed to high bending and twisting loads in a crash landing and should be avoided

d. If fuel tanks must extend close to the bottom of the fuselage, tank fittings and tank accessories should not protrude from the tank surface, or they should be so designed that they tend to recede into the tank without leakage in a crash.

e. Fuselage fuel tanks should not extent close to the bottom of the fuselage and should be protected by bottom structure.

f. Fuel tanks should be located so that a collapsing landing gear does not result in a major fuel tank leak.

g. Wing fuel tanks should be located behind spars and leading edges to provide maximum protection against horizontal crash impact loads. Prevention of major fuel leakage caused by fuel inertia loads in the tanks during a crash landing should be considered in tank design to the greatest practicable extent. Fuel tanks which withstand, without major leakage, the same crash inertia loads as the seats of the occupants are desirable for a balanced crash safety level of an air vehicle.

h. Components and accessories containing flammable fluids should be located where ground contact is impossible avoided in a crash environment. Flammable fluid lines should be routed so they are protected by structure upon impact.

i. Flexible flammable fluid lines with ample slack should be used in areas where deformations are likely to occur in a crash.

j. Metals which have low friction-spark tendency should be used in areas of the air vehicle that come in contact with the ground during a wheels up landing, whenever practicable.

k. The electrical system should be designed so as not to provide an ignition source after a crash. A method for quickly de-energizing electrical ignition sources should be provided.

l. Electrical components should be located and installed in such a manner as to avoid becoming an ignition source.

m. Electrical components should be mounted near heavy structure and away from flammable fluid tanks and lines.

Include fuels and other flammable fluids and their system design and location, electrical system design and location, materials selection, high temperature systems and equipment location, and component failure modes and effects.

Bladder cells should be considered in locations where damage to fuel tanks is likely in a belly landing. Three and a four ply nylon fabric with rubber liner and with plies laminated on the bias have proven to be very suitable for cell construction due to their inherently high elongation values and strength.

Engine nacelles and pylons should be constructed so that fuel leakage from ruptured wing fuel tanks, which is carried spanwise by wetting conduction, is prevented from entering an engine compartment. The nacelle and pylon skin joint with the lower wing surface, and pylon and nacelle skins should be as liquid-tight as practicable to dispose of major leakage of fuel along the fuselage skin to the ground.

REQUIREMENT LESSONS LEARNED (3.4.7.7)

The following paragraphs contain some of the safety guidelines to be employed to give an air vehicle an inherent resistance to post-crash fire hazards. Protective measures may be provided by active system and passive designs for ignition source suppression and by designs for fuel alteration and fuel containment. Generally, the ignition sources which should be considered during a crash episode are electrical sources, hot surfaces, friction sparks, or flames. While fire prevention can be affected by the control of any or all of the three basic elements of fire; prevention designs are most easily and effectively applied to the elements of fuel and ignition sources, hence these two methods are discussed in greater detail.

a. Fuel containment. Containment of air vehicle engine fuel is the most significant means of minimizing or preventing fire fatalities to occupants who have survived a moderate-to-severe crash. During the design phase, ensure fuel containment designs which will result in crash hazards to the air vehicle occupants or permit fuel tanks to be easily damaged are eliminated. Concern should be applied to the areas of the tank location, shape, materials, fittings, and attachments. Apply the designs noted in the guidance for separation (see "Isolation and separation of combustibles and ignition sources" in this appendix), such as prohibition of permanent fuel tanks in personnel or cargo compartments. Consider the fuel containment design criteria contained in USARTL-TR-79-22E, and the documents listed therein. Another recommended document is FAA ADS - 24.

Good initial fuel containment design features can complement the primary strength of the structure and should eliminate the need for modifications that must be included later, adding needless weight and cost.

b. Flammable fluid components and lines. Locate components and accessories containing flammable fluids where ground contact is impossible in a crash environment. Route flammable fluid lines so that they are protected by structure upon impact. Avoid locating fuel or hydraulic lines in the wing leading edge section and utilize flexible lines with ample slack in areas where crash deformation is likely. Consider using breakaway, self-sealing couplings or impact operated shutoff valves in high hazard areas which justify their complexity. Shutoff valves are required in the tank-to-engine lines and consideration should be given to their location and operation. Containment is lost, if the shutoff valves are carried away with detached pod, pylon, or fuel line. Ideally, locate the valves inside the tank at the outlets. Maintainability considerations may preclude this location and a location immediately outside the tank may be required. Shutoff valve operation from the cockpit is usually manual. However, unanticipated emergencies require that more consideration be given to adequate automatic valve operation. Fuel tanks which withstand, without major leakage, the same inertia loads as the seats of the occupants are desirable for a balanced crash safety level of an air vehicle.

   Bladder cells should be considered in locations where damage to fuel tanks is likely in a belly landing. Three and a four ply nylon fabric with rubber liner and with plies laminated on the bias have proven to be very suitable for cell construction due to their inherently high elongation values and strength.

   Engine nacelles and pylons should be constructed so that fuel leakage from ruptured wing fuel tanks, which is carried spanwise by wetting conduction, is prevented from entering an engine compartment. The nacelle and pylon skin joint with the lower wing surface, and pylon and nacelle skins should be as liquid-tight as practicable to dispose of major leakage of fuel along the fuselage skin to the ground.

c. Fuel alteration. Studies are now being made regarding the feasibility of using antimist additives to alter the dynamic dispersion of low volatility fuel in a manner which negates the mist fire and explosion hazards associated with the neat fuel. The additives generally consist of high molecular weight polymers and dramatically affect the number and relative size of fuel droplets formed under dynamic crash or gunfire impact conditions. The combination of a low volatility fuel with this additive provides an excellent approach for minimizing both the fuel vapor and mist fire and explosion threats. Fuel alteration compatibility studies and experimental efforts are presented in the literature. Some of the relevant reports are AGARD CP-84-71, Army Contract DAA 005-73-C-0249 Report 9130-73-112, and USAAVLABS-TR-65-18. Fuel misting additives have been incorporated into military applications. The preceding information is provided for historical purposes only.

d. Hot surfaces. Locate landing lights where they should not be exposed to direct crash impact. It has been verified that the incandescent filament in a landing light is hot enough to provide fuel ignition for a period of 0.75 to 1.50 seconds after the bulb has been broken. Since crash tests using simulated fuels have shown massive fuel spillage in progress as early as 0.20 second after impact, it is readily apparent that this ignition source deserves careful attention for a crashworthy design. A location in the vicinity of the trailing edge is considered satisfactory.

e. Friction sparks. Use metals which have low friction sparking tendencies where ground contact can occur during a crash landing. Hot surface hazards and primary sparking should develop as a result of friction between contacting surfaces during a crash. If the abrading metal produces sparks of high enough thermal energy, ignition is possible. The thermal energy of the spark is a function of bearing pressure, slide speed of the metal, hardness of the metal, and the temperature at which the metal particles will burn.

See table G-I for the minimum conditions under which certain abrading metals will ignite combustible mist. A reduction of the friction spark ignition hazard can best be achieved by selecting materials of the lowest possible sparking characteristics (table G-II), particularly for those areas of predictable crash damage (see NACA TN 2996 and NACA TN 4024).

TABLE G-I. Minimum conditions for ignition of abraded metal particles.

METAL	MINIMUM BEARING PRESSURE lb/in^2	DRAG SPEED m/h
Titanium	21-23	less than 5
Chrome-Molybdenum	30	10
Magnesium	37	10-20
Stainless Steel	50	20
Aluminum	1455*	40

*Ignition was not obtained with aluminum.

(extracted from USAAMRDL-TR-71-22)

TABLE G-II. Sparking characteristics of common construction metals.

MATERIAL	SPARK APPEARANCE	IGNITION CAPABILITY
Aluminum	None	Minimum
Steel	Thin, orange streaks	Possible
Titanium	Bright	Certain

f. Electrical ignition sources. Since the vehicle electrical system extends to virtually every part of the vehicle and since the minimum electrical energy required for ignition is so small (about 0.15 25 milli Joule under ideal conditions), it constitutes an excellent ignition source. Therefore, in the electrical design, provide a method for quickly de-energizing electrical ignition sources, such as batteries, generators, and inverters. Provide for either a pilot or a crash-activated system with adequate precautions included to prevent inadvertent operation. Ensure that the activation time does not exceed 0.20 second.

   Design the system so that all nonessential buses are de-energized and only the emergency DC circuits needed to operate minimum lighting, communication, and crash-fire prevention systems remain energized. Route and protect electrical power lines required for emergency systems to minimize the possibility of crash damage and ignition of any combustible material. In addition, locate the elements listed below outside of the areas of anticipated impact:

   1. Electric batteries. Electric batteries which can be an ignition source should be located where they are unlikely to be exposed to crash damage. Batteries retention should be designed to withstand the same acceleration loads as the crew seats.
   2. Wire bundles
   3. Inverters
   4. Generators and alternators
   5. Magnetos
   6. Radar reflector and related electronics

g. Crash-fire prevention systems. Combine the above elements into an integrated system. Design a crash fire prevention system that provides for rapid inerting of ignition sources (engine and electrical) and prevention of the dispersion of flammables at the moment of crash. The utilization of phenomena peculiar to the crash environment (excessive displacement or structural break) to activate automatic fuel containment measures should be considered. Design electrical circuitry so that a single operation deactivates all circuits which are not necessary for crash-fire emergency operation. Crash-fire prevention system activation circuits can be designed to include any level of automatic and manual interrelationship. Every redundancy adds complexity and only an engineering analysis of a given situation can provide a basis for final selection of a circuit.

G.4.4.7.7 Post-crash fire prevention.

Post-crash fire prevention shall be verified by ___(TBS)__.

VERIFICATION RATIONALE (4.4.7.7)

This verification requirement is dictated by crew safety.

VERIFICATION GUIDANCE (4.4.7.7)

TBS should be filled in with analysis and inspection and should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle. Analysis, laboratory, component and ground tests; and demonstrations may be used to verify the adequacy of the provided post-crash fire prevention designs.

VERIFICATION LESSONS LEARNED (4.4.7.7)

Post-crash fire prevention should be considered a safety-critical condition.

G.3.4.7.8 Fire and explosion hazard detection.

The function of the detection system is to detect a fire, overheat, or explosion and transmit that information to the crew. Hazard detection systems shall be installed in all areas containing power plant installations and areas where the uncontrolled release of energy or combustible materials could result in a fire, overheat, or explosion hazard to the air vehicle or personnel. A separate detector system shall be provided for each fire zone that requires a different emergency procedure.

REQUIREMENT RATIONALE (3.4.7.8)

Although good design practice dictates that all reasonable fire and explosion hazard prevention techniques be employed in the design of an air vehicle system, it is not always possible to prevent the occurrence of fire and explosion hazards to an acceptable level. In these cases, a detection system is required to detect the hazard, provide warning to the crew, and provide for the initiation of automatic corrective action where provided. The intent of this requirement is to ensure detection systems are provided in all the stated locations. Propulsion and ancillary power unit installations are examples of areas where the occurrence of fire related hazards cannot always be prevented.

REQUIREMENT GUIDANCE (3.4.7.8)

While conducting the fire hazard analysis, determine the areas of the air vehicle in which fire and related hazards can occur. These hazard areas are characterized by the existence of a combustible material and an ignition source at an unacceptable level of risk. The hazard of concern at a given location can be excess temperature, fire, explosion (combustion in a confined space with associated pressure rise), smoke, or combustible vapors. The detection system should be able to detect the specific hazard.

REQUIREMENT LESSONS LEARNED (3.4.7.8)

Analysis should be conducted during the design phase to determine if potential hazards exist which require detection and crew warning. The C-5, and F, F-111, and B-1B were both modified with additional detection systems and other fire protection systems in areas which were not previously protected.

G.4.4.7.8 Fire and explosion hazard detection.

Fire and explosion hazard detection shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.7.8)

The need for a detection system in a given location is dependent on the probability of the uncontrolled coexistence of the three basic elements of fire and explosion in that location. Detection systems are required in all propulsion installations because the necessary elements for fire are always present when an engine is operating as has been shown by many years of experience. It should be ensured that these systems are installed where required.

VERIFICATION GUIDANCE (4.4.7.8)

TBS should be filled in with analysis, component tests, ground tests, and inspection.

The required analyses and inspections should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle.

VERIFICATION LESSONS LEARNED (4.4.7.8)

Experience has shown that fire hazards which require a detection system can occur in air vehicle areas, such as wheel wells, weapon bays, accessory drive compartments, avionics compartments, cargo compartments, and around bleed air ducts.

It is a difficult task to determine with absolute certainty whether or not a detection system is required in a certain area other than propulsion installations. The need for a detection system is dependent on a hazard of sufficient probability, which cannot be eliminated or controlled by other design means. In order to preclude the necessity of a modification program because of insufficient detection system coverage, as was the case in the C-5, and , F-111, and B-1B programs, it should be ensured during the design phase that adequate coverage is provided.

G.3.4.7.9 Detection system performance.

The ___(TBS 1)___ detection system(s) installed in ___(TBS 2)___ shall detect ___(TBS 3)___ in ___(TBS 4)___.

REQUIREMENT RATIONALE (3.4.7.9)

The requirements for hazard detection sensitivity, range, and response time can vary depending on the nature of the hazard and location. Detection system performance requirements and the type of hazard to be detected may be different for different areas of the air vehicle. If these requirements are different, then a separate set of requirements should be stated for each location.

REQUIREMENT GUIDANCE (3.4.7.9)

TBS 1 Fill in blank with type of detection system.

TBS 2: Fill in blank with detection system location(s).

TBS 3: Fill in blank with the detection system performance parameters like detection distance, detection temperature, flame size.

TBS 4: Fill in blank with detection system response time.

Fire detection systems should be provided for all potential fire zones. The detector system should be designed for highest reliability to detect a fire and to minimize the occurrence of false alarms. It is desirable that it only respond to a fire and misinterpretation with a lesser hazard such as engine over-temperature, exhaust gas and bleed air leakage should not be possible. If indication of lesser hazard conditions is desirable, an independent system should be used. A fire detection system should be reserved for a condition requiring immediate measures such as engine shutdown, fire extinguishing, or bailout. A separate detector system should be provided for each fire zone. One single detector system may be provided for two or more fire zones if a fire or overheat condition in either zone requires the same emergency procedure. A fire in any zone should be identified to the crew with sufficient information to control the hazard. Fire detection systems should not be incorporated with other systems, which if failed, could prevent normal operation of the detector system.

a. Function. The detector system performance:

   1. The detection systems should be capable of responding to fire and overheat hazards when the compartment is designed to contain these hazards.

   2. The alarm signal should continue as long as the hazard exists.

   3. The fire and overheat detection systems should clear the alarm output when the hazard no longer exists.

   4. The fire and overheat detection systems should reset after alarm clearance and be capable of hazard detection for all subsequent fire or overheat conditions.

   5. Detector system components located within and close to potential fire zones should withstand, without failure, a 2000°F flame for a period not less than 5 minutes.

b. Types of detectors. Fires or dangerous fire conditions should be detected by one or any combination of the following techniques:

   1. Radiation sensing detectors: Radiation detectors operate on the principle of sensing visible flame. They are most useful where the material present will burn brightly soon after ignition, such as in a power plant accessory section.

   2. Continuous-type fire detectors. These detector systems employ continuous lengths of heat sensing wires and can be used wherever the hazard is evidenced by temperatures exceeding a predicted set value. Also, some continuous-type systems operate on a temperature rate-of-rise principle in addition to a discrete level.

3. Unit type. As the name implies, the unit type detector is a single element, which operates on a heat sensing principle. Unit type detectors are most effectively used in small compartments or confined passages.

4. The detector system should be of rugged construction, to resist maintenance handling, exposure to fuel, oil, dirt, water, cleaning agent, extreme temperatures, fire, vibration, salt air, fungus, and altitude or any other natural and induce environment. The detector units should be light in weight, small and compact, and readily adaptable to desired positions of mounting.

Two or more engines should not be dependent upon a single detector system. The installation of common zone detection equipment prevents the detection system from distinguishing between the engine installations, necessitating shutting down both engines in the even of fire.

For the detection of fire and overheat conditions in propulsion and secondary power installations, the vast majority of military and commercial air vehicles utilize temperature sensing systems which were designed in accordance with MIL-F-7872. These systems have a 5-second response to a 2000°F fire when a 6-inch length is heated. The 5-second response is adequate for fire and over-heat hazards when the compartment is designed to contain these hazards.

When it is determined that 5-second response to a fire is not adequate or if it cannot be ensured that the thermal detection can be optimally located to detect the fire, then an optical detection system with a response time and a detection distance should be specified. The specified distance should be compatible with the compartment dimensions and the mounting locations for the detectors. The required detection time is dependent on the allowable fire size and duration. Detection systems which detect infrared (IR) or ultraviolet (UV) radiation from a fire can provide volumetric coverage of distances of 10 feet or more if necessary, with a response time of 1 second or less, down to the millisecond range. These systems can be used to detect fire or developing explosions, but cannot detect an overheat condition. For most fire situations, detection of a 1 foot diameter pan fire at a distance of 10 feet within 1 second should be sufficient. If dual hazards exist which require fast fire detection and over temperature detection, then two systems will be required. Smoke detection systems have been used in cargo compartments, avionics compartments, and other areas of the air vehicle where a fire hazard may exist in class A materials. Smoke detection systems are an FAA requirement and should be required for Air Force air vehicle if FAA certification is necessary.

Heat sensing fire detector sensing elements should be located as close as practicable to sources of flammables such as fuel strainers, and ignition sources such as generators and alternators, where the proximity of these flammables and ignition sources constitute a possible source of fire. They also should be located at points where the ventilation air leaves the compartments so that temperature indication can be obtained with a minimum length or minimum number of sensing elements. Radiation detectors should be located such that any flame within the compartment is sensed, considering the cone of vision of the sensor and the fact that direct flames as well as reflected flames are sensed. Detectors should not be located directly adjacent to combustion sections or any area where in the event of “burnthrough,” the high temperature would incapacitate the system prior to providing alarm. They should however be located so that they will indicate the “burnthrough.”

REQUIREMENT LESSONS LEARNED (3.4.7.9)

Diodes should not be used to separate the detector systems.

Types of detectors. Fires or dangerous fire conditions should be detected by one or any combination of the following techniques:

a. Radiation sensing detectors: Radiation detectors operate on the principle of sensing visible flame. They are most useful where the material present will burn brightly soon after ignition, such as in a power plant accessory section.

b. Continuous-type fire detectors. These detector systems employ continuous lengths of heat sensing wires and can be used wherever the hazard is evidenced by temperatures exceeding a predicted set value. Also, some continuous-type systems operate on a temperature rate-of-rise principle in addition to a discrete level.

c. Unit type. As the name implies, the unit type detector is a single element, which operates on a heat sensing principle. Unit type detectors are most effectively used in small compartments or confined passages.

The detector system should be of rugged construction, to resist maintenance handling, exposure to fuel, oil, dirt, water, cleaning agent, extreme temperatures, fire, vibration, salt air, fungus, and altitude or any other natural and induce environment. The detector units should be light in weight, small and compact, and readily adaptable to desired positions of mounting.

Detector system components located within and close to potential fire zones should withstand, without failure, a 2000°F flame for a period not less than 5 minutes.

Detector system components for any fire zone should not pass through or be close to other fire zones, unless they are protected against false warnings and being rendered inoperative from fires in such zones. This requirement should not be applicable with respect to zones which are simultaneously protected by the same warning and extinguisher system.

The minimum allowable bend radius of continuous type sensing elements, as recommended by the manufacturer, should be adhered to. Mounting brackets should be as short as possible, and spaced according to the manufacturer's recommendation in order to prevent damage by vibration. Where sensors are located in the area of high pressure ratio exhaust systems, special provisions, such as close interval support should be made to prevent destructive-sensor vibration.

Sensor systems should be designed so that it is not necessary to disassemble or remove sections to perform frequent maintenance on the air vehicle. Connectors should be readily accessible.

Connectors used in firewalls should remain intact and prevent flame penetration for at least 15 minutes when exposed to a 2000°F flame and the vibration of application. Firewall connectors and connectors used in or close to potential fire zones should be able to remain operable for at least 5 minutes when subjected to a 2000°F flame and the vibration of application. All connectors used in the detector systems should be environment-free. Exposed terminal blocks should not be used in any portion of the system.

Electric wires or components for the detector system which are located in or close to a fire zone should withstand a flame of 2000°F for 5 minutes under the vibration of application.

G.4.4.7.9 Detection system performance.

Detection system performance shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.7.9)

The detection capability (response time, detection distance) should be verified to ensure that the fire hazard can be detected in sufficient time to allow for corrective action and safe recovery of the air vehicle.

VERIFICATION GUIDANCE (4.4.7.9)

TBS should be completed with analysis, component tests, on-aircraft tests, and inspection.

The required analysis and inspection should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle. Detection system performance can most easily be determined by laboratory test.

VERIFICATION LESSONS LEARNED (4.4.7.9)

Fire detection response time should be used as part of a fire timeline to determine total time that a fire hazard condition may exist on an aircraft.

G.3.4.7.10 Detection system failures.

In the event a critical detection system(s) fails in a manner that the intended hazard can no longer be detected, the system shall provide an automatic system fail indication to the crew. All detection systems shall have a manual test feature which will allow the crew to determine if the system is operational. All propulsion installation fire detection systems and the following systems are considered critical: ___(TBS)___.

REQUIREMENT RATIONALE (3.4.7.10)

The ability of a hazard detection system to function is important to the overall safety of the crew and air vehicle. Therefore, the pilot or some other crew member should have the capability to determine if the detection system(s) can perform its intended function at the beginning of a mission and at other times if deemed necessary. In certain situations, the inability to detect a hazard may be a necessary bit of information to the pilot or crew. In this situation, an automatic fail indicator should be provided. A means to determine which detection systems are critical should be established and accomplished.

REQUIREMENT GUIDANCE (3.4.7.10)

TBS should be filled in with a list of critical systems.

The detection system should provide an automatic indication to the crew in the event of a failure of the detection system (fault evident). The detection system should be designed so that no single system fault should leave a potential hazard area without detection.

While the fire hazard analysis is being conducted during the design phase, a determination of critical hazard detection systems which require an automatic fault warning for the crew should be made. Include the hazard criticality and potential consequences of undetected hazard.

REQUIREMENT LESSONS LEARNED (3.4.7.10)

Long-term maintenance damage or wear and tear as well as sudden catastrophic failures such as an engine turbine disk failure can cause the detection system to fail in such a manner that a fire cannot be detected.

G.4.4.7.10 Detection system failures.

It shall be verified by __(TBS)__ that in the event a critical detection system(s) fails in a manner that the intended hazard can no longer be detected, that the system provides an automatic system fail indication to the crew.

VERIFICATION RATIONALE (4.4.7.10)

Fire detection systems are required to ensure safety of flight. It is necessary to be able to conduct a preflight test to ensure that the system is capable of providing this necessary function. This is presently a standard feature on Air Force systems. However, these systems can fail in flight without the crew knowing that a safety of flight system is non-operational. The crew should be informed of this situation.

VERIFICATION GUIDANCE (4.4.7.10)

TBS should be filled in with analysis, component tests, on-aircraft tests, and inspection.

The required analysis and inspection should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle. The existence of system failure indication features and manual test features can be determined by analysis and inspection during the appropriate system design review. The actual performance of these failure indication systems can be verified by laboratory test.

VERIFICATION LESSONS LEARNED (4.4.7.10)

False indications of a fire in a USAF bomber resulted in crew ejection from an aircraft when no fire occurred.

G.3.4.7.11 Detector output.

The detection system(s) shall provide an alarm signal output which is suitable for interfacing with the appropriate crew warning systems and any provided automatic fire control system or the respective explosion suppression system. Each individual detection system shall interface with a separate crew warning device, unless the multiple systems convey the same information to the crew and result in the same crew action.

REQUIREMENT RATIONALE (3.4.7.11)

It should be ensured that the necessary system interfaces are considered and provided early in the program so that costly redesign will not be required. Separate crew warning devices are required for warning systems requiring separate crew actions in order to prevent confusion.

REQUIREMENT GUIDANCE (3.4.7.11)

The detection systems should provide an alarm signal output that interfaces with the appropriate cockpit warning system. Alarm outputs from detection systems for separate hazards that require different procedures should not be combined into a common alarm signal.

During the appropriate design reviews during the preliminary design phase, inspections should be conducted to ensure that the necessary crew warning interfaces are provided.

Include the crew warning system and system test.

The above requirements have been standard practice for many years although not formally stated.

Each detector system should actuate an individual light or lights which are in the direct line of sight of the crew member responsible for execution of the emergency procedure. The lights should indicate the location of the fire. If these indicator lights are not also in the direct line of sight of the remaining cockpit crew members, master warning lights should be provided which are in the direct line of sight of these crew members. The master warning light should be illuminated when any indicator light is illuminated.

Detector output interfaces and displays should be coordinated with cockpit working groups to ensure that pilots or crew have an opportunity to provide inputs to the design.

REQUIREMENT LESSONS LEARNED (3.4.7.11)

Failure to include pilot/crew inputs on the design has resulted in redesign of systems after deployment.

G.4.4.7.11 Detector output.

It shall be determined by inspection and analysis that an alarm signal has been provided to warn the crew of a hazard detection and that this output is suitable as the input to the appropriate crew warning system and any required automatic fire control system or the respective explosion suppression system. The inspection and analysis will verify that the alarm outputs from detection systems for separate hazards which require differing emergency procedures have not been combined into a common alarm signal.

VERIFICATION RATIONALE (4.4.7.11)

Inspection and analysis are required during the design phase to ensure that the required and desired system interfaces are developed and maintained.

VERIFICATION GUIDANCE (4.4.7.11)

The required analysis and inspection should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle. Ensure the necessary verification inspections are conducted.

VERIFICATION LESSONS LEARNED (4.4.7.11)

Detector output and performance should be considered a safety-critical function.

G.3.4.7.12 False alarm.

The detection system(s) shall not produce a false alarm due to system failure or exposure to normal or expected ambient environmental conditions.

REQUIREMENT RATIONALE (3.4.7.12)

All hazard detection systems should provide dependable and reliable detection of hazards in order that the crew can quickly perform the necessary emergency procedures. The integrity of the system will be compromised if the design, installation, and integration of a hazard detection system into an air vehicle results in multiple false alarms. This can result in the hesitation of crews carrying out necessary emergency procedures as well as costly mission delays and aborts. Normal or failure conditions, which are not hazards, should not cause an false alarm.

REQUIREMENT GUIDANCE (3.4.7.12)

The detection systems should not produce a false alarm due to any single system fault or exposure to normal environmental conditions. Non-environmental factors such as component failures, faults, or wire shorts should be considered required.

REQUIREMENT LESSONS LEARNED (3.4.7.12)

The United States Air Force (USAF) has had a wide range of experience with false alarm rates on air vehicle detection systems. The F-4, T-38, and F-111 experienced high false alarm rates, while the C-9, A-7, and A-10 air vehicles have experienced low false alarm rates. The F-4, T-38, and F-111 were all difficult installations, because installation clearances were minimal, resulting in a high probability of damage to detectors and wiring. These air vehicles required the use of numerous sensors, connectors, and interconnecting wiring which increased the potential for maintenance and installation damage.

G.4.4.7.12 False alarm.

It shall be determined by analysis, component tests, inspections, and ground tests, that the detection system will not produce a false alarm when exposed to normal or expected environmental conditions.

VERIFICATION RATIONALE (4.4.7.12)

The surest means of determining if a detection system will not have false alarm problems is by an extended service test in the air vehicle while operating under the most severe conditions for the particular detection system. Prototype or full scale development testing may be necessary. If air vehicle testing is not possible, then a series of laboratory tests should be conducted under the most severe conditions (defined via analysis) that can occur in the air vehicle which may cause a false alarm.

VERIFICATION GUIDANCE (4.4.7.12)

The required analysis and inspection should be part of the fire and explosion hazard analysis done to determine the protection required for the total air vehicle. Environmental conditions can be tested in the laboratory to determine if false alarms result. If a new detection concept is being contemplated, flight-testing should be considered. It could also be verified by analysis per similar systems' performance that the acceptable false alarm rate will not be exceeded.

VERIFICATION LESSONS LEARNED (4.4.7.12)

The lack of strict attention to detail during the design of detection system installation has resulted in poor performance from the standpoint of false alarms in some USAF air vehicles.

G.3.4.7.13 Detection set point.

The alarm set point of the ___(TBS 1)___ detection system shall be ___(TBS 2)___.

REQUIREMENT RATIONALE (3.4.7.13)

The selection of the alarm set point of a hazard detection system is a tradeoff between detection sensing and the probability of false alarms. If the alarm set point selected is too low, detection time and sensitivity will be improved; however, normal ambient conditions may result in an alarm. If the alarm set point is too high, false alarms will be less likely, but the hazard may not be detected in a timely manner. The trade-off between sensitivity and tendency to false alarm should be based on the criticality of the potential fire hazard. The alarm set-point may be dictated by other performance requirements.

REQUIREMENT GUIDANCE (3.4.7.13)

TBS 1 should be filled in with the type of detector (i.e., IR, UV, smoke, vapor, or other).

TBS 2 should be filled in with the detector alarm set point. The alarm set point should be established as high as possible without causing the system sensitivity or response time to be adversely effected. For thermal detection systems, previous practice has been to set the alarm point 150-250°F above the maximum expected temperature which would be sensed by the detection system. This philosophy should preclude false alarms due to higher than expected normal temperatures, hot day environments, or due to minor non-hazardous leakage of hot gas or air from the propulsion installation. This same philosophy should be applied to other types of detection systems such as IR, UV, smoke, vapor, or other detection systems to ensure normal and non-hazardous conditions do not result in a system alarm. This requirement should also include ambient environmental conditions and desired detection response time.

REQUIREMENT LESSONS LEARNED (3.4.7.13)

Improper detection set point of the F-4 fire detection may be a major source of false alarms on that air vehicle. Testing conducted by Ogden Air Logistics Center indicated that engine bay temperatures equal to or slightly exceeding the nominal fire detector set points can exist for short time periods under certain flight conditions.

G.4.4.7.13 Detection set point.

The alarm set point of the detection system should be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.7.13)

Some means of establishing an alarm set point should be specified to ensure acceptable system sensitivity without unnecessary tendency for false alarms.

VERIFICATION GUIDANCE (4.4.7.13)

TBS should be filled in with analysis, inspection, and ground tests. The verification should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle. The surest method of properly establishing the alarm set point is by conducting an instrumented flight test under the worst case environmental and flight conditions. If this is not practical during the design phase, the set point should be established by analysis or from engine qualification tests. Instrumented flight tests should then be conducted on one of the first prototypes or production air vehicles. During the appropriate system design review, it should be determined, by inspection and analysis, that an appropriate alarm set point has been established.

VERIFICATION LESSONS LEARNED (4.4.7.13)

Lack of verification testing on the F-4 air vehicle resulted in the detection system set point being too close to normal operating temperatures. More recent designs have successfully defined the alarm rate so that few false alarms are experienced.

G.3.4.7.14 Detection indication clearance.

The ___(TBS 1)___ detection system shall clear the alarm output when ___(TBS 2)___.

REQUIREMENT RATIONALE (3.4.7.14)

Information that a hazard no longer exists is necessary information for the crew, as is the warning of the initial hazard. All systems require the capability to inform the crew, within a reasonable period of time, when the hazard being detected no longer exists. This will provide vital information of the effectiveness of any hazard control procedures that may have been employed and whether or not additional actions are necessary.

REQUIREMENT GUIDANCE (3.4.7.14)

TBS 1 should be filled in with the type of system (for example IR, UV, smoke, vapor, or other)

TBS 2: It is desirable that the alarm output clear as soon as possible after the hazard has terminated. Temperature sensing systems have to cool down and the time required is a function of thermal mass and differential temperature. A 30-second time has been specified in the past for this type of system. UV, IR, and other types of systems may be able to clear the alarm in a shorter time.

REQUIREMENT LESSONS LEARNED (3.4.7.14)

A fire timeline is a useful tool to determine the total time that a fire hazard may exist. This time line should start with initiation of the fire through all procedures available to the crew to eliminate the hazard.

G.4.4.7.14 Detection indication clearance.

Detection indication clearance shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.7.14)

Detection indication clearance should be verified by analysis, component tests, on-aircraft tests, and laboratory test. The laboratory test should simulate air vehicle conditions as much as possible.

VERIFICATION GUIDANCE (4.4.7.14)

TBS: The analysis and inspection should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle. Detection systems which utilize different detection techniques may require different clearing times.

VERIFICATION LESSONS LEARNED (4.4.7.14)

System integration tests on the air vehicle should be conducted during qualification as well as during Acceptance Testing.

G.3.4.7.15 Detection repeatability.

The detection system(s), after ___(TBS 1)___ resets, shall be capable of ___(TBS 2)___ hazard detection.

REQUIREMENT RATIONALE (3.4.7.15)

The detection system should be a resetting type in order to provide warning in the event the hazard reoccurs after a period of remission.

REQUIREMENT GUIDANCE (3.4.7.15)

TBS 1: A minimum required number of resets should be specified. A minimum of 3 is recommended.

TBS 2: If reduced detection performance is allowable after the detection system is exposed to the hazard, it should be stated.

The detection system should not require manual resetting.

Include the hazard type and hazard damage potential to detection systems.

REQUIREMENT LESSONS LEARNED (3.4.7.15)

Ensure that a fire time line is prepared including reset times of the detection system. The fire timeline can be used to define other requirements such as containment, ventilation, and suppression requirements.

G.4.4.7.15 Detection repeatability.

Detection repeatability shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.7.15)

The most practical method to determine alarm repeatability is by laboratory test.

VERIFICATION GUIDANCE (4.4.7.15)

TBS: The required analysis and inspection should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle. A minimum number of alarm cycles should be specified if the system does not have an unlimited reset capability. The verification test setup should be representative of the actual installation and actual hazard being detected.

VERIFICATION LESSONS LEARNED (4.4.7.15)

Detection reset times are faster with optical sensor versus eutectic salt or pressure devices.

G.3.4.7.16 Fire and explosion hazard control location.

Control systems and designs shall be provided for all areas which are fire or explosion potential areas and those adjacent areas as required to ensure effective hazard control.

REQUIREMENT RATIONALE (3.4.7.16)

It is not always possible to prevent the occurrence of fire or explosion hazards to an acceptable level, even though all reasonable prevention techniques have been employed in the design of the air vehicle. Generally, there are areas of the air vehicle where all three basic elements of fire and explosion are present simultaneously and a single failure will result in fire or explosion (fire and explosion potential areas). Additional protection in the form of fire and explosion hazard controls will be required in these areas. This control may need to be extended to adjacent areas to ensure effective protection. The intent of this requirement is to guarantee that control systems and designs are provided in all stated locations.

REQUIREMENT GUIDANCE (3.4.7.16)

Distinct examples of fire and explosion potential areas (historically known as fire zones) are the propulsion and ancillary power unit installations. By analysis and inspection, it can be determined to what other areas hazard control should be extended. Fuel tank dry bays, electronic bays and cargo compartments have been provided with control methods on past and present air vehicles. Areas or hazards of concern at a given location can be excess temperature, fire, explosion, smoke, and toxic vapors, including the space available for control systems and design installations.

Fire extinguishing systems which incorporate a second discharge line should be designed so that the first discharge is directed to its respective compartment without requiring positioning of valves to select the compartment.

The discharge openings of the lines should not be threaded so as to minimize the possibility of closure by caps which could be left on by oversight.

Stainless steel or other materials with equivalent fire barrier qualities should be used for all portions of extinguishing systems within and close to potential fire zones. Exceptions are discharge tubing in cargo and baggage compartments, which may be of aluminum alloy, and valve seals, which may be of an elastomer material. This material should not react chemically with the extinguishing agent to cause leakage.

The containers should be readily accessible for installation, removal and inspection. Containers should be located in such a manner that the pressure gage is readily visible for inspection by maintenance personnel.

Control systems for fire extinguisher systems should not pass through any potential fire zone. Any portion of the controls which must be located in a potential fire zone for justifiable reasons should be able to operate for a period of no less than five minutes when subjected to a 2000°F flame without failure. The fire extinguishing system may be electrically or mechanically controlled.

Electrical components and circuitry of fire extinguishing systems should be as simple and reliable as possible. When electrical components and circuitry are located in fire zones, they should be able to operate for at least fifteen minutes when subjected to a 2000°F flame without failure. They should also integrate into the air vehicle electrical system so that any other electrical failure will not affect the operation of the system. Complete electrical circuits should be ensured to provide direct ground contact for all electrical components such as agent containers, solenoids, or directional valves. The reliability of grounding through tubing or support structure is poor because the anodized fittings offer considerable electrical resistance. Relays should be avoided if possible. If relays must be used, two independent relays should be used in such a way that failure of one relay does not cause malfunction of the system. When the discharge triggering device is electrically operated (squib or solenoid), two such devices with two separate and independent electrical circuits from the circuit breaker outward should be provided. A single circuit with single relay is acceptable for protection of equipment that is used on the ground only. Electric control systems should be designed so that accidental grounding of the circuit through a discharged squib does not cause malfunction of other system circuits. Care should be taken to make certain the power supply is not affected by fire control procedures.

Squibs in container discharge valves should be protected against inadvertent discharge due to heat influx from a fire if such a discharge jeopardizes the intended function of the extinguisher system. Any squib should be an integral part of the electrical connector or other provisions should be made to ensure that the squib(s) cannot be left out when the connector is attached to the container.

REQUIREMENT LESSONS LEARNED (3.4.7.16)

A fire extinguishing systems which incorporates a second discharge line should be designed so that the first discharge is directed to its respective compartment without requiring positioning of

valves to select the compartment.

Seal materials should not react chemically with the extinguishing agent and cause leakage

Ambient temperature around the container should neither rise to a point causing inadvertent discharge at maximum ambient operating temperature, nor fall below the minimum temperature necessary for adequate rate of discharge. If the container is located adjacent to the area which it protects and could be subjected to overheating in case of a fire, discharge through the relief line into the protected area is acceptable. Each container should be furnished with a safety outlet incorporating a frangible disc type diaphragm in order to relieve excessive pressure that may occur in the container. The blowout pressure of the disc should be equal to the container pressure at the maximum ambient temperature plus 50°F, but not less than 210°F. The fusible plug relief setting should be 50°F in excess of the maximum ambient temperature, but not less than 210°F.

Use of the main discharge outlet as a means of safety relief is also acceptable.

Pressure indicators should be of such design as to enable reading with accuracy sufficient to determine safe operating levels of the pressure vessel. An indicator with temperature compensation should be used whenever possible. If temperature compensated gages are not used, a placard should be placed near the gage to provide container pressure variations with agent temperature. For example, this placard should be used as follows: When the pressure indication is below the value shown on the placard at the estimated agent temperature, the container should be removed and weighed. If the weight is below the weight indicated on the container, the container should be charged with nitrogen to 600 psi +25 –0 at 70°F as indicated on the container gage.

Each container should be furnished with a safety outlet incorporating a frangible disc type diaphragm or a fusible alloy type plug in order to relieve excessive pressure that may occur in the container. The blowout pressure of the disc should be equal to the container pressure at the maximum ambient temperature plus 50°F but not less than 210°F. Refer to pressure variation as a function of temperature for the agent being used.

G.4.4.7.16 Fire and explosion hazard control location.

It shall be verified by ___(TBS)___ that hazard control designs and systems have been provided in all locations as specified.

VERIFICATION RATIONALE (4.4.7.16)

The provision of control systems and designs in all required locations should be verified to ensure the completeness of the fire and explosion hazard protection provisions.

VERIFICATION GUIDANCE (4.4.7.16)

The need for a hazard control design or system in a given location is dependent on the probability of the uncontrolled co-existence of the three basic elements of fire and explosion in that location.

TBS: During the appropriate system design review, it should be determined by analysis and inspection that all necessary locations are provided with control designs and systems. This analysis and inspection should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle.

VERIFICATION LESSONS LEARNED (4.4.7.16)

Failure of component testing of fire protection control panels has resulted in operational failures which resulted in an aircraft mishap.

G.3.4.7.17 Combustible fluid control.

Provisions shall be made to terminate the flow of flammable fluids and oxidizer and reducing agents into identified compartments. Limit the quantity of these fluids that may enter the compartments when the fluid quantity is sufficient to contribute to the cause, size, and scope of any fire or explosion within these compartments. These provisions shall function in conjunction with any provided fire extinguishing system.

REQUIREMENT RATIONALE (3.4.7.17)

The objective of this requirement is to limit the fire size and duration by cutting off the supply of fluids that can contribute to the fire.

REQUIREMENT GUIDANCE (3.4.7.17)

Normal means to accomplish this is by use of shutoff valves, either electrical or mechanical. This requirement applies to fluids entering the identified compartment. Engine oil and hydraulic system shutoff means are not required for turbine engine installations having integral or engine mounted oil tanks. Traditionally, these engine oil and hydraulic systems have been designed without shutoff valves because inadvertent actuation could result in complete power loss and expensive repairs. These systems are otherwise designed to minimize fire and explosion hazards (see FAR Part 25).

Include the type of fluids to be controlled, availability of space for control location, location chosen for control, control actuation time, control type (mechanical or electrical), material selection and environmental conditions at control location.

REQUIREMENT LESSONS LEARNED (3.4.7.17)

Air vehicles in the past have generally been designed to meet the following criteria:

Special consideration should be given to the location of the fire shutoff valves. For a pylon-mounted engine, the fire shutoff valve should be mounted on the upper end of the pylon. For a fuselage or wing mounted engine, the fire shutoff valve should be mounted as near as possible to the engine compartment, but not in the compartment. Some installations may require both a tank shutoff valve and a fire shutoff valve to minimize the quantity of fuel which can drain into the engine compartment after the valve is closed and to minimize the length of unprotected line which can drain the tank if the line is broken.

Electrically-operated valves should not change position during flight as a result of a short circuit, stray voltage, electrical power failure, or normal mechanical forces. Shutoff valves need not be provided for drain lines and lines used with a closed-loop fluid system peculiar to a system or equipment within the fire zone. For example, the integrated drive generator oil cooling system lines between the generator and the heat exchanger. Fuel fire shutoff valves and their associated wiring should be located so that they will not be damaged in the event of an engine burst or a landing gear failure.

The preferred location for the shutoff valves is outside the fire zone. If the valves are located inside the fire zone they should be able to withstand 2000°F flame for 5 minutes to permit operation of the valve and be capable of remaining closed without internal or external leakage for the duration of the fire. Controls for the shutoff valve that are located inside the fire zone should meet the same fire resistance requirements as the shutoff valve. Hydraulic controls should also meet these fire resistance requirements without leakage of hydraulic fluid.

Oil shutoff valves have been provided for each engine of multi-engine air vehicles. The emergency procedure should incorporate a separate step for closure of the oil valve if engine rotation cannot be stopped and if major damage of the engine can be expected from oil starvation. The control should be such that the oil valve is always open when the fuel feed valve is open.

Shutoff valves actuated by a servomechanism should travel from full-open to full-closed in one second or less. Electric shutoff valves which employ terminal switches for limitation of valve travel should be so designed that reasonable tolerances are allowed for adjustment of the terminal switches. Solenoid shutoff valves should not be used for equipment which is essential for mission performance and should be designed to shut off the flow to a fire zone when failed.

G.4.4.7.17 Combustible fluid control.

It shall be verified by analysis, test, and inspection that fluid control has been provided in all specified locations. The adequacy of the control provisions should be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.7.17)

The lack of this control method in a required location will complicate, if not defeat, the crew actions necessary to control a potential or actual fire hazard. The same is true if the control provisions are inadequate.

VERIFICATION GUIDANCE (4.4.7.17)

TBS: The required analysis, test, and inspection should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle. Functional checkout and adequacy of the control provisions are normally verified by ground tests. Special cases may also require laboratory or component tests. The use of ground tests and demonstrations will determine whether the provisions work as designed without impacting flight safety.

VERIFICATION LESSONS LEARNED (4.4.7.17)

Location of the main fuel shutoff valve was an important consideration for control fuel flow to the engine compartment on a developmental fighter program. Improper access by ground fire fighting personnel resulted in the inability to shut off fuel to a burning air vehicle.

G.3.4.7.18 Ventilation termination.

Means shall be provided to terminate the ventilation or cooling airflow when termination of this airflow will contribute to the extinguishment of fire occurring within specified compartments.

REQUIREMENT RATIONALE (3.4.7.18)

The objective of this requirement is to limit the fire size and intensity by cutting off air to the fire.

REQUIREMENT GUIDANCE (3.4.7.18)

The preferred location for the shutoff devices and controls is outside the fire zone. If they are located inside the fire zone, they should be able to withstand 2000°F for 5 minutes without failure.

Air shutoff valves should be provided for potential fire zones which are equipped with fire extinguishing, for any single air inlet flowing more than five cubic feet per minute of air to a fire zone, unless it can be demonstrated by analysis or test that the airflow is not defeating the effectiveness of fire extinguishing. Bleed air shutoff valves should be provided on multi-engine air vehicles, using an interconnected distribution system, unless the duct is made of stainless steel or titanium not less than 0.015 inch thick, or equivalent material, within the fire zone. The shutoff valve may be a simple check valve or a controlled valve. Shutoff valves should be provided in air ducts which originate in a potential fire zone and lead to another compartment in the air vehicle. Shutoff valves actuated by a servomechanism should travel from full-open to full-closed in one second or less. Electric shutoff valves which employ terminal switches for limitation of valve travel should be so designed that reasonable tolerances are allowed for adjustment of the terminal switches. Solenoid shutoff valves should not be used for equipment which is essential for performance of a mission and should be designed to shut off the flow to a fire zone, when failed.

During a fire emergency, the doors close with actuation of the firewall shutoff valves. However, with the advent of the extinguishing agent concentration analyzer and jet engine installations with low air flow, the need for engine nacelle ventilation shutoff has been almost eliminated. With the analyzer, it is possible to determine agent concentration under air flow conditions. There are still other compartments that may benefit from ventilation shutoff. The use of this control method will need to be determined separately for each particular compartment.

Include availability of space for ventilation termination, location chosen for ventilation termination, actuation time, type (mechanical or electrical), material selection, and environmental conditions at chosen locations.

REQUIREMENT LESSONS LEARNED (3.4.7.18)

Some installations have used cooling air intake doors to achieve nacelle or compartment isolation.

G.4.4.7.18 Ventilation termination.

It shall be verified by analysis and inspection that the ventilation termination required has been provided in all specified locations.

VERIFICATION RATIONALE (4.4.7.18)

The lack of this control method in a required location will complicate, if not defeat, the crew actions necessary to control a potential or actual fire hazard. The same is true when the control provisions are inadequate.

VERIFICATION GUIDANCE (4.4.7.18)

The required analysis and inspection should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle. Ground tests and demonstrations should be used to functionally checkout and verify the ventilation termination provisions. The use of ground tests and demonstrations will determine if the provisions work as designed without impacting flight safety.

VERIFICATION LESSONS LEARNED (4.4.7.18)

Low observable requirements can create unique interfaces for requirements and verification.

G.3.4.7.19 Electrical ignition source control.

Provisions shall be made to de-energize all electrical ignition sources that could contribute to the cause, size, and scope of fire or explosion within specified compartments. These provisions shall function in conjunction with any provided fire extinguishing system.

REQUIREMENT RATIONALE (3.4.7.19)

The intent of this requirement is to limit the sources of electrical ignition or re-ignition in a fire situation.

REQUIREMENT GUIDANCE (3.4.7.19)

In the case of an engine nacelle fire, the generator is normally deactivated and power into the nacelle is cut off. Lesser means may be sufficient for other compartments. Include the location chosen for control, control actuation time; control type (electrical or mechanical), material selection, and environmental conditions at location of control.

REQUIREMENT LESSONS LEARNED (3.4.7.19)

In the past, the shutoff of electrical power was accomplished by deactivating the generator and cutting off power to the affected compartment or nacelle when the fire emergency control was operated. Since electrical arcing and sparking due to electrical faults or subsequent to heat or fire damage could be a source of ignition or re-ignition, these sources are normally eliminated by deactivation. The preferred location of the shutoff devices is outside the fire zone. If the shutoff devices and controls are located inside the fire zone, they should be able to withstand a 2000°F flame for five minutes without failure.

G.4.4.7.19 Electrical ignition source control.

It shall be verified by analysis, inspection, and ground tests that the electrical ignition source control has been provided in all specified locations.

VERIFICATION RATIONALE (4.4.7.19)

The lack of this control method in a required location will complicate, if not defeat, the crew actions necessary to control a potential or actual fire hazard. The same is true if the control provisions are inadequate.

VERIFICATION GUIDANCE (4.4.7.19)

The required analyses and inspections should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle. Ground tests and demonstrations should be used to functionally checkout and verify the adequacy of the electrical ignition source control provisions. The use of ground tests and demonstrations will determine if the control provisions work as designed without impacting flight safety.

VERIFICATION LESSONS LEARNED (4.4.7.19)

It is also important to ensure battery back-up circuits are de-energized.

G.3.4.7.20 Fire barriers.

Fire barriers shall be provided to control the spread of fire between specified compartments and adjoining compartments and areas. The barriers between ___(TBS 1)___ and ___(TBS 2)___ areas shall withstand temperatures of ___(TBS 3)___°F for ___(TBS 4)___ minutes without failure.

REQUIREMENT RATIONALE (3.4.7.20)

Fire barriers are an established extension of isolation used to control fire spread and to control overheating.

REQUIREMENT GUIDANCE (3.4.7.20)

TBS 1, TBS 2: Describe the compartments and areas. Include the barrier location, size and shape, hazards involved (fire or explosion), material selection, particulars of air vehicle construction, and environmental conditions at installed location. Fire barriers can consist of firewalls, fire shrouds, and insulation blankets and can include the air vehicle skin and structure. Appropriate design should be used to ensure that fire barriers will function to prevent the spread of fire.

TBS 3, TBS 4: The materials used in the fire barrier should be fireproof and able to withstand a 2000°F flame for 15 minutes using standard test methods under the environmental conditions that exist at the installed location, especially pressure differentials and vibration.

REQUIREMENT LESSONS LEARNED (3.4.7.20)

Firewalls and fire shrouds are usually made of stainless steel or titanium at least 0.012-inch thick, or other materials of equivalent fireproof capability. Insulation blankets are constructed from various suitable insulating materials with metal foil backing or wrap. The thickness of fire barriers depends on the materials chosen and the particulars of the installed location, especially the presence of structure. In order to prevent blanket expansion due to pressure differentials, provide small shielded vent holes in the cold side foil in areas least susceptible to fuel exposure. The recommended minimum foil thickness for insulation blankets is 0.004 inch. A screen has been incorporated on the cold side of blankets with thin foils to prevent the loss of insulating material from damaged blankets. Use a lacing method that will not decrease the thickness of the blanket due to diametrical expansion of the protected component. Fire barrier connectors and the passage of all plumbing, ducts, wiring, and controls, through fire barriers should be as fireproof as the fire barrier itself. Under no fire conditions should the fire barrier be penetrated by fire because of failure of fittings. Special concern should be given to the location of insulation blankets to bleed air lines. Ensure that the blanket integrity will not be compromised by leaking or ruptured bleed air lines.

The fire barrier should be as tight as possible in order to preclude leakage of liquids and vapors. A hole of 0.040 inches diameter in a firewall 0.015 inches thick can cause propagation of flames through the firewall. Experience has also shown that access doors or joints in fire barriers should be avoided since fire barriers may buckle severely due to heat, resulting in gaps in the fire barrier at the doors or joints. If access doors or joints must be provided in fire barriers for justifiable reasons, they should be closed by closely-spaced fasteners of such type that hazardous gaps will not result during a fire.

The closer the fire barrier must be installed to the outer case of a combustor, the more protection will be required to cope with the torch-like flame resulting from a burned-through combustor. Titanium should not be used for fire barrier material in the vicinity of burner cans, where molten material can drip on it when a burn-through occurs, or when the fire barrier is a vital load-carrying structural member. Fasteners, grommets, and sealants should possess the same fireproof characteristics as the fire barrier material. Fillers should be used sparingly and only where necessary.

Consideration should be given to the difficulties of removing and replacing any movable pieces of airframe which have been sealed with fillers. Structurally loaded fire barriers should be avoided so that early failure will not occur due to the loss of strength even though flame penetration may not be imminent.

Materials used close to the protected side of the fire barrier should be of a type which will not burst into flames as a result of heat conduction or radiation from a fire in the fire zone. Structure and equipment should be protected by insulation, shielding, or cooling if heating due to a fire can cause a safety-of-flight hazard. High-strength fasteners with aluminum components, such as lock-bolts and high-shear rivets, should not be used.

The accessory section of a power plant should be separated from the hot burner, turbine, and tailpipe section by a liquid and vapor-tight fire shield, when practical. It is desirable to govern the pressure of the burner, turbine, and tailpipe section above that of the accessory section to compensate for the lack of complete sealing which may occur after a reasonable service time. The entire fire shield, or portions thereof, may be made of aluminum alloy if the hazard from an existing fire is not increased in case of burn-through. Partial aluminum alloy fire shields, with the rest of the fire shield made of stainless steel, should be considered when local burn-through can be accomplished by proper location of ventilation openings or by burnout panels. Careful consideration should be given to the possibility of high pressures building up in the hot engine compartment in case of a failure which causes release of exhaust gases. Such pressure in combination with the high exhaust temperature could cause penetration of an aluminum fire shield and carry an ignition source into the accessory compartment, thereby increasing the hazard potential.

Engines with high compression ratios may require location of the fire shield forward of the last compressor stage to prevent ignition of leaking flammable fluid by the hot compressor case.

A fire shield should be provided between the hot section and the accessory section of an auxiliary power plant, when practical. The fire shield should be liquid and vapor-tight. It is desirable to govern the hot section pressure above that of the section containing the flammable fluid components.

Whenever satisfactory isolation of exhaust systems from flammable fluid equipment, lines, and tanks by location is not practical, isolation by steel shrouds should be considered. Sufficient distance between exhaust pipe and shroud, plus forced air cooling and insulation if necessary, should be applied to keep the surface on the side of the potential flammable fluid leakage at least 50°F below the minimum autogenous ignition temperature of the flammable fluids involved. The shrouds should be liquid-tight.

Exhaust systems and shrouds tend to warp. Such warping should be considered in the design of exhaust systems so that exhaust and flammable fluid leakages will not occur to cause a fire hazard or a false fire warning signal.

Heat radiation from exhaust flanges and annular heavy sections may be sufficient to directly damage wiring, aluminum alloy structure, and hose assemblies located in the plane of the flange. Adequate shielding or insulation should be provided, if necessary.

The skin and skin structure of potential fire zone enclosures (or portions thereof), or the skin and skin structure adjacent to potential fire zone enclosures (or portions thereof), should be made of stainless steel or titanium, at least 0.012 inch thick, or of equivalent material, if necessary, to protect against the following:

a. Burning of a fire out of a potential fire zone and subsequent burning into non-protected, adjacent areas, around the fire barrier, either through the skin or through openings in the skin.

b. Burning of a fire out of a potential fire zone through the skin and subsequent impingement of flames on vital structure or on integral fuel tanks, if such impingement can cause safety-of-flight hazard. In order to prevent re-entry or impingement of a fire with the minimum use of stainless steel or titanium skin structure, the following should be considered:

    1. Openings such as ventilation outlets in the skin of potential fire zones should be located and designed so that re-entry of flames, or impingement with resulting hazard, downstream of the fire zone cannot occur.

    2. Fire egress should be encouraged at places where re-entry or impingement cannot occur. This can be done by proper location of ventilation openings, or by burnout panels.

    3. Fire penetration is most likely in areas of potential flammable fluid leakage, at ventilation air exits, and at and near the bottom of the compartment. These areas should receive highest attention in a fire containment analysis.

Ensure design of the fire barrier permits ground fire fighting equipment to be used in engine bays or nacelles.

G.4.4.7.20 Fire barriers.

It shall be verified by analysis and inspection that fire barriers have been provided in all specified locations. The adequacy of the provided fire barriers should be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.7.20)

The lack of this control method in a required location will complicate, if not defeat, the crew actions necessary to control a potential or actual fire hazard. The same is true if the control provisions are inadequate.

VERIFICATION GUIDANCE (4.4.7.20)

The required analysis and inspection should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle.

TBS: Laboratory, component and ground tests and demonstrations should be used to verify the adequacy of the provided fire barriers. Unique firewall connectors or passages should be demonstrated to be satisfactory by actual test. The adequacy of fire barriers is normally determined by using the fireproof tests of SAE AS1055. The test fire apparatus per SAE AS1055 produces a test fire with a heat flux of approximately 10 BTU/ft^2/sec. This ideally simulates the heat flux from a typical JP-8 fire with free convection which is nominally 9 BTU/ft^2/sec. Other test fire apparatus such as propane burners only produce heat fluxes up to 6 BTU/ft^2/sec and do not provide an adequate materials test. Pressure differential across the fire barrier should be simulated. These tests will closely simulate a severe in-flight fire and permit an acceptable assessment of fire barrier material. Worst case conditions (airflow, location) should be considered and risk acceptance should not be used in determining barrier requirements.

VERIFICATION LESSONS LEARNED (4.4.7.20)

New spray-on or formed fire barrier materials have proved effective for fire containment which may negate the need for a stainless steel or titanium shield.

G.3.4.7.21 Fire hardening.

Fire hardening provisions shall be used to protect components or systems which if damaged by fire, explosion or overheat conditions, would result in an increased hazard or the uncontrolled propagation of the hazard to other air vehicle compartments. These identified components shall maintain their functional integrity for ___(TBS)___.

REQUIREMENT RATIONALE (3.4.7.21)

In areas of the air vehicle where it has been determined that fire, explosion, or overheat hazards can occur, components, devices, or systems which contain flammable fluids, or oxidizer or reducing agents should be designed or protected in such a way that these components, devices, or systems will not release the flammable fluids, or oxidizer or reducing agents for a specified period of time. By protecting these components from failure other hazardous fluids will not add to the already existing hazard and compound the hazard control problem.

REQUIREMENT GUIDANCE (3.4.7.21)

TBS: It is recommended that the provided fire hardening be required to resist the identified hazard for 5 to 15 minutes. Examples of components or systems to be considered would be fuel and hydraulic lines or components, oil lines or tanks, and airlines or other components which contain materials which would compound the hazard if destroyed by the original hazard. These fire hardening requirements should apply to other flight critical components located in the hazard area such as flight controls, electrical equipment, and critical structure.

REQUIREMENT LESSONS LEARNED (3.4.7.21)

Lines and equipment which carry flammable fluids and are located close to the burner, turbine, and exhaust sections of the engine should be of the highest possible order of reliability and should be fireproof. Tubes carrying flammable fluids in or close to a potential fire zone should be made of stainless steel, or equivalent material. Hoses carrying flammable fluids in or close to a potential fire zone should withstand a flame of 2000°F for at least 5 minutes without leakage, at the lowest fluid flow rate and the highest fluid temperature, and under vibration of operation. Fittings should have an equal resistance to fire. These requirements of fire resistance apply also to vent and drain lines, unless a failure of such lines and fittings will not add to a fire hazard. Hoses for emergency equipment in fire zones should be as fireproof as possible, and they should be routed and protected, if necessary, so that they are not damaged by consequence of the failure which started the fire, thereby incapacitating the hoses when they are needed most.

Shielding of high-pressure hydraulic lines should be considered to minimize the possibility of hydraulic fluid contacting ignition sources by spray. Hose assemblies should be protected by shielding or other means against temperatures in excess of the maximum specified allowable operating temperature for the particular hose.

Oil tanks for auxiliary power plants may be located in their surrounding compartment, but should be designed to withstand a 2000°F fire for ten minutes without leakage.

Combustion air ducts should be of fireproof construction for a distance sufficient to prevent damage from backfiring or reverse flame propagation.

G.4.4.7.21 Fire hardening.

It should be verified by analysis, coupon tests per SAE AS 1005 and inspection that fire hardening as specified has been provided in all specified locations.

VERIFICATION RATIONALE (4.4.7.21)

The lack of this control method in a required location will complicate, if not defeat, the crew actions necessary to control a potential or actual fire hazard. The same is true if the control provisions are inadequate.

VERIFICATION GUIDANCE (4.4.7.21)

The required analysis and inspection should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle. Laboratory, component and ground tests, and demonstrations may be used to verify the fire hardening provisions. SAE AS1055 should be referenced for test methods to determine the capability of items to withstand fire.

VERIFICATION LESSONS LEARNED (4.4.7.21)

Ensure the actual aircraft configuration is used for testing.

G.3.4.7.22 Smoke and other hazardous vapor control.

Means shall be provided for the protection of the crew and passengers from smoke and other hazardous vapors that occur within these compartments or enter these compartments from outside sources.

REQUIREMENT RATIONALE (3.4.7.22)

The dangers to the health of the crew and passengers presented by smoke, toxic products of combustion, fire extinguishing agents, fuels, reducing agents and similar vapors indicate a need to provide the crew and passengers with means of protection from smoke and these vapors.

REQUIREMENT GUIDANCE (3.4.7.22)

Provisions should be made to evacuate smoke and fire extinguishing agent and any other of the noted vapors from crew and passenger compartments. After every discharge of extinguishing agent in the cabin, cargo or baggage compartment, the crew and passenger compartments should be ventilated whether or not smoke is present. In the case of a fire, the smoke and vapors should be evacuated as soon after fire extinguishment as possible. It is desirable that the cabin ventilation system has capacity sufficient to supply fresh air in quantities great enough to allow quick purging of personnel compartments. To prevent re-ignition, ventilation should not be re-established too soon to confined areas, such as lavatories and coat compartments. Means should be provided to close off airflow between crew and passenger compartments. Provisions of smoke masks and goggles for crew members should be considered.

REQUIREMENT LESSONS LEARNED (3.4.7.22)

Ensure commercial-grade electronics (e.g., laptop computers) that are installed aircraft can meet the requirements for smoke and hazardous vapor control.

G.4.4.7.22 Smoke and other hazardous vapor control.

It shall be verified by analysis and inspection that means for the control of smoke and other hazardous vapors as specified has been provided in all specified locations.

VERIFICATION RATIONALE (4.4.7.22)

The lack of this control method in a required location will complicate, if not defeat, the crew actions necessary to control a potential or actual fire hazard. The same is true if the control provisions are inadequate.

VERIFICATION GUIDANCE (4.4.7.22)

The required analysis and inspection should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle. Ground tests and demonstrations should be used to functionally checkout and verify the means provided to protect the crew and passengers from smoke and other hazardous vapors. The use of ground tests and demonstrations will determine if the provisions work as designed without impacting flight safety.

VERIFICATION LESSONS LEARNED (4.4.7.22)

Aircraft that are used for passengers or (including VIP aircraft) may have non-military-qualified equipment installed.

G.3.4.7.23 Overheat control.

Provisions shall be made to control overheat conditions which are of sufficient temperature to cause a hazard to the air vehicle.

REQUIREMENT RATIONALE (3.4.7.23)

Overheat hazards, such as leakage of high temperature bleed air or high temperature gases from an engine or APU can cause serious damage to an air vehicle and various subsystems. If these hazards can occur, there should be a method of terminating the over-temperature condition or protecting against the effects of the overheat condition. Uncontrolled overheat conditions can result in more serious hazards.

REQUIREMENT GUIDANCE (3.4.7.23)

When it has been determined that overheat conditions occur in a given area, it should be ensured that adequate control measures have been incorporated. These control measures could be shutting off the source of bleed air in the case of a bleed air leak or shutting down an engine in the case of a hot gas leak from an engine. In some cases it may be possible to design the equipment or structure to withstand the over-temperature condition.

REQUIREMENT LESSONS LEARNED (3.4.7.23)

Certain older air vehicles such as USAF models of the F-4 have extensive high temperature bleed air systems which do not have an overheat warning system or the capability to shutoff the bleed air in the event of a leak. There have been several cases of serious accident, destroyed air vehicles, and crew fatalities which were directly attributed to bleed air overheat conditions which went undetected and developed into uncontrolled fires.

G.4.4.7.23 Overheat control.

It shall be verified by analysis, inspection, and on-aircraft tests that overheat control as specified has been provided in all specified locations

VERIFICATION RATIONALE (4.4.7.23)

The lack of this control method in a required location will complicate, if not defeat, the crew actions necessary to control a potential or actual fire hazard. The same is true if the control provisions are inadequate.

VERIFICATION GUIDANCE (4.4.7.23)

The required analysis and inspection should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle. Ground tests and demonstrations should be used to functionally checkout and verify the overheat control provisions. The use of ground tests and demonstrations will determine if the provisions work as designed without impacting flight safety.

VERIFICATION LESSONS LEARNED (4.4.7.23)

Overheat control sensors may become part of an integrated mission system on an aircraft and the integrations should be verified.

G.3.4.7.24 Engine and auxiliary power unit compartment fire extinguishing.

Fire extinguishing systems shall be provided for fire control and termination in the engine compartment(s) when fire within these engine compartments cannot be controlled and contained by other lesser means. The system shall provide within the compartment a concentration of agent sufficient to extinguish any fire within a time duration sufficient to minimize damage within the compartment and prevent the spread of the fire to other compartments. This agent concentration shall be maintained within the compartment for a time duration sufficient to prevent reignition of the fire.

REQUIREMENT RATIONALE (3.4.7.24)

The purpose of this requirement is to establish the need and performance requirements for engine compartment fire extinguishing.

REQUIREMENT GUIDANCE (3.4.7.24)

Fire extinguishing systems should be provided in the main power plant installation of all multi-engine air vehicles. Fire extinguishing systems are not required in single-engine air vehicles, except for first procurement of a small quantity of a new model air vehicle.

Spring-loaded fire access doors in main and auxiliary power plants should be provided only if required by the air vehicle model specification. This door should be in such a position that the nozzle of a CO_2 extinguisher can be thrust against the door, forcing it open, and permitting CO_2 to be injected directly into the compartment. The spring should be sufficiently strong to hold the door shut against air loads. Quick-release latches should not be used. The size of the door should be $5^1/_2$ x 10 inches. The door should be located near the bottom, at a point where burning flammable fluid cannot drain on the operator of the extinguisher nozzle. The door should be marked, "Access for Fire Extinguisher." For auxiliary power plants, a door should be provided if a fixed fire extinguishing system is not provided.

Oil tanks for auxiliary power plants may be located in their surrounding compartment, but should be designed to withstand a 2000°F fire for ten minutes without leakage.

The use of halons, as well as other halogenated fluorocarbons, was determined to be associated with the destruction of Earth's ozone layer. Production of halons was stopped in the United States by Presidential decree on 1 January 1994, and no new procurements requiring the use of ozone depleting chemical (ODCs) were allowed by the Department of Defense after 1 July 1993. As a result, the Halon Replacement Program for Aviation was initiated by the U.S. Air Force in collaboration with the U.S. Navy, Army and the FAA, to develop and demonstrate the best available substitutes for halons for air vehicle engine nacelle and dry bays applications.

Under this program, HFC-125 was chosen as the best extinguishant for subsequent development. Details on the experimental program, test conditions, and results that created the data used to develop the design model are outlined in WL-TR-95-3077 (SURVIAC TR-95-011), and associated Phase II and III Wright Laboratory Technical Reports. Reference the AFRL-VA-WP-TR-1999-3068 (WL-TR-97-SURVIAC-TR-97-028) report for the design model developed to facilitate the sizing of air vehicle on-board fire protection system with HFC-125.

"ENGINE NACELLES/AUXILIARY POWER UNITS (APUs) HFC-125 DESIGN EQUATIONS," an extract from AFRL-VA-WP-TR-1999-3068 (WL-TR-97-SURVIAC-TR-97-028) report, reads:

> The engine nacelle is defined as the region surrounding the exterior of the jet engine case, shrouded by an outer cover, and typically ventilated. Auxiliary Power Units (APU) are machinery units that provide supplemental, auxiliary, or emergency power to all or some subsystems of the aircraft.
>
> Limitations: The design formulas has been configured to provide protection for fire events not subject to hot surface re-ignition, as is consistent with the performance of existing halon systems. If hot surface temperatures cannot be avoided (such as insulated bleed air ducts), the duration period required for the design concentration during certification may have to be expanded to the duration of time that the fuel will be expected to be in proximity to the hot surface. Under these conditions, the sizing estimation formula will not be sufficient to assess final sizing requirements.
>
> The sizing formula (used to estimate the expected extinguishant mass required to meet certification standards) features a quantity Xe/(100-Xe) in the second term of the formula (Xe being the required concentration of extinguishant), which is not present in the original halon formulas. This design model process will identify required concentrations in the range from 14.5 percent (14.5%) to 26 percent (26%), depending upon the operating conditions.
>
> Two step design formula process:
>
> a. Calculate the design concentration required using the formula E-1, using relevant values of air temperature, air mass flow rate, and fuel type.
>
>   1. If the range of air temperature and air mass flow rate vary considerably in the flight envelope, several combinations of relevant maximum air temperature and corresponding mass flow rates should be tried to assure the highest air temperature and minimum m air mass flow rate will give a conservative worst case estimate, but could be a slight overdesign.
>
>   2. For this formula the values input for maximum air temperature and air mass flow rate should never be outside the bounds relevant for the formula ((100^{o}F to 275^{o}F) and (0.9- 2.7 lb/sec), respectively). If the actual maximum operating condition is outside of this bound, the closest extreme value should be used. The impact on the accuracy of the results has been shown in experiment to be minimal.

3. If more than one flammable fluid is present in the engine nacelle or APU (such as hydraulic fluids or oils), use the highest fuel constant value corresponding to the fluids present.
4. If a single system protects both one or more engine nacelles and an APU, calculate the required concentration and corresponding mass for either application independently, and use the higher of the two mass requirements.

b. Calculate the expected extinguishant mass requirement, using the concentration calculated in "a.", the volume of fire zone (nacelle or APU) and the actual air mass flow rate (even if outside the bounds considered in “a.”).

c. Design the extinguishant container capacity consistent with current design practice and use mass estimates in "b.", for use in design trade-study comparisons and as a starting point for certification testing.

d. Perform the certification discharge experiments (using existing Halonizer or Statham analyzer equipment as is used for halon systems to measure concentrations real-time, but recalibrated for HFC-125), with the criteria being the attainment of the design concentration calculated in "a." at all measurement points in the nacelle simultaneously for at least 0.5 seconds.

e. If certification is not met, increase the container capacity or modify the distribution system to eventually pass certification.

Concentration Xe Estimation Formula:

Equation E-1:

Xe+ 21.10 + 0.0185 AIRT - 3.124 Wa + 5.174 (Fuel Constant) + 0.0023 (AIRT) x (FUEL CONSTANT) + 1.597 (Fuel Constant)^2

Xe:	certification design concentration
AIRT (^{o}F):	maximum ventilation air temperature in the nacelle or APU during operations
Wa:	internal air mass flow rate in the nacelle or APU during operations
Fuel Constant:	coefficient to account for presence of JP fuel, hydraulic fluids, or oil

The variables ranges permissible for insertion into formula E-1 are:

AIRT	100-275°F
Wa	0.9-2.7 lb/sec

Fuel Constant

If JP fuel, use	0.3586
If hydraulic fluid, use	0.4053
If oil, use	0
If fire-resistant hydraulic fluid (Skydrol), use	0

(use highest coefficient of fluids present)

Note the following limitations:

a. Evaluate maximum engine nacelle and APU air temperature and corresponding air mass flow rates at various points in the flight envelope to determine the maximum necessary Xe (overall maximum air temperature and minimum air mass flow rate in flight can be used as conservative estimate).

b. If value of actual air temperature or Wa is outside bounds of permissible variable ranges, then input at allowable extreme closest to actual value (this impact on the effectiveness of calculated Xe has been shown in experiment to be minimal).

c. If an engine nacelle and APU are both protected with a single system, determine required concentration and mass separately for both applications independently, then size for larger requirement.

Concentration duration for certification: All measuring probes should measure at least Xe simultaneously for a minimum of 0.5 seconds.

Engine and APU Mass Estimation Formula E-2:

The formula E-2 is a theoretically derived formula (not empirical) to estimate the mass of extinguishant required in storage in a system to pass the certification process with Xe calculated from E-1. The formula was derived with similar principles to that used for earlier halon certification, and the formulas are similar in structure. Formula E-2 will calculate system sizes that will range between 2.3 and 4.3 times the volume of optimally designed halon systems for identical applications, with a corresponding weight growth ratio only about 80 percent (80%) of the volume growth ratio compared to a halon system. The estimated HFC-125 system size and weight may actually be much closer in size to an existing halon installation, due to the oversizing of many previous halon designs.

Equation E-2:

MASS(lb) = 0.003166XeV + 4.138 x (Xe /(100-Xe))x W actual

Xe (from formula E-1):	engine/APU concentration for certification (Formula E-1)
V:	free volume of nacelle or APU (subtracting volume due to internal components)—ft^3
W actual :	actual maximum air mass flow rate (no experimental bounds)—lb/sec “

REQUIREMENT LESSONS LEARNED (3.4.7.24)

In military air vehicles, single engine air vehicles are usually not fitted with fire extinguishing systems. On some Air Force air vehicles such as the B-52 and KC-135, the engines are located in pods below the wing and separated from the rest of the air vehicle by a pylon. The engine compartment is isolated from the pylon with a horizontal firewall. These air vehicles have no fire extinguishing system installed on the basis that it is improbable that a nacelle fire would be totally destructive to the air vehicles. There are also other military multiengine combat air vehicles such as the F-4 which do not incorporate fire extinguishing systems on a calculated risk basis. However, almost without exception fire extinguishing is provided in all military transport and cargo-type air vehicle engine nacelles.

Most air vehicle engine installation fire extinguishing systems generally employed a halogenated hydrocarbon type fire extinguishant (table G-III) because of its greater effectivity and attendant reduced system weight penalty. Table G-IV illustrates the two types of systems currently in use. The conventional and high rate discharge (HRD) systems are very similar with the exception of the method of agent distribution. The HRD system utilized open-end nozzles and relies on the high velocity of the agent discharge for proper dispersal within the nacelle. Consequently, high vapor pressure agents such as halon 1301 are best.

suited for HRD applications. In contrast, the conventional system utilized perforated tubing for agent distribution with consequent penalties of restricted flow and generally higher total system weight. Low vapor pressure agents such as Bromochloromethane (Halon 1011) (CH_2BrC1) are best suited for the latter application. Dibromodifluoromethane (Halon 1202) (CBr_2F_2), an intermediate volatility extinguishant, has been used successfully in both types of systems. Recently developed air vehicles utilize the HRD type system.

The USAF has had excellent experience with the various halogenated agents. A review of accidents and incidents over a six-year period (1964-1970) showed that these fire extinguishing system installations have been more than 90 percent (90%) effective. In cases where the system has failed, extenuating circumstances were usually involved such as lack of rapid fire detection, utilization of improper fire emergency procedures, and mechanically damaged nacelles.

The use of halons, as well as other halogenated fluorocarbons, was determined to be associated with the destruction of Earth's ozone layer. Production of the halons was stopped in the United States by Presidential decree on 1 January 1994, and no new procurements requiring the use of ODCs were allowed by the Department of Defense after 1 July 1993. Halons deplete the ozone layer and are cited for information only.

General: Following shutdown of combustible flow into the protected zone, the extinguishing system should control and extinguish the fire and control a possible reignition of the fire. The recommended extinguishing agent for hydrocarbon-air fires is Bromotrifluoromethane (Halon 1301) ($CBrF_3$) described in ASTM D5632/D5632M. The recommended Halon 1301 concentration and duration is at least 6 percent (6%) by volume in air for at least 0.5 second to control hydrocarbon-air fires such that damage within the affected compartment is kept to a minimum, fire spread to other compartments will be prevented, and reignition will be prevented. These recommendations are based on conditions at normal cruise and may need to be adjusted for other flight conditions or unusual fire situations. Current agent discharge times are on the order of 1 second. This may vary between agents, but the idea is to provide the necessary concentration of agent within the shortest possible time after fire awareness.

a. Quantity of agent: As a design guide, the following formulas may be used to determine the minimum quantity (weight) of agent to be discharged into each engine:

   1. For rough nacelle interior with low airflow and for smooth nacelle interior regardless of airflow, whichever of the following formulas provides the larger value of W:

      $W = 0.05V$

      $W = 0.02V + 0.25Wa$

   2. For rough nacelle interior with high airflow: $W = 3(.02V + 0.25Wa)$

   3. For deep frame nacelle interior with high airflow: $W = 0.16V + 0.56Wa$.

TABLE G-III. Physical properties of selected agents.

CHEMICAL NAME	BROMOCHLORO-METHANE	DIBROMODIFLUORO-METHANE	BROMOCHLORO-DIFLUOROMETHANE	BROMOTRIFLUORO-METHANE	DIBROMOTETRA-FLUOROETHANE
Halon Number	1011	1202	1211	1301	2402
Chemical Formula	CH_2BrC1	CBr_2F_2	CBrC1F2	$CBrF_3$	$CBrF_2CBrF_2$
Molecular Weight	129.4	209.8	165.4	148.9	259.8
Boiling Point, Atmos. Press., °F	153.0	73.0	24.8	-72.0	117.3
Freezing Point, °F	-125.4	-223.0	-257.0	-282.0	-166.8
Critical Temp., °F	567.0	390.0	309.0	153.5	418.0
Critical Press., psia	953.	593.	595.	574.	500.
Critical Density, lbs./gallon	5.75	6.96	5.94	6.2	6.58
Density at 70°F, lbs./gallon (liquid)	16.1	19.0	15.25	13.1	18.0
Density at 130 °F, lbs./gallon (liquid)	15.4	17.9	14.15	10.4	17.1
Heat of Vaporization at 760 mm. Press. Btu./lb	101.5	50.9	57.6	50.8	45.0
Vapor Press. At 130°F Psig	0.	25.	75.	435.	4.
Vapor Press. At -65°F Psig	0.	0.	0.	2.5	0.

TABLE G-IV. Types of air vehicle fire extinguishing systems.

SYSTEM TYPE	AIRCRAFT	Agent	AGENT [1] QUANTITY FORMULA	NACELLE NET 1	NACELLE VOLUME ft^3	AGENT WT/SHOT lbs	TOTAL SYSTEM WT lbs	DISTR. RQMT. COMPLIANCE
Conventional	C-130	CH_2BrC1	(Design Guide)	1726	61	13.5	60	Motion Pictures
	B-57	C H_2BrC1	0.56 Wa +	1189	42	13.5	52	
	C-97	CH_2BrC1	0.16V	3396	120	33.0	120	
High Rate Discharge	DC-9	$CBrF_3$	W = 0.05V Or W = 0.02V +	3679	130[2]	8.4	37.1	Agent Concentration Analyzer
	C-141	CBr_2F_2	0.25 Wa	3255	115	7.0	72	
	C5-A	CBr_2F_2	(Whichever is greater)	3934	139	7.5	87.2	

[1] V = Net volume of zone in cu. ft.
Wa = Air flow (normal cruise) in lbs/sec.

[2] Includes APU and both engines

Where: W = Weight of agent in pounds

Wa = Pounds of air per second passing through the zone at normal cruising condition

V = Net volume of the zone in cubic feet (gross volume of the zone less the volume of major items of equipment)

b. Definitions:

1. Low airflow signifies airflow rate of 1 pound or less per second at cruise
2. High airflow signifies airflow rate exceeding 1 pound per second at cruise
3. Smooth nacelle denotes no circumferential ribs protruding into nacelle
4. Rough nacelle denotes circumferential ribs protruding less than 6 inches into nacelle
5. Deep frame nacelle denotes circumferential ribs protruding 6 inches or more into nacelle or nacelle configuration with cavities 6 inches or more in depth (measured transversely)

For potential fire zones not located in nacelles, the formula of "1." may be used.

Where long discharge lines are used, an increase in the value of W obtained in the formulas may be required in order to compensate for agent lost in wetting the discharge lines.

Include the location of system, location of agent storage containers, agent quantity, agent, system actuation method, type of compartment (fuselage, wing, nacelle), material selection, and environmental conditions at system locations.

Development of engine fire extinguishing equipment for the protection of air vehicle in flight parallels air vehicle development. The need for fire extinguishing systems is reflected in these legacy Air Force Design Handbooks and Military Specifications: AFSC DH 1-6, AFSC DH 2-2, AFSC DH 2-3, MIL-I-83294, and MIL-E-22285. Military Specification MIL-E-22285 requires the use of Ozone Layer Depleting Substances and is cited merely for illustration.

The Solid Propellant Gas Generator (SPGG) is a viable alternative to halon for in-flight fire suppression. SPGG technology relies upon the controlled burning of solid reactants to produce inert gases such as CO_2, N_2, and H_20. Additionally, chemical flame inhibitors can be added to the propellants to enhance their extinguishing efficiency. SPGG is a non-ozone depleting fire suppression technology and it has many advantages over typical liquid fire extinguishing agents that are commonly stored in pressurized bottles. For instance, SPGG systems do not require periodic hydrostatic testing, and large volumes of gas are conveniently stored by the reactants in a solid form. Moreover, the mass flow rate of the SPGG discharge can be tailored to increase system effectiveness in preventing hot surface re-ignition.

The SPGG technology is limited by the high temperature of the discharge gases. The high temperatures necessitate cooling of the discharge gases and insulation of the distribution lines. If these actions are not taken, the distribution lines may melt and they could become potential ignition sources for leaking fuel. Furthermore, hot distribution lines have a tendency to increase in length during generator discharge, and an inadvertent actuation of the system could pose a hazard to maintenance personnel. Remedies for these limitations have been developed, but they have all contributed to a more complex system design that results in increased cost and weight. Additional concerns include the high cost of qualification and a high life cycle cost. The SPGG propellants are based on automotive airbag technology but they are not produced in high volume. Also, present designs requires that the squib be an integral part of the generator, thereby limiting the life of the generator to the life of the squib. Moreover, particulate in the exhaust of the generators could be a concern from a clean up and corrosivity point of view. Since the extinguishing mechanisms are not well understood, a metric for sizing SPGG systems has not been developed, and if such a metric is developed, it is likely to be different for each different propellant and propellant manufacturer. More development testing of SPGG is required to refine the understanding of the extinguishing mechanisms and provide better insight into how to design an SPGG system and incorporate it into an airframe. Limited development testing of this technology have been accomplished by Air Force Research Laboratory Flight Dynamics Directorate's Vehicle Subsystems Division. All testing data and recommendations will be documented in two technical reports. The first was drafted by Battelle Memorial Institute and scheduled for completion on 25 November 1997. This report is a comprehensive assessment and description of the test program and the data collected. The second report was drafted by the National Institute of Standards and Technology. This report concentrates on an analysis of the data collected in an effort to provide insight into the extinguishing mechanisms of the gas generator. This report was due on 15 November 1997. All reports will be available through the Defense Technical Information Center (DTIC).

The Navy has also conducted substantial SPGG development testing for application on the F/A-18E/F engine bay fire extinguisher system.

G.4.4.7.24 Engine and auxiliary power unit compartment fire extinguishing.

It shall be verified by analysis and inspection that fire extinguishing systems have been provided in all specified locations. It should be verified by ___(TBS)___ that the systems will produce and maintain an agent concentration as required.

VERIFICATION RATIONALE (4.4.7.24)

The lack of this control method in a required location or an inadequacy in a provided system or equipment will result in uncontrolled fire damage to the air vehicle.

VERIFICATION GUIDANCE (4.4.7.24)

The required analysis and inspection should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle. Laboratory, component, ground and flight tests and demonstrations may be used to verify the adequacy of the provided fire extinguishing system(s). Under actual or simulated cruise condition or at some other preferred flight condition, the system should be discharged and agent concentration and duration goals should be verified by use of an appropriate method of measuring agent concentration (such as the Statham Analyzer).

TBS: Through use of the Statham Analyzer, it is possible to determine agent concentration and duration and establish adequacy of the fire extinguishing system without the need for fire testing. In addition, the fire extinguishing system can be tailored to the installation to provide a minimum weight system.

VERIFICATION LESSONS LEARNED (4.4.7.24)

When conducting verification tests that require discharge of a fire suppressant ensure all regulatory and environmental requirements have been met.

G.3.4.7.25 Habitable compartment fire extinguishing.

Provisions shall be made for the extinguishing of fire in habitable compartments of the air vehicle when the fire hazard therein cannot be controlled by lesser means.

a. When a total flooding fire suppression system is used, the system shall provide within the compartment a concentration of agent sufficient to extinguish any fire within a time duration sufficient to minimize damage within the compartment, minimize the production and spread of smoke and toxic vapors within the compartment and prevent the spread of the fire to other compartments. This agent concentration shall be maintained within the compartment for a time duration sufficient for the crew to perform any necessary additional corrective actions. The agent, in its use concentration range, shall not present a toxic hazard nor interfere with vision.

b. When portable fire extinguishers are used, they shall be in accordance with BB-E-2879. The quantity and placement of extinguishers per compartment shall be in accordance with ___(TBS)___.

REQUIREMENT RATIONALE (3.4.7.25)

The intent of this requirement is to establish the criteria for the systems and equipment to be provided for habitable compartment fire extinguishing.

REQUIREMENT GUIDANCE (3.4.7.25)

If the respective Service maintains an Occupational Safety and Hazard Standard for fire extinguisher placement and quantity, the TBS should be replaced with the reference.

Habitable compartments are considered fire zones when combustible materials are used in the furnishings or lines or equipment containing materials, which can participate in fire or explosion, are located therein. Materials less fire-resistant than aluminum alloys should not be used where ambient temperatures exceed 500°F. Materials used for cabin interiors should not ignite spontaneously at the highest temperatures of installation, or at temperatures lower than 140°F, and they should be self-extinguishing after removal of the flame. Whenever possible, cabin interior finish materials should be those which produce the smallest amount of toxic gases when burned or decomposed by heat. Fabrics of vegetable, animal, and synthetic textile fibers and plastics should not be used where ambient temperatures exceed 250°F.

Crew smoking is considered a most likely source of ignition, thus berths should be placarded against smoking. Compartments where smoking facilities are not provided should be placarded against smoking. If provided, smoking facilities should be in the form of an adequate number of fireproof, self-contained, removable ash receptacles with covers.

The habitable compartment fire zone definition should consider paper and other materials and supplies the crew will be required to have to perform a normal mission. The amount of these materials, equipment, and supplies or the size of the compartment may require fire extinguishing provisions to control adequately the possible fire hazards that may occur. The control provisions may be either total flooding (system), portables (fire extinguishers), or a combination of both. Compartment size is a major deciding factor in the make-up of the provisions. Considerations for each type of protection are as follows:

a. Total flooding is an extension of the engine type fire extinguishing system with limits on the maximum concentration of agent in habitable compartments to protect personnel. The usual system for total flooding uses Bromotrifluoromethane (Halon 1301) at 6 percent (6%) by volume for various time duration depending on the hazard. The system on the C-5 air vehicle maintains this concentration for five minutes. Additional guidance is given below:

    1. Function: Active: Fire extinguishment in crew, passenger, cargo, avionics, and other enclosed compartments.

    2. Configuration: Radiation detector or thermal detector and fire extinguisher agent container(s), dischargeable by squib, containing Bromotrifluoromethane, both placed inside the compartment to be protected. The remainder of the system incorporates control and test panels and necessary wiring.

    3. Principle of Operation: The flame or the heat buildup triggers the detector(s) which activates a warning light on the panel(s). Then, agent can be manually or automatically discharged in the selected zone.

    4. Application Constraints: Use this type of system where there is a fixed enclosure about the hazard that is adequate to enable the required concentration to be built-up and maintained for the required period of time to ensure the effective extinguishment of the fire in the specific combustible materials involved and for the crew to perform any necessary additional corrective actions. Use concentration of less than 10

percent (10%) by volume to prevent toxic hazards to personnel. Six percent (6%) by volume of Halon 1301 will extinguish most flammable solids and gases. Obtain latest design details from: AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL.

5. Performance: Excellent method for fire extinguishment in a closed compartment, where an electrically nonconductive medium is essential or desirable and a clean agent is needed.
6. Penalties: Weight from the standpoint of an airborne system; however, if an extinguishing system is needed, Halon 1301 has the best weight vs. extinguishing potential.
7. Weight: .03 - .08 lbs/cu ft
8. Availability: Well developed systems for total flooding systems are available. These systems are very similar to engine compartment fire extinguishing systems which have considerable service experience.
9. Maintainability: System requires thorough inspection and checkout, including container periodic weight and pressure check.

b. Portables should be procured to an existing specification for flight qualified units. Portable fire extinguishers for existing and new Navy air vehicles should contain carbon dioxide as the fire extinguishing agent and be procured to BB-E-2879.

Include the location of system and portables, location of agent storage containers and portables, agent quantity, agent, system actuation method, type of compartment (cockpit, crew, troop, cargo), size of compartment, hazards within compartment, material selection, and environmental conditions at system and portable locations.

REQUIREMENT LESSONS LEARNED (3.4.7.25)

Total flooding systems should be designed so that their operation does not present hazards to the crew or to other personnel. Portable fire extinguishers should contain sufficient agent to combat incipient fires and should have a spray pattern and effective agent throw range suited to the hazards to be protected against and the compartment size. The agents used should not reduce visibility upon discharge and should not cause mechanical problems, be corrosive, or electrically conductive.

Wood and plywood used for cabin interiors should be permanently covered with a flame-resistant material. Textiles that are used for upholstery, floor covering, and interior trim, which are made flame-resistant by treatment, should not lose their flame-resistant quality after dry cleaning or laundering. If treated textiles are used which lose flame resistance with age, or dry cleaning, or laundering, suitable safe maintenance requirements should be given in the applicable Maintenance Instruction Manual. Treatment of materials of any kind (coating, doping) should not impair the flame resistance qualities of material used in habitable compartments. Nitrate dope should not be used in cabin interiors.

Storage facilities provided for storage of blankets, pillows, magazines, and newspapers should be located and designed so that the contents will not be ignited by light bulbs, matches, or cigarette ashes. Blankets are acceptable without treatment if they contain a minimum of 95 percent (95%) wool. Closely-woven, short-napped textiles are superior. Fire resistant containers for waste material should be made of aluminum alloy or other material with equivalent fire barrier qualities.

G.4.4.7.25 Habitable compartment fire extinguishing.

It shall be verified by analysis and inspection that provisions have been made for the extinguishing of fire in habitable compartments of the air vehicle.

VERIFICATION RATIONALE (4.4.7.25)

The lack of this control method in a required location or an inadequacy in a provided system or equipment will result in uncontrolled fire damage to the air vehicle.

VERIFICATION GUIDANCE (4.4.7.25)

The required analysis and inspection should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle. Laboratory, component, and ground tests and demonstration may be used to verify the fire extinguishing provisions.

VERIFICATION LESSONS LEARNED (4.4.7.25)

(TBD)

G.3.4.7.26 Non-habitable compartment fire extinguishing.

Provisions shall be made for the control and termination of fire in all non-habitable compartments of the air vehicle (other than engine), when fire within these compartments cannot be controlled and contained by lesser means. Provisions shall address whether fire in such compartments is or is not accessible in flight. Systems for compartments that are not accessible in flight shall provide within each compartment a concentration of agent sufficient to extinguish any fire within a time duration sufficient to minimize damage and prevent the spread of the fire to other compartments. This agent concentration shall be maintained within the compartment for a time duration sufficient to prevent reignition of the fire.

REQUIREMENT RATIONALE (3.4.7.26)

The systems used for non-habitable compartment of an air vehicle can be just as hazardous as uncontrolled fire in engine compartments. The location, size, or usage of a non-habitable compartment may disallow access or make impractical the application of lesser means of fire control.

REQUIREMENT GUIDANCE (3.4.7.26)

Non-habitable compartments such as baggage and cargo compartments should be completely lined with fire resistant material such as aluminum alloy or other material with equivalent fire barrier qualities. Consideration should be given to the effect of heat within non-habitable compartments on adjacent parts of the air vehicle.

If a fire is easily discernible and is accessible in flight, a hand fire extinguisher for each non-habitable compartment such as baggage and cargo compartments should be provided.

If sufficient access to non-habitable compartments such as baggage and cargo compartments is available in flight to extinguish a fire with a hand fire extinguisher, but a fire is not easily discernible, a separate system of smoke or fire detectors for each compartment, and a hand fire extinguisher readily available for each compartment, should be provided. No hazardous quantities of smoke, flames, or extinguishing agent should enter crew or passenger compartments when access to the non-habitable compartment is opened.

If the fire is not easily discernible and is not accessible in flight, separate systems of smoke or fire detectors for each non-habitable compartment, and a built-in, total-flooding fire extinguisher system should be provided. Agent containers for built-in systems should not be located within baggage or cargo compartments. No hazardous quantity of smoke, flames or extinguishing agent should enter the crew or passenger compartments. Ventilation and draft within each non-habitable compartment should be controlled so that fire extinguishing is effective. The total flooding fire extinguishing systems used for non-habitable compartments may be variations of the halon agent systems used for engine compartments or may be liquid nitrogen (LN_2) systems. These systems may be applied to fuel tank dry bays, electronic bays, electrical supply bays, or ancillary power units. For LN_2 systems, which are an extension of the fuel tank inerting system, agent concentration is measured by the effect the nitrogen has in reducing the oxygen level within the compartment. This type of system is designed to flood the compartment and to lower the oxygen level to 10 percent (10%) or less in the time duration necessary to cope with the particular fire hazard. LN_2 systems are not recommended for habitable compartments. Additional guidance is given in below:

a. Function: Active: Fire extinguishment in unmanned compartments of the air vehicle.

b. Configuration: Liquid nitrogen for these compartments is supplied from the on-board LN_2 inerting system tank.

c. Principle of Operation: When a fire is detected in one of the unmanned zones, a corresponding alarm zone light comes on. Nitrogen is fed into the selected compartment to reduce the oxygen concentration to levels which will not support combustion.

d. Application Constraints: This system would normally be used only when LN_2 is available on-board from the LN_2 fuel tank inerting system. Design the system: (a) to provide sufficient LN_2 flow to lower the oxygen concentration in the protected zone to 10 percent (10%) or less in ten seconds, and (b) so that the nitrogen discharge will not result in pressure above the design limit of the compartment. Obtain latest design details from AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL.

e. Weight: .1 - .5 lbs/cu ft (Nitrogen only)

f. Penalties: Logistics problems of LN_2, however if LN_2 is available for fuel tank inerting, it will be available for fire fighting.

g. Availability: Valving and system components are similar to those used in LN_2 inerting system.

h. Maintainability: Required maintenance is compatible with that performed on typical fuel and vent systems.

If a fire can be completely confined without endangering the air vehicle or the occupants, no detector or extinguishing system should be required. However, flame, smoke, and noxious gases should not enter crew or passenger compartments in hazardous quantities. Ventilation and draft within the baggage and cargo compartments should be controlled. Ventilation and draft airflow through such compartments should not exceed three cubic feet per hour per cubic foot of volume and should preferably be less. For larger compartments, lesser airflow may be applicable.

For air vehicles used exclusively to transport cargo, separate systems of smoke or fire detectors should be provided. Means should be provided to shut off the ventilating airflow to or within the compartment. No hazardous quantities of smoke, flames, or extinguishing agent should enter the flight crew area.

Portable fire extinguishers for existing and new Navy air vehicles should contain carbon dioxide as the fire extinguishing agent and be procured to BB-E-2879.

Include the type of compartment, in-flight accessibility, location of system, location of agent storage containers, agent quantity, agent, system actuation method, material selection, and environmental conditions at system location.

REQUIREMENT LESSONS LEARNED (3.4.7.26)

A fire incident on a cargo air vehicle equipped with a LN_2 firefighting system indicated a need for fireproof extinguisher discharge line. The use of aluminum lines in this application was based on weight consideration, early detection, and timely agent discharge. In this case the fire burned a large opening in the compartment and the nitrogen was not fully effective. Early detection by optical means with automatic agent discharge may be necessary in some zones. In fire zones the standard practice has been to make tubing and nozzles fireproof to ensure discharge of the agent at specified locations.

Re-entry of exhaust gases into wing cavities may occur on installations with engines mounted on the wing. Gases may travel spanwise under some flight conditions. The wing cavities should be analyzed for potential fire hazards and for hazardous deterioration of structural material, and appropriate protection should be provided.

The occurrence of ignition and sustained burning within baggage is very unlikely. Generation of moisture and inert gases during the smoldering action within baggage may cause any fire to die out, or many hours will probably pass before even a small open flame results. The probability of continued burning is further reduced by increased altitude, decreased air temperature, increased relative humidity, and increased density of clothing pack. Increasing velocity of air passing over baggage containing fire increases the burning rate of the fire. The degree of increase depends on the compactness of the baggage.

G.4.4.7.26 Non-habitable compartment fire extinguishing.

It should be verified by analysis, inspection and test that fire extinguishing systems have been provided in all specified compartments. It should be verified by ___(TBS)___ that the systems will produce and maintain an agent concentration as required.

VERIFICATION RATIONALE (4.4.7.26)

The lack of this control method in a required location or an inadequacy in a provided system or equipment will result in uncontrolled fire damage to the air vehicle.

VERIFICATION GUIDANCE (4.4.7.26)

TBS: The required analysis and inspection should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle. Analysis, and laboratory, component, and ground tests and demonstrations should be used to verify the fire extinguishing provisions. Fire tests of the LN_2 system should be run in a compartment that is sized to be similar to the air vehicle component. The detection system should be used to signal for activation of the nitrogen flow. Lines sizes, flow rates, and flow duration of the LN_2 system should be replicated for tests.

VERIFICATION LESSONS LEARNED (4.4.7.26)

Performance of the LN_2 fire extinguishing system can best be assessed by actual fire tests at this time. A multiprobe oxygen analyzer with rapid response is needed to substitute for fire tests.

G.3.4.7.27 Explosion suppression.

Areas containing or adjacent to those containing flammable fluids which are not designed to withstand overpressures that may result from combustion reactions shall be provided with explosion suppressive systems either when prevention designs are not sufficient, practicable or the most efficient means of providing the required overpressure protection, or in accordance with ___(TBS 1)___. Both active, automatically operating systems and passive systems may be provided. When provided, explosion suppression system(s) shall comply with the following requirements:

a. System characteristics (type and size) shall be based on the highest expected energy-level mission-related ignition source.

b. The system shall be fully functional and provide required performance during the following phases of ground or flight operations: ___(TBS 2)___.

c. Pressure increases that may result from combustion reactions of flammable fluids which are contained within or may enter the protected areas shall be limited to levels which will not cause damage to the protected area (compartment, system, or air vehicle structure). The structural pressure limit shall be determined by _(TBS 3)_.

d. The system shall prevent subsequent reactions.

REQUIREMENT RATIONALE (3.4.7.27)

The intent of this requirement is to establish the need for explosion (combustion reaction overpressure) suppression system(s) and to establish the criteria applicable to these systems.

REQUIREMENT GUIDANCE (3.4.7.27)

TBS 1: (TBD)

TBS 2: (TBD)

TBS 3: (TBD)

Explosion suppression systems have been used to prevent catastrophic fuel tank explosions and destruction of the air vehicle. Less complex means (fire and explosion hazard prevention designs) should first be investigated and proven not to be the best means of providing this protection. Also, the basic air vehicle compartments, equipment's and systems should be designed so that under normal operating conditions, explosion suppression systems are not required.

Usually, the requirements for an explosion suppression system are based on survivability and vulnerability considerations. In a few cases, non-combat air vehicle may require the protection provided by an explosion suppression system. For example, supersonic air vehicles, such as the SR-71, have a fuel tank inerting system because of the high skin and fuel tank wall temperatures generated during supersonic flight. It may be desirable to protect the fuel tanks of certain, high value and critical resource air vehicles (C-5, for example) as an extra precautionary measure. If the requirement for explosion suppression is know to exist prior to conducting the various analyses, the requirement may be so stated.

System criteria should be based on experience with present and past systems. The factors which most influence system characteristics are ignition source, the protected fluids, and required operational capability. The suppressing media and its method of usage, along with the allowable maximum overpressure, should be described for both active and passive systems. Based on system operational or hazard analysis, it should be specified when the explosion suppression system is required to be placed in use. On some air vehicles, the fuel system may require full-time protection while other air vehicles may only require protection during particular operational or mission conditions. Active systems require a description of desired crew displays and controls.

Include the hazard to be protected against, type of system, locating of system, suppressing media, method usage, system actuation method (if used), type and size of protected area, material selection, detection system characteristics (if used), and environmental conditions at system location. Consider overhaul periods, and maintenance cost and service.

The invention of explosion suppression was initiated by an obvious need for the protection of fuel tanks in combat air vehicles. The vast majority of air vehicles which presently have fuel system explosion protection capability are combat air vehicles protected with reticulated foam which was developed and widely used during the war in Southeast Asia (SEA). A limited number of air vehicles such as the C-5 and SR-71 are protected with a nitrogen inerting system. The F-16 uses halon fire extinguishing agent to inert the fuel tanks.

REQUIREMENT LESSONS LEARNED (3.4.7.27)

An explosion is caused by the combustion of fuel and heating of air which causes a rapid increase in pressure inside the compartment or fuel tank. Explosion protection has been provided by preventing or limiting the amount of fuel which can burn, or the release of energy due to heating, through oxygen dilution, heat absorption and chemical flame quenching techniques. Nitrogen inerting, passive baffle and chemical inerting or suppression systems are approaches currently employed. Fuel slosh and agitation (over-enrichment) and fuel additives (fuel alteration) have not been used much beyond the R&D test phase.

The allowable structural pressure limits should be determined by test or conservative analysis. The allowable overpressure should be known before the explosion suppression system characteristics can be determined. Also needed is identification of the protected fluids and of the possible ignition sources since these can be a factor in determining the needed suppressing media. Ignition source determination should be used on hazards analyses, survivability-vulnerability studies, or other operational requirements and should consider all possibilities (electrical arc, lightning, 50 cal. API, 23 mm High Explosive Incendiary Tracer (HEIT)).

The nature of the ignition source, size, energy, and number of ignition sources can have an influence on the design of the selected explosion suppression system. The energy and number of ignition sources will increase the rate of pressure rise of the combustion process. For chemical flame quenching (inerting) systems using halon fire extinguishing agent, the energy of the ignition source affects the concentration of agent required to prevent the maximum allowable compartment pressure rise from being exceeded. For chemical flame quenching (suppression) systems (which use fast reaction detection and extinguishing agent discharge systems) multiple ignition sources may require faster acting detection and agent discharge systems to prevent the maximum allowable compartment pressure rise from being exceeded.

The following considerations are particular to each of the four types of systems presently in use:

a. Oxygen dilution systems. The dilution of a potentially explosive atmosphere by an inert gas is an effective means of eliminating the fire or explosion hazard. This approach utilizes an inert gas such as nitrogen to reduce the oxygen concentration to a level that will not support the normal combustion process. Data generated under natural or combat-induced ignition sources (gunfire) indicates that for most applications, maintaining the oxygen concentration below the nine volume percent level will preclude the damaging combustion overpressures. The inerting concept has been successfully demonstrated on both commercial and military air vehicles and the entire fleet of C-5A air vehicles has been retrofitted with inert gas protection based on a stored LN_2 system.

   The C-5A inerting system converts the stored LN_2 to gas prior to the introduction of the nitrogen into the fuel system. The nitrogen is released either into the fuel or the ullage. The bubbling of the nitrogen through the fuel serves two functions. First, it scrubs (removes) the dissolved oxygen that would be released during flight, and second, it improves the thermal stability of the fuel. The control of the rate and size of the nitrogen bubble is critical to ensure that the oxygen is removed (nitrogen scrubbing requires droplet size in the order of 2.5 mm (0.10 inch diameter). The oxygen rich gas is swept out of the ullage and through the vent system. Make-up nitrogen required by fuel usage or altitude changes is provided via the vent system. Typical design considerations for LN_2 inerting systems are described below. A LN_2 system is used on the SR-71 air vehicle.

1. Design.

(a.) Nitrogen inerting system: The nitrogen inerting system should be completely automatic and should require no attention from the flight crew during flight except for the monitoring of high and low fuel tank pressure indicator lights. The system should prevent explosions and fire by maintaining the oxygen concentration of the ullage space below the level of 9 percent (9%). The nitrogen may also be made available for fire extinguishing in other areas of the air vehicle.

(b.) Configuration: Fuel and vent systems should be closed systems for nitrogen inerting. Dry bays need not be closed, but should be designed for minimum nitrogen usage.

(c.) Inerting gas: The nitrogen gas used for inerting should be stored onboard the air vehicle in the liquid form and converted to gas as required. The liquid nitrogen should comply with A-A-59503 or A-A-59155.

(d.) Self-Generating inerting gas: If exhaust gas is used as the inerting agent, a flame arrestor should be used to prevent flame from entering the fuel tank and a check valve should prevent flow of fuel or fuel vapor into the inerting gas supply system. The temperature of the inerting agent at the tank entrance should not exceed 120°F. The inerting gas, when entering the fuel tanks, should be free of harmful amounts of water, corrosive material, and materials which contaminate the fuel or fuel system. The gas should not adversely affect the pumpability, burning, and electrical characteristics of the fuel.

(e.) Nitrogen storage: The liquid nitrogen should be stored in lightweight dewars. The dewar assembly should include a pressure relief valve and a blowout disc. The heat transfer characteristics of the dewar should be the minimum practicable without sacrificing necessary strength and rigidity. There should be no leakage from the dewar. The dewar should have a quantity and pressure readout capability.

(f.) Capacity: The capacity of the liquid nitrogen dewar should be adequate to supply nitrogen gas for inerting for the duration of a mission or, if specified by the procuring activity, for two or more missions. A reserve should be provided that will supply nitrogen gas for inerting an unattended air vehicle for a minimum of 48 hours after completion of the missions without reservicing. Provisions for growth capability should be incorporated as specified in the air vehicle system specification.

(g.) Operation: Nitrogen gas should dilute the oxygen content below 9 percent (9%) in all ullage and vent spaces and maintain a slight positive pressure at all times for all operating conditions to prevent the entrance of air. The nitrogen should fill the volume as fuel is used by the air vehicle.

(h.) Entrained air: The nitrogen inerting system should remove oxygen from the air entrained in fuel to prevent the oxygen concentration from exceeding 9 percent (9%) during increases in altitude. This method should not include the use of ground equipment.

(i.) Pressurization: Nitrogen gas should pressurize the ullage and vent spaces during decreases in altitude to maintain a safe differential pressure between the tanks and ambient.

(j.) Ground: The nitrogen inerting system should maintain inerted ullage and vents while no electrical power is applied to the air vehicle and the air vehicle is unattended.

(k.) Damage: The nitrogen inerting system should maintain inert ullage and vent spaces with no electrical power applied for a minimum of 5 minutes with a 100 square inch hole in any one fuel tank.

(l.) Pressures: At no time should the positive or negative pressures in the fuel tanks and vents exceed the design pressure limits of the air vehicle, regardless of the failure of any component. In the event that the supply of nitrogen is depleted or that a malfunction or pressurization occurs, the inerted areas should vent to ambient.

(m.) Malfunction: Crew override controls should be provided to vent the tank and shut off the inert gas supply.

(n.) Servicing: The system should be serviced through a single-point, dry-break, quick-disconnect coupling. The coupling should be for liquid nitrogen only and it should not be possible to connect any other liquid gas servicing coupling. The system should be capable of receiving nitrogen at a minimum rate of 10 gallons per minute (gpm) at pressures from 40 to 150 psig. The servicing connection should be accessible from the outside of the air vehicle, and the instrumentation necessary for servicing (such as quantity and dewar pressure gages) should be visible from the servicing coupling. A cover should be provided to protect the coupling when not in use.

(o.) Nitrogen inerting system components: Components of the nitrogen inerting system should comply with applicable specifications.

(p.) Vent valves: Vent valves should control internal tank pressure within the limits of the air vehicle.

(q.) Checkout panel: A panel should be provided to test all phases of the inerting system for proper operation during preflight checkout. Indicator light(s) should be provided on the panel to signal when the vent valves have allowed air to enter the system.

(r.) Gas analyzer: A means should be provided as a part of the air vehicle to verify that the fluid serviced to the nitrogen inerting system is an inert gas.

(s.) Redundancy: Redundancy of components should be incorporated as necessary to ensure a fail-safe system.

2. Test.

(a.) Nitrogen inerting system tests: The operation of the nitrogen inerting system should be demonstrated for each required mission profile to verify that the quantity of nitrogen is adequate and that the oxygen concentration of the inerted space never exceeds the 9 percent (9%) limit. Also, the pressure in each tank should be measured and recorded during maximum rate of climb and descent with the nitrogen inerting system operating.

(b.) A failure effect demonstration test program should be conducted based upon the results of failure analysis studies. Only those failures where a reduced level of performance may occur or where special crew attention or control techniques are required need be demonstrated. When the failure effect has been demonstrated during subsystem tests, the test need not be repeated; however, the previously conducted failure demonstrations should be described in the failure analysis report.

(c.) Nitrogen inerting components: The nitrogen inerting system components should be tested in accordance with approved contractor specifications.

(d.) Dewar holddown test: Before first flight it should be demonstrated that the holddown fixture for the dewars can withstand the specified loadings.

Advanced inerting concepts under development will be self-generating. This will eliminate the need for replacement of the nitrogen as required by the LN_2 system. Two potential concepts are promising, a permeable membrane system and a molecular sieve system. These systems generate inert gas onboard the air vehicle by separating oxygen and nitrogen from the air. Both systems are in the development phase for air vehicle use, but are being used in commercial applications for N_2/O_2 separation.

b. Heat absorption systems. The use of baffle material to quench the initial combustion reaction flame front has proven to be an effective method of explosion suppression. Overpressure damage to air vehicle fuel tanks and cavities is prevented by controlling the rate of burning after ignition of the fuel vapors. Control is accomplished through the removal of energy from the combustion process by the absorption of heat and by mechanical interference of the baffle material. The reduced burning rate results in lower combustion overpressure within the fuel tank and provides time for overpressure to relax within the fuel tank and to be vented through the fuel tank vent system.

The baffle material generally used by the U.S. Air Force is a flexible, reticulated, polyurethane foam which conforms to MIL-PRF-87260. Types I and II (coarse pore) and type III (fine pore) are polyether foams. Type IV (coarse pore) and type V (fine pore) are polyether foams. Type IV is intended for use in previous types I and II applications. Type V is intended for use in previous type III applications. The foams are intended for use in a temperature range of -30°F to +160°F (+135°F for polyester) with intermittent temperatures not to exceed +200°F.

Three additional characteristics of importance to the herein intended usage are weight, fuel displacement, and fuel retention. At a nominal foam density of 1.3 lb/ft^3, the foams weigh 0.18 lb/gallon of volume. Fuel displacement by the foam is the same for both fine pore and coarse pore at 2 percent (2%) (nominal) by volume. In respect to fuel retention, the amount of fuel which will be retained on the surface of the foam, and is no longer usable to the air vehicle, is 4 percent (4%) (nominal) by volume for the fine pore foam and 2 percent (2%) (nominal) by volume for the coarse pore foam.

A fourth additional characteristic of importance herein is volume swell upon exposure to fuel. The actual amount of swell is dependent upon the percentage of aromatics in the fuel. Past foam usage with available jet fuels has disclosed a fuel swell factor of up to 5 percent (5%) (nominal) for the polyester foams (types I, II, and III) and fuel swell factors from 10 percent (10%) to 20 percent (20%) for the polyether foams (types IV and V).

Two other types of baffle material are expanded metal mesh and fibrous nylon material. Two reports on testing of the metal mesh material by the Air Force Research Laboatory's Propulsion Directorate are available: AFWAL-TR-80-2031 and AFWAL-TR-80-2043.

Described below are typical design considerations regarding baffle material usage for explosion suppression in Air Force air vehicle fuel tanks. Reticulated foam has been used on several air vehicles, including the A-7, A-10, F-15, and C-130.

1. Design: Baffle material used in the fuel subsystem should comply with MIL-PRF-87260 and should be installed in accordance with the installation criteria provided by the procuring activity. The baffle material should not degrade the performance of the fuel subsystem beyond the limits specified in the fuel subsystem detail specification. The fuel subsystem should meet all the performance requirements with or without the baffle material installed, excluding the explosion protection provided by the baffle material. It should be possible to remove the baffle material from the tanks and operate the air vehicle without removing or adding any other hardware. For example, bladder tanks should be designed for sufficient support without the baffle material installed. Any components fastened in the tank because of the baffle material should be sufficiently tested to verify that these components can be retained if the baffle material is removed. For example, if vent guards are placed at vent openings to prevent the baffle material from getting into the vent openings, these guards should be subjected to vibration tests without the baffle material in place. The baffle material should be included in all specified simulator and ground and flight tests. Testing of components should be conducted in the most severe condition. The baffle material acts as a slosh and vibration attenuator, therefore, slosh and vibration tests for components should be conducted without the baffle material installed.
2. Test: There are no specific simulator tests for the baffle material; however, the fuel subsystem should be monitored during all testing to determine any detrimental effects on the subsystem caused by the baffle material. Reference should be made to procuring activities' installation criteria.

c. Chemical flame quenching (chemical extinguishant inerting systems). The provision for fuel tank explosion protection by using a halon fire extinguishing agent to inert the fuel vapors has recently been applied to the F-16 air vehicles. The agent is dispensed at the option of the pilot. Additional agent is bled in to keep the agent concentration at the proper level.

d. Chemical flame quenching (chemical extinguishant suppression systems). This type of system is presently used on the 707 air vehicles for surge tank lightning strike protection and on the ALL air vehicles to protect the device compartment. Additionally, several military air vehicles were equipped with this type of system in the 1950s. The British developed this type of system which consists of extremely sensitive pressure or flame detectors which sense an impending explosion and cause discharge of an inhibiting agent. This agent suppresses the explosion before the pressure can reach a dangerous level. The theoretical pressure resulting from a vapor-phase explosion is independent of the size of the tank and the intensity of the ignition source except in the case of extremely small tanks. It is dependent on the ratio of combustible to oxidizing medium, pressure of the mixture prior to ignition, and the temperature of the mixture prior to ignition. The effect of the fuel vent on the rate of pressure rise has been studied. Any opening to atmosphere will tend to relieve the pressure buildup in the tank and, if a sufficient ratio of vent area to tank volume can be obtained, the results are significant. Vapor-air concentrations are used as a criterion to establish the effectiveness of chemical extinguishant explosion suppression systems. However, vapor-mist explosions can occur over a wide range of conditions. The effect of total pressure on the minimum ignition temperature is small, so little effect on explosion generation can be realized by tank pressure changes. Chemical extinguishant explosion suppression systems rely on a one-shot ordnance operated device to distribute the suppression agent. Therefore, specify this type of system only if recurrence of an explosion from the same cause is unlikely. Ensure that the explosion suppression system senses the explosion initiation and quenches the burning before an unsafe pressure level is reached. Design the system installation so that the complete area volume is protected. Specify the required response time for dispensing the extinguishing agent.

e. Neither of the remaining two methods have been applied to air vehicles. These are described in the following paragraphs:

    1. Over-enrichment: Laboratory testing has shown the feasibility of preventing fuel tank explosions by keeping the vapors fuel rich. This was done through artificial means of fuel slosh and agitation. This method has not been applied to air vehicle usage.

    2. Fuel alteration: This is another method that has not progressed past research and development testing. Additives are put into the fuel to change its characteristics and reduce vapor production.

G.4.4.7.27 Explosion suppression.

It should be verified by analysis, inspection, and component-, subsystem- and system-level tests that explosion suppression systems have been provided in all specified locations.

VERIFICATION RATIONALE (4.4.7.27)

The lack of this control method in a required location or an inadequacy in a provided system or equipment will result in uncontrolled explosion and fire damage to the air vehicle.

VERIFICATION GUIDANCE (4.4.7.27)

The required analysis and inspection should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle. During the appropriate design reviews, it should be determined by inspection of the appropriate analyses and system requirements whether an explosion suppression system is required and if so, is it being provided. The requirement for an explosion suppression system can be generated by several different sources and it should be ensured that adequate review is conducted.

Inspection, analysis, laboratory, component, ground and simulated flight test and demonstrations may be used to verify the system provisions. Analysis, inspection and test should be used for verifying that the provided explosion suppression system(s) are fully functional and capable of required performance during the planned phases of ground or flight operations. Under actual or simulated flight condition, active systems should be discharged and agent concentration, time to reach suppression levels, and goals should be verified by use of an appropriate method of measuring agent concentration. By analysis, inspection, and test of the selected design during the appropriate design review, it should be determined that the explosion suppression system will limit the overpressures to the required levels.

VERIFICATION LESSONS LEARNED (4.4.7.27)

Verification requirements for oxygen dilution and flame quenching systems, in accordance with MIL-F-38363, are contained above in "Explosion suppression" Lessons Learned.

G.3.4.7.28 Dry bay and void compartment fire and explosion protection.

Provisions shall be made for fire extinguishing in dry bays and void compartments when the fire hazards cannot be controlled by lesser means.

REQUIREMENT RATIONALE (3.4.7.28)

Dry bay fire and explosion protection systems are in widespread use for new combat air vehicles. A fire in a dry bay typically requires a rupture of the flammable fluid components and the generation of an ignition source. For this reason, it is assumed that this scenario is created when a ballistic projectile impacts a dry bay in flight, rupturing fuel system components and generating tremendous ignition energy. Although this is the assumed primary initiation means, other initiation sources such as overheated, shorting electrical circuits in avionics bays or burning stored munitions propellants can also be responsible in certain instances.

REQUIREMENT GUIDANCE (3.4.7.28)

Dry bays of US military air vehicles and helicopters are those areas within the air vehicle that lie between the skin mold line and some inner enclosures, and are volumes formed by adjacent air vehicle structure, such as stiffeners and bulkheads. Dry bays can include wing leading and trailing edges, landing gear, avionics and weapons bays, and related zones where a catastrophic rupture of flammable fluid and an ignition supply, such as from a ballistic impact, can create a sustained fire. Dry bays should be considered continuous if they are pneumatically connected to other bays.

Both passive and active techniques have been developed to prevent ignition or suppress an early dry bay fire. The passive approach consists of filling the void completely or partially, which is especially applicable for thin voids. The active approach consists of timely automatic suppression of ignition with inert gas, or a liquid or power chemical extinguishing agent. This is especially applicable for large equipment dry bays.

Some dry bay protection methods and materials are similar to those used for ullage protection. The main difference is that the ullage is a closed void, whereas dry bays are open. The best approach or combination of techniques depends on the anticipated threat(s), and the design of the fuel system, including its surrounding air vehicle structure.

REQUIREMENT LESSONS LEARNED (3.4.7.28)

Dry bay fire protection was designed into, but not limited to, the following military air vehicles: A-10, C-5, C-130, F-4, F-5, F-14, F-15, F-16, F-18,F-22, UH-60, and AH-64.

The Halon Replacement Program for Aviation generated data which supported the development of extinguisher system sizing models using HFC-125 for dry bays. It also assessed the ballistic impacts as the means of fire initiation. Details on the experimental program, test conditions, and results are outlined in WL-TR-95-3039 (SURVIAC TR-95-010). The design model equation can be found in WL-TR-97-3066 (SURVIAC TR-97-029).

G.4.4.7.28 Dry bay and void compartment fire and explosion protection.

It should be verified by analysis and inspection that fire and explosion suppression have been provided in all dry bays and void locations.

VERIFICATION RATIONALE (4.4.7.28)

The lack of this control method in a required location or an inadequate provided system or equipment will result in uncontrolled explosion and fire damage to the air vehicle.

VERIFICATION GUIDANCE (4.4.7.28)

The required analysis and inspection should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle. Determination should be made during the appropriate design reviews whether an explosion suppression system is required. The requirement for an explosion suppression system can be generated by several different sources and it should be ensured that the adequate analysis is conducted.

Inspection, analysis, and laboratory, component, ground, and simulated flight tests and demonstrations may be used to verify the adequacy of the system protection provisions. Analysis, inspection, and test should be used to verify the explosion suppression system(s) provided are fully functional and capable of required performance during the planned phases of ground or flight operations. Under actual or simulated flight conditions, active systems should be discharged and agent concentration, time to reach suppression levels, and goals should be verified by use of an appropriate method of measuring agent concentration. It should be determined by analysis, inspection, and test of the selected design during the appropriate design review that the explosion suppression system will limit the overpressures to the required levels.

VERIFICATION LESSONS LEARNED (4.4.7.28)

Different fuel types may have flammability limits that affect dry bay fire protection. During the conversion from JP-4 to JP-8, the envelope of flammability changed and an update to fire protection design and verification was required.

G.3.4.7.29 Control systems actuation display and operating devices.

A means of operating fire and explosion control systems and of displaying crew warnings and automatic actuation of the system shall be provided.

REQUIREMENT RATIONALE (3.4.7.29)

This requirement is to define the characteristics of the system to be provided to indicate to the aircrew the need to operate a control system and provide the means of actuation.

REQUIREMENT GUIDANCE (3.4.7.29)

Include the details of fire and explosion hazard protection monitoring and actuation and operating device interlocks.

After a fire and overheat hazard condition and its location have been detected, it is necessary to perform the correct emergency operation immediately and in the proper sequence to effect prompt hazard elimination. For this reason the basic design of the crew display and operating device system and the arrangement of the warning devices, handles, switches and circuitry should be such that the emergency procedure is as simple and clear as possible. Each new air vehicle should be analyzed to determine the type of crew display and operating device system which should be incorporated. The procedures should be as simple and clear as possible and the arrangement of the handles and switches and the circuitry of the system should be such that misdirection of the charge of agent is impossible.

Single operation devices should be used, where space permits, to shut off all fire and explosion sources such as flammables, air, oxidizer or reducing agents, and ignition sources for every region possibly affected by the hazard condition and also initiate necessary operational functions evolving from the shutoff. When fire extinguishing is provided, the switches for its activation should be located so that they are covered by the emergency handles and cannot be activated before the emergency handle is pulled.

Where space is limited, push button warning lights have been used as a substitute for “T-handles”. The buttons are usually covered by frangible covers to prevent inadvertent actuation and provide a visual indication that the buttons have been actuated. These covers have been a source of trouble on some air vehicles. Also, active type explosion suppression systems (oxygen dilution, fuel vapor inerting and flame suppressing) require crew controls to activate and deactivate the system.

Emergency operations and their sequencing may vary with different air vehicles. However, in general, the following emergency operations are required in the event of fire:

a. Engine fire.
    1. Feather propeller, if applicable.
    2. Shut off engine.
    3. Apply engine brake, if applicable.
    4. Shut off all non-essential flammable fluids to the engine (fuel, oil, hydraulics, anti-icing fluid). Essential fluids are those required to:
        (a.) prevent further damage to the engine,
        (b.) allow safe continuation of flight,
        (c.) allow a safe auto-rotation landing, or
        (d.) accomplish the required emergency procedures.

5. Shut off ventilating and cooling air, if required.
6. Shut off bleed air from other engines if they can discharge into a fire zone such as in the case of a bleed air duct burnthrough in a potential fire zone.
7. De-energize electrical circuits to the engine compartment or nacelle (with the exceptions of the feathering, fire-fighting and essential circuits).
8. Select and arm the circuit for discharge of the extinguishing agent.
9. Actuate fire extinguishing system.

b. Equipment fires.
   1. Shut off equipment.
   2. Shut off all flammable fluids to the equipment.
   3. Shut off ventilating and cooling air, if required.
   4. De-energize electrical circuits to the equipment compartment.
   5. Select and arm the circuit for discharge of the fire extinguishing agent.
   6. Actuate fire extinguisher.

The indicator lights should stay illuminated as long as a fire warning indication persists.

Dimming provisions should not be provided for the fire warning indicator lights.

Where light signals are used for fire warning, each signal should include at least two MS or AN lamps of equivalent wattage.

The emergency handle should be red in color and have the words “FIRE-PULL” engraved or embossed thereon, or the words should be integrally lighted in accordance with MIL-STD-411. Adequate marking adjacent to the handle to indicate the potential fire zone associated with the control should identify each emergency handle.

Single emergency handles should require 20 to 25 pounds of pull to operate them. The operation of the emergency handle should either be reversible, or reactivation of the shut-down engine should be established by other means.

REQUIREMENT LESSONS LEARNED (3.4.7.29)

If APU’s are being operated on the ground provide an automatic mode to detect, shut down the APU, and discharge fire suppressant if required.

G.4.4.7.29 Control systems actuation display and operating devices.

The means of control system actuation display and operating devices shall be verified by analysis, inspection, component tests, and on-aircraft tests.

VERIFICATION RATIONALE (4.4.7.29)

Verification of the proper sequencing, configuration, and location of the fire and explosion hazard control systems actuation displays and operating devices is necessary to the flight safety of the air vehicle.

VERIFICATION GUIDANCE (4.4.7.29)

The required analysis and inspection should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle. Ground tests and demonstrations should be used to functionally checkout and verify the provided control systems actuation display and operating devices. The use of ground tests and demonstrations will determine if the provisions work as designed without impacting flight safety.

VERIFICATION LESSONS LEARNED (4.4.7.29)

A Fire Timeline is useful when developing verification requirements for control system response.

G.3.4.7.30 Control systems integrity assurance provisions.

Provisions shall be made for the crew to confirm that the system is 100 percent (100%) fully operational.

REQUIREMENT RATIONALE (3.4.7.30)

This requirement defines the features of the systems intended to be used by the crew during preflight checks to determine the operational condition of the circuits and components of the control systems.

REQUIREMENT GUIDANCE (3.4.7.30)

System safety dictates the inclusion of necessary controls and displays to indicate that the systems are operational and fully functional and to indicate that a system has failed and protection is not being provided. Configuration, location, and method characteristics should be specified. Design the monitoring system so that its electrical continuity can be verified as part of the preflight or prelaunch check. For continuity checks, specify equipment that is specifically designed for this application. Inadequate equipment may cause system actuation during the check. Indicator light standards dictate an amber light, if crew response is not required, and red light, if immediate crew response is required.

REQUIREMENT LESSONS LEARNED (3.4.7.30)

The standard method to verify fire extinguishing agent container pressure has been by providing a pressure gage on the container. On the C-5 air vehicles, where the containers are approximately 20 feet above the ground, or on others, where the pressure gages are not readily available, pressure switches are used on the containers with lights in the cockpit. When the bottle pressure falls below a preset pressure, the light will come on.

On explosion suppression systems using LN_2 the suppressant reservoirs are usually hermetically sealed and have no gages. However, the system is usually provided with a status indicator which indicates if the system has been used.

G.4.4.7.30 Control systems integrity assurance provisions.

It shall be verified by analysis, inspection, and test that a means to ensure 100 percent (100%) full operational capability has been provided.

VERIFICATION RATIONALE (4.4.7.30)

Verification of the proper location, configuration, and operation of the control systems integrity assurance provisions is necessary to the flight safety of the air vehicle.

VERIFICATION GUIDANCE (4.4.7.30)

The required analysis and inspection should be part of a fire and explosion hazard analysis done to determine the protection required for the total air vehicle. Ground tests and demonstrations should be used to functionally checkout and verify the 100 percent (100%) full operational capability of the control systems. The use of ground tests and demonstrations will determine whether the provisions work as designed without impacting flight safety.

VERIFICATION LESSONS LEARNED (4.4.7.30)

Control System Integrity should be considered a Safety Critical Function. Further guidance can be found in MIL-STD-1798.

G.3.4.7.31 Ground fire fighting.

Ground fire fighting access provisions shall be provided for all designated fire zones. These ground fire fighting access provisions shall be compatible with standard ground fire fighting extinguishing agent dispensing systems. Ground fire fighting provisions shall also be considered for other internal areas.

REQUIREMENT RATIONALE (3.4.7.31)

Preplanned access doors or other access provisions could greatly facilitate the introduction of fire extinguishing agent to potential fire sites.

REQUIREMENT GUIDANCE (3.4.7.31)

In addition to providing access doors to known fire zones, consideration should be given to providing ground access to other potential fire areas which could be caused by gear up landing or be due to maintenance.

Include the fire zone location, size, weight, and extinguishing agent flow requirements.

REQUIREMENT LESSONS LEARNED (3.4.7.31)

Spring loaded, push-in doors and louvers have been used successfully to provide ground access for propulsion installations.

G.4.4.7.31 Ground fire fighting.

The adequacy and proper installation of ground fire fighting access provisions should be verified by inspection.

VERIFICATION RATIONALE (4.4.7.31)

Inadequate access to internal fire sites will hamper or defeat ground fire fighting actions.

VERIFICATION GUIDANCE (4.4.7.31)

In some cases, this requirement has been deleted when the location of the protected area made the design impractical. For example, the C-5 engine installation is located 20 feet above the ground, where the average fire fighter has difficulty reaching.

VERIFICATION LESSONS LEARNED (4.4.7.31)

(TBD)

G.5 PACKAGING

G.5.1 Packaging.

For acquisition purposes, the packaging requirements shall be as specified in the contract or order (see 6.2). When packaging of materiel is to be performed by DoD or in-house contractor personnel, these personnel need to contact the responsible packaging activity to ascertain packaging requirements. Packaging requirements are maintained by the Inventory Control Point's packaging activities within the Military Service or Defense Agency, or within the military service's system commands. Packaging data retrieval is available from the managing Military Department’s or Defense Agency's automated packaging files, CD-ROM products, or by contacting the responsible packaging activity.

G.6 NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

G.6.1 Intended use.

The fire and explosion hazard protection subsystem descriptions in this appendix are intended for use in air vehicle systems developed to perform combat and combat-support missions in environments unique to military weapon systems.

G.6.2 Acquisition requirements.

Acquisition documents should specify the following:

a. Title, number, and date of the specification.

G.6.3 Definitions.

Detection system: The detection system is defined as all those components, wiring, connectors, relays, control units, crew displays, power supplies, and any other components necessary to detect a hazard and transmit that information to the crew and for everyday operations and test of the system.

G.6.4 Acronyms.

The following list contains the acronyms/abbreviations contained within this appendix.

API	Armor Piercing Incendiary
COTS	Commercial Off The Shelf
EPU	Emergency Power Unit
FEHA	Fire and Explosion Hazard Analysis
FMEA	Failure Modes and Effects Analysis
HEIT	High Explosive Incendiary Tracer

HRD	High Rate Discharge
IR	Infrared
LN_2	Liquid Nitrogen
LO	Low Observable
MEPU	Monopropellant Emergency Power Units
ODC	Ozone Depleting Chemical
SEA	Southeast Asia
SPGG	Solid Propellant Gas Generator
SPU	Secondary Power Unit
UV	Ultraviolet

G.6.5 Subject term (key word) listing.

Alarm

Combustible

Cooling

Detector

Drainage

Fire barrier

Fire hardening

Hazard resistance

Isolation

Lightning

Ventilation

G.6.6 Responsible engineering office.

The office responsible for the development and technical maintenance of this appendix is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL. Requests for additional information on this appendix can be obtained from AFLCMC/ENRS, BLDG 28 RM 118, 2145 MONAHAN WAY, WPAFB OH 45433-7017 USA; DSN 674-5476; COMMERCIAL (937) 904-5476; ENGINEERING.STANDARDS@US.AF.MIL.

G.6.7 Amendment notations.

The margins of this specification are marked with vertical lines to indicate modifications generated by this amendment. This was done as a convenience only and the Government assumes no liability whatsoever for any inaccuracies in these notations. Bidders and contractors are cautioned to evaluate the requirements of this document based on the entire content irrespective of the marginal notations.

APPENDIX H

AIR VEHICLE ELECTRICAL POWER SUBSYSTEM

REQUIREMENTS AND GUIDANCE

H.1 SCOPE

H.1.1 Scope.

This appendix provides the requirements, verifications, tailoring guidance, and background information for the Electrical Power Subsystem provided for in Part 1 of this specification. This appendix has been developed and coordinated by technical personnel from the Air Force, Navy, and Army and has been approved as an official guide for use by Government personnel for assistance in tailoring the air vehicle subsystems specification for acquisition and model specifications. This appendix is a mandatory part of the specification. The information contained herein is intended for compliance.

H.1.2 Structure.

The appendix structure replicates the structure of the Air Vehicle Subsystems Specification except it places each corresponding section 3 requirement and section 4 verification together.

H.1.3 Appendix.

This appendix provides tailoring guidance and background information for individual paragraphs of the Air Vehicle Subsystems Specification. Guidance gives recommendations on how to tailor the specification paragraph. Where __(TBS)__ appears, the guidance paragraph provides recommended values or text that the Using Service may use to insert in the __(TBS)__. When contractors are expected to complete the __(TBS)__, the Guidance paragraph will so state. The Using Service makes the final decision on whom completes the __(TBS)__ in the specification. Finally, Lessons Learned are provided to give insight to past events that could impact the tailoring of the specification.

H.1.4 Deviations.

Projected designs for given applications which will result in improvement of the system performance, reduced life cycle cost, or reduced developmental cost through deviations from this guidance, or where requirements of the specification results in compromise in operational capability, should be brought to the attention of the Using Service.

H.1.5 Environmental impact.

Air Vehicle Subsystems will be designed such that their operation, maintenance, and repair may be accomplished without violating the most stringent environmental regulations applicable to locations where subsystems are used or supported. Compliance with environmental regulations will not prevent subsystems from achieving and sustaining mission performance capability. Materials, processes, and environmental control equipment necessary to meet these environmental requirements must currently be available in the Using Service's maintenance and supply system. The design will not use environmentally unsuitable materials such as ozone depleting fluorocarbons, chlorofluorocarbons, and halons, or highly volatile organic compounds in solvents and coatings during development, production, operation, maintenance, or repair. The Environmental Protection Agency maintains an online list of toxic chemicals and hazardous substances on its Ozone Layer Depletion Website at http://www.epa.gov/ozone/snap/ that should be consulted. The Significant New Alternatives Policy (SNAP) Program available thereon identifies substitutes for ozone depleting chemicals.

The contractor will conduct an environmental analysis of air vehicle subsystems.

H.1.6 Responsible engineering office.

The responsible engineering office (REO) for this appendix is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL.

H.2 APPLICABLE DOCUMENTS

H. 2.1 General.

The documents listed in this section are specified in sections 3 and 4 of this handbook. This section does not include documents cited in other sections of this guide specification or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3 and 4 of this handbook, whether or not they are listed.

H.2.2 Government documents

H.2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this appendix to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

INTERNATIONAL STANDARDIZATION AGREEMENTS

NORTH ATLANTIC TREATY ORGANIZATION/
AIR AND SPACE INTEROPERABILITY COUNCIL

ASCC AIR STD 25/18	Connectors for 28 Volt DC Servicing Power
STANAG 3109	Symbol Marking of Aircraft Servicing and Safety/Hazard Points
STANAG 7073	Connectors for Aircraft Electrical Servicing Power

(Copies of these documents are available at http://quicksearch.dla.mil, http://nso.nato.int, www.airstandards.org, and www.ihs.com to qualified users.)

DEPARTMENT OF DEFENSE SPECIFICATIONS

MIL-E-7016	Electric Load and Power Source Capacity, Aircraft, Analysis of
MS17793	Schematic Wiring Diagram (External AC Power Connector, Aircraft)
MIL-PRF-18148/3	Receptacles, Electric, Aircraft Storage Battery

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-704	Aircraft Electric Power Characteristics
MIL-STD-7080	Selection and Installation of Aircraft Electric Equipment

(Copies of these documents are available online at http://quicksearch.dla.mil or from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia PA 19111-5094 USA.)

H.2.3 Non-Government publications.

The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

SAE INTERNATIONAL

SAE AS35061	Connector, Receptacle, External Electric Power, Aircraft 28 Volt DC Operating Power
SAE AS50881	Wiring, Aerospace Vehicle
SAE AS90362	Connector, Receptacle, External Electric Power, Aircraft 115/200 Volt, 400 Hertz

(Copies of these documents are available from www.sae.org; SAE International, 400 Commonwealth Drive, Warrendale PA 15096-0001 USA; and from www.ihs.com to qualified users.)

H.2.4 Order of precedence.

Unless otherwise noted herein or in the contract, in the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

H.2.5 Streamlining.

The Air Vehicle Subsystems Specification has been streamlined. The documents listed in this appendix which are required for acquisition have the same status as those referenced directly in section 2 (first tier). All other documents referenced through tiering may be used for guidance and information only.

H.3 REQUIREMENTS

H.4 VERIFICATIONS

H.3.1 Definition

H.4.1 Definition

H.3.2 Characteristics

H.4.2 Characteristics

H.3.3 Design and construction

H.4.3 Design and construction

H.3.4 Subsystem characteristics

H.4.4 Subsystem characteristics

H.3.4.1 Landing subsystem

H.4.4.1 Landing subsystem

H.3.4.2 Hydraulic subsystem

H.4.4.2 Hydraulic subsystem

H.3.4.3 Auxiliary power subsystem

H.4.4.3 Auxiliary power subsystem

H.3.4.4 Environmental control subsystem

H.4.4.4 Environmental control subsystem

H.3.4.5 Fuel subsystem

H.4.4.5 Fuel subsystem

H.3.4.6 Aerial refueling subsystem

H.4.4.6 Aerial refueling subsystem

H.3.4.7 Fire and explosion hazard protection subsystem

H.4.4.7 Fire and explosion hazard protection subsystem

H.3.4.8 Electrical power subsystem.

The electrical power subsystem shall be sized and configured to provide onboard generation, conversion, storage, distribution, and control of the electric power required for all phases of vehicle operation, including ground maintenance.

REQUIREMENT RATIONALE (3.4.8)

The electrical power subsystem is the primary energy source for operation of electrical and electronic equipment onboard the air vehicle. Proper specification of the functional and performance characteristics is essential for the safe and reliable operation of the electrical power subsystem.

REQUIREMENT GUIDANCE (3.4.8)

There are a number of options that should be considered when configuring an electrical power subsystem. Some elements of the design are dependent on the criticality of utilization equipment regarding safety and mission success. Some aspects of the electrical subsystem configuration are discussed below.

Consideration should be given to the use of uninterruptible power sources for fly-by-wire flight controls and other flight critical loads that require continuous power to maintain control of the air vehicle. Not only are redundant sources typically required, but these sources usually should be capable of instantly assuming the loads without manual or automatic switching which would degrade subsystem integrity. In contrast to the emergency power units for less critical loads, which may operate only when needed, sources of uninterruptible power should be capable of continuous in-flight operation. The number of failures of sources of uninterruptible power which should be accommodated without interruption or degradation of power to flight critical loads normally should be identified. On air vehicles with flight critical subsystems requiring electrical power, the electrical power subsystem also becomes flight critical.

Independent emergency power sources are normally required in the event of failure of the primary power source. Emergency sources usually should operate over the entire flight envelope and be capable of supplying all loads essential for control of the vehicle and personnel safety. A means of verifying the operational readiness of the emergency power source prior to flight should be provided. Transfer of essential loads to and from the emergency power source should be accomplished without transients of a magnitude hazardous to the vehicle or personnel.

The required period of operation of an emergency source is a critical parameter that should be specified. When the emergency source is energy-limited as in the case of a storage device such as a battery, the available energy should be sufficient to ensure operation for the required time period. 30 minutes is the minimum time for emergency power operation that should be considered. This period is generally sufficient for the crew to regain control of the air vehicle and make an emergency landing. Other types of emergency sources, such as generators, may not be time limited. The power rating of the emergency source should be sufficient to supply the emergency loads identified by an electrical load analysis. This analysis can be performed in accordance with MIL-E-7016.

The response time for initially supplying emergency power is also a consideration. This area involves factors such as means of sensing power failure, manual or automatic power transfer, and the time required for the emergency unit to come up to speed or otherwise respond. Should normal power subsequently be restored, manual or automatic means for returning loads to the main source should be provided. Automatic transfer can be detrimental if it surprises the crew with an additional disturbance at a critical time.

To maintain confidence in the reliability of the emergency power source, it should be given an operational check before each flight, if possible. If not, other means of verifying operational readiness should be provided.

Air vehicle operational requirements may necessitate an onboard auxiliary power unit (APU) to provide electric power for certain modes of ground or air operation. The electrical power subsystem should be capable of generating, controlling, and distributing APU electric power in a safe and effective manner. Auxiliary power requirements for ground maintenance, subsystem checkout, manned alert, lighting, cargo loading, starting, or other operations should be specified as determined from analysis of air vehicle operational requirements. The quantity of APU power required should be specified; whether both ground and airborne operation are required, whether parallel operation with main generator(s) or ground power is required, or whether no-break power transfer to and from the APU is required. In some installations, the APU may be able to serve as an emergency power source.

Electrical power subsystems often provide several different power forms such as 115 volt, 400 Hz, AC; 115 volt, 60 Hz, AC; 270 volt DC; and 28 volt DC. There is normally one primary power source with electronic conversion equipment being used to change the primary power form to other forms. This conversion equipment often forms a major portion of the electrical power subsystem and its successful design is important in achieving a stable and reliable subsystem.

Additional guidance on tailoring the specific requirements of the electrical power subsystem is provided in the individual subparagraphs.

REQUIREMENT LESSONS LEARNED (3.4.8)

Experience has shown that an emergency power source intended for operation only after a malfunction has occurred is not a suitable backup for fly-by-wire flight controls. The startup and operating reliability of the emergency power units in the past have been deficient for this purpose. Consideration should be given to have full-time redundant power sources to meet the fly-by-wire requirements.

One air vehicle started out with a mechanical flight control system with a fly-by-wire system as a backup. Part way through the design, the fly-by-wire became primary with the mechanical system only usable in certain portions of the flight envelope. This late change resulted in significant redesign of the electrical subsystem to meet redundancy and uninterruptible power requirements.

Despite excess capacity, redundancy, and all other measures taken to ensure a reliable subsystem, total failures of the primary power sources do occur. For multi-generator air vehicles there is the tendency to assume that the redundancy of main generators will suffice for the emergency requirement. Experience has shown otherwise. Many modern multi-generator air vehicles have experienced total failure of the primary power subsystem. An independent emergency power source should be considered for this situation. Installation of a permanent magnet generator on each engine shaft is an approach to provide last ditch power to keep the air vehicle in the air.

Serious consideration has been given to eliminating the emergency generator from several programs as a cost and weight savings. However, on several occasions during the flight test program, the emergency generator was required to supply power following multiple failures of the main electrical subsystem.

The method of returning emergency loads to the normal power source on one air vehicle was changed from automatic to manual following an in-flight incident. A flight control transient resulting from main generator failures had just settled out when normal power was again restored. When the flight controls were then automatically transferred back to main power, the crew was surprised with a second disturbance as severe as that caused by the original failure.

Another incident illustrates the criticality of emergency power control logic. A partial failure of the hydraulic subsystem powering the emergency generator caused it to be powered up to speed by an overlooked hydraulic “sneak circuit.” When the emergency generator tried to power the essential bus, there was insufficient hydraulic power to support it. As a consequence, the essential bus cycled on and off a malfunctioning emergency power unit thereby adding a critical electrical problem to the original hydraulic failure.

APUs have proven to be beneficial to most air vehicles. They eliminate the need to connect external electrical power for any maintenance, checkouts, and other operations. They can also provide electrical power for alert situations, emergency power, and hot turns.

H.4.4.8 Electrical power subsystem.

The size and configuration of the electrical power subsystem to provide onboard generation, conversion, storage, distribution, and control of the electric power required for all phases of vehicle operation shall be verified incrementally by __(TBS)__.

VERIFICATION RATIONALE (4.4.8)

Verification is required to assure that performance, interface, and functional requirements are met.

VERIFICATION GUIDANCE (4.4.8)

TBS: Verification should be accomplished incrementally and encompass planning, procedure preparation, and reporting. Verification should be accomplished by test, analysis, inspection, or a combination thereof.

Analysis should be considered for many aspects of the development such as assessing electrical loading, distribution bus structure, circuit sizing, and failure mode assessment. Electrical load analysis techniques, such as those in MIL-E-7016, are crucial to understanding the electrical loading of each component of the electrical power subsystem under various flight and ground conditions.

Laboratory tests should be performed on a subsystem mockup that accurately simulates the air vehicle installation. Testing should include the most adverse electrical loading, environmental, fault, and endurance conditions required of the subsystem.

Air vehicle ground and flight tests of the installed electrical power subsystem should be performed under the most adverse conditions of electrical loading, cooling, and flight maneuvers. Failure modes that are hazardous to personnel or the air vehicle should be simulated.

Some aspects of the subsystem can be verified by inspection such as installation of external power connectors.

VERIFICATION LESSONS LEARNED (4.4.8)

The development of a laboratory based electrical power subsystem demonstrator has been shown to be essential in evaluating electrical power subsystem performance under various operating conditions. With the ever-increasing integration of different subsystems onboard air vehicles, the need for high fidelity capability in subsystem integration laboratories is paramount.

H.3.4.8.1 Electrical power characteristics.

The characteristics of the electrical power provided at the terminals of the power utilization equipment shall be in accordance with __(TBS)__.

REQUIREMENT RATIONALE (3.4.8.1)

It is necessary to establish a standardized electric power interface to ensure electrical compatibility between the electrical power subsystem and the equipment using electric power. This standard establishes both electrical power quality requirements that the electrical power subsystem is to provide as a supplier of power to utilization equipment and the parameters within which the using equipment must operate acceptably. Interface characteristics typically controlled include voltage, frequency, distortion, and phase displacement, including steady state and transient limits.

REQUIREMENT GUIDANCE (3.4.8.1)

TBS should normally be filled in with the current issue of MIL-STD-704 for the electric power interface for new air vehicles. If there are overriding considerations that require deviation from the standard, the appropriate limits and interface requirements from MIL-STD-704 together with the peculiar air vehicle limit and interface requirements should be specified. Interface characteristics that are typically controlled include voltage, frequency, distortion, and phase displacement, including steady state and transient limits.

When the electrical power subsystem of an existing air vehicle is modified, the specified power quality should be compatible with the original air vehicle requirements to ensure that existing utilization equipment will continue to function properly. Therefore, the current version of MIL-STD-704 should be specified for modifications only if it ensures power quality equal to or better than the original requirement. Comparison of the requirements of the current version of MIL-STD-704 with earlier versions of the specification should be performed to make this determination.

For unmanned air vehicles, special requirements may dictate electrical power with different characteristics than MIL-STD-704. In these cases, MIL-STD-704 should be considered as a guide when preparing the electrical power characteristics specifications for both the electrical power subsystem and the using equipment.

Since the requirement in this specification actually only defines the electrical power quality of the electrical power subsystem, the compatibility of all utilization equipment with the electrical power subsystem should be checked. The power quality standard should be included in each vendor specification and all utilization equipment should be tested prior to installation on the vehicle.

REQUIREMENT LESSONS LEARNED (3.4.8.1)

Some air vehicles have had problems of incompatibility between air vehicle power and utilization equipment. In some cases, the electrical power subsystem had to be reworked to accommodate the equipment even though the original power quality requirements were met. Frequently, utilization equipment have not been designed or tested to the vehicle power quality standards, resulting in incompatibilities and redesign of the equipment. These problems point out that the power interface requirements should be carefully chosen and consistently applied to both the electrical power subsystem and the utilization equipment.

Requirements for power quality are contained in MIL-STD-704, which was first issued in October 1959. Present requirements have evolved through several revisions to MIL-STD-704. Requirements for some unmanned air vehicles have deviated from this standard.

Commercial standards such as SAE AS1831 are very similar to MIL-STD-704 and should be given consideration as an alternative power quality standard, if trade studies show a cost or weight savings. Company standards and commercial standards must be reviewed closely when used to define power quality supplied to Government Furnished Equipment (GFE). Government Furnished Equipment typically is qualified to a version of MIL-STD-704 and may have problems operating on company standards.

H.4.4.8.1 Electrical power characteristics.

Electrical power subsystem compliance with the electrical power characteristics requirements shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.8.1)

Verification is required to ensure that performance, interface, and functional requirements are met.

VERIFICATION GUIDANCE (4.4.8.1)

TBS should be filled in with the particular analyses and tests appropriate for the electrical power subsystem under consideration. The following elements should be considered in determining these requirements.

a. Component requirements and test results should be analyzed to ensure that component performance is consistent with overall subsystem requirements.

b. The entire electrical power subsystem should be tested as a whole to verify that the power quality at the inputs to the utilization equipment is within specified limits for all normal and abnormal conditions. Laboratory testing of the electrical power subsystem in an air vehicle configuration should be conducted to demonstrate this requirement. The electrical power subsystem laboratory testing should be in a configuration that includes all components of the subsystem up to the utilization equipment (including wire, cabling and connectors and circuit protection devices). Testing should include the most adverse electrical loading, fault, and endurance conditions required of the subsystem.

VERIFICATION LESSONS LEARNED (4.4.8.1)

Experience has shown that retaining functional subsystem mockups throughout the life of the program allows for continued testing and analyses of subsystem design and resolution of failures.

H.3.4.8.2 Capacity.

The electrical power subsystem shall provide electrical power in sufficient quantity for all modes of vehicle operation plus additional capacity for growth loads as follows: __(TBS)__. In addition, the capacity for generating, conversion, emergency, and starting equipment shall be defined separately.

REQUIREMENT RATIONALE (3.4.8.2)

It is essential to define the required capacity of the electrical power subsystem since it is a critical design parameter affecting the air vehicle design. Weight and volume impacts can be significant.

REQUIREMENT GUIDANCE (3.4.8.2)

TBS should be filled in with the required capacity of the electrical power subsystem as determined by the total electrical power requirements of the air vehicle. All modes of air vehicle operation should be considered as well as provisions for load growth and any necessary redundancy. Electrical power subsystem capacity should normally be at least twice the maximum continuous load of the initial production air vehicle to provide for growth, unless other overriding considerations prevent this growth capacity. Providing for this level of growth is commonly implemented for cargo and bomber air vehicles. Smaller growth margins (on the order of 30 percent (30%)) are often used for fighter air vehicles because the increased weight associated with larger capacity components is usually considered to be unacceptable. Factors listed below should be considered.

a. Steady state and short duration load requirements
b. Component power ratings
c. Capacity derating factors such as temperature and altitude (including oil supply, input speed, and horse-power)
d. Growth requirements
e. Redundancy for flight critical subsystems

The MIL-E-7016 procedures can be used for the analysis of load requirements and power source capacity.

Some limited application air vehicles and most missiles do not require growth capacity. In such cases, consultation with the procuring activity should be considered.

REQUIREMENT LESSONS LEARNED (3.4.8.2)

As a general rule, air vehicle electrical loads continue to grow after the initial design. Some air vehicles have been forced to eventually change to larger generators or add additional generating capability as the loads increased. Experience has shown that extra capacity has also been needed for failure conditions, which resulted in a generator loss, to ensure that all subsystems can still function. Growth capacity has also prevented brownouts from occurring.

Some air vehicles that were converted over to special mission purposes required an entirely new electrical subsystem. At times, even a 100-percent (100%) growth capacity has not be enough. It has not been uncommon to see original equipment 40 KVA generators replaced with 120 KVA generators.

H.4.4.8.2 Capacity.

The ability of the electrical power subsystem to meet the capacity requirements shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.8.2)

Analyses of air vehicle requirements are needed to establish the capacity required of the electrical power subsystem for initial loads, growth and redundancy. Subsequent testing is necessary to confirm actual air vehicle loads and electrical power subsystem capacity.

VERIFICATION GUIDANCE (4.4.8.2)

TBS should be filled in with the appropriate mixture of analysis and test for the particular application. MIL-E-7016 provides an approach and associated procedures for summarizing and documenting both steady state and short duration electrical loading conditions in determining the required capacity of the electrical power subsystem and its components.

Actual air vehicle loads and installed subsystem performance should be determined by air vehicle testing.

Actual loads of individual electrical power users often will not be available until vendors have tested their equipment to verify the actual power utilized. Close work with the vendors early in the program can obtain the best estimates on loads so that the electrical power subsystem may be sized correctly from the start.

VERIFICATION LESSONS LEARNED (4.4.8.2)

In the early stages of design, the electrical power needed is usually underestimated by the vendor; and by the time the first operational air vehicle is delivered, the actual loads are above the original estimates. Experience has shown that careful review of vendor estimates of needed power early in the program has been helpful to assure that the electrical subsystem was sized correctly. Adding 25 percent (25%) larger generators halfway through the design can severely impact the total subsystem design.

H.3.4.8.3 External ground power compatibility.

The electrical power subsystem shall accept and distribute maximum required levels of power from external sources identified as being required for ground operations, while maintaining electrical power characteristics in accordance with "Electrical power characteristics" in this appendix; including transfer between onboard equipment and the external sources in both directions. The electrical power subsystem shall protect against unsuitable external power being applied to the air vehicle. If applicable, external power receptacles shall meet interface requirements in accordance with the latest international agreements included in North Atlantic Treaty Organization Standardization Agreements (NATO STANAGs) and Air Standardization Coordinating Committee (ASCC) Standards and shall meet the following additional requirements: __(TBS)__.

REQUIREMENT RATIONALE (3.4.8.3)

External power is usually necessary for ground operations such as maintenance, ground alert, air vehicle lighting, and engine starting. Therefore, the ability to utilize external ground power sources, and to interface with such, is important.

REQUIREMENT GUIDANCE (3.4.8.3)

TBS should be filled in with consideration of the following.

a. External power receptacles should be accordance with international agreements included in NATO STANAGs and ASCC Standards.

b. External power receptacles should be accessible from ground level and should be located to minimize hazards to ground personnel. They should not be located in or near hazardous areas such as air inlets or exhausts, APU or jet fuel starter exhaust, propellers or propeller blasts, or fuel servicing or vent areas. The safe and convenient location of external power receptacles should be a prime consideration to facilitate servicing and to minimize hazards to the ground crew.

c. When dictated by operational requirements, the receptacle should be designed so that the power cable and plug will pull out of the receptacle when the air vehicle moves forward, if ground maintenance personnel forget to remove the plug.

d. Consideration should be given to the use of the external power receptacle for connecting load banks to the air vehicle for ground checkout of the electrical power subsystem.

e. Receptacles should be isolated from air vehicle power circuits when the mating plug is disengaged to ensure that dangerous voltages are not present.

The quantity of ground power that the electrical power subsystem is to be designed to handle can be obtained from the electrical load analysis per MIL-E-7016. Protection against poor quality external power should be considered to prevent damage to the electrical power subsystem and power-using equipment. MIL-PRF-24021 covers external power monitors that provide this protection. Some air vehicles require that the transfer from ground power to air vehicle power, and the reverse, be made without power interruption because of sensitive on-board equipment. This requirement should be invoked as needed. Peculiar power transfer transients over and above MIL-STD-704 or alternative power quality standards should be specified.

NATO STANAG 7073 and ASCC AIR STD 25/18 presently specify interface requirements for 28 volt DC and 115 volt, 400 Hz, external power connectors.

NATO STANAG 3109 specifies marking requirements. Receptacles for 28-volt DC external power should meet SAE AS35061 to comply with the documents. Receptacles for 115 volt, 400 Hz external power should meet SAE AS90362 and be connected in accordance with MS17793. Pins E and F of these receptacles should not have 115 volt AC applied by the air vehicle since these pins mate to 28 volt DC circuits in some ground power carts. Prominent identification of the receptacle should be used to facilitate air vehicle servicing by ground crews.

REQUIREMENT LESSONS LEARNED (3.4.8.3)

Some air vehicles use the external power receptacle to connect loads to the air vehicle for ground check of the onboard electrical power subsystem. This approach has eliminated the need to operate onboard equipment as loads for this purpose.

Use of incompatible interfaces has caused damage to air vehicle equipment when using the ground power carts provided by some installations.

H.4.4.8.3 External ground power compatibility.

The ability of the electrical power subsystem to meet external ground power requirements shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.8.3)

Analyses of external power requirements are necessary in order to design the electrical power subsystem interface with external power. Subsequent testing is required to confirm that the external ground power performance requirements of the electrical power subsystem are met.

VERIFICATION GUIDANCE (4.4.8.3)

TBS should be filled in with an appropriate combination of tests, analysis, and inspection in consideration of the following.

The procedures of MIL-E-7016 can be used to analyze the electrical loading requirements for external power. The capability of the electrical power subsystem to accept and distribute the maximum external power requirements while maintaining the required power quality should be determined by a combination of analyses and tests. Testing should normally be performed at both an electrical mock-up and onboard the air vehicle.

Protection of the air vehicle against accepting unsuitable external power should be verified by analyses and tests.

Proper selection and installation of external power receptacles can be verified primarily by inspection of applicable drawings and the air vehicle.

VERIFICATION LESSONS LEARNED (4.4.8.3)

External power receptacles have been standardized to assure that any air vehicle can be provided external power at any location. This approach eliminates the need for onboard APUs. If the standard power receptacle is not used, then special power carts or adapters will be required at remote locations.

H.3.4.8.4 Power distribution.

Electric power shall be distributed from the various power sources to the air vehicle loads as follows: __(TBS)__.

REQUIREMENT RATIONALE (3.4.8.4)

An effective distribution subsystem is needed to transmit electric power to the using equipment in a safe and reliable manner.

REQUIREMENT GUIDANCE (3.4.8.4)

TBS should be filled in with consideration of power quality, load priorities, reliability, vulnerability, and safety.

The bus structure and distribution circuits should be configured so that normal electrical power subsystem operational loads receive power from the air vehicle primary power source(s), ground power, or an auxiliary power source as applicable.

If an electrical power subsystem failure reduces the amount of available power below total air vehicle requirements, non-flight critical and pre-selected loads should be automatically disconnected as necessary to maintain subsystem integrity.

Flight critical loads should have first priority to primary power and should be supplied from the emergency power source when primary power is not available.

Load management should be implemented by vehicle control and management system for all flight loads (for example, electromechanical and electro-hydrostatic actuators), except the flight-critical loads, through Electrical Load Management Centers (ELMCs). This will allow for better load management or load shedding in case of different conditions of loss of power for different mission scenarios.

The distribution wiring should be sized such that the power quality requirements of “Electrical power characteristics” in this appendix are maintained at the terminals of the utilization equipment. The power distribution subsystem interfaces with avionics wiring and the airframe. Therefore, the requirements of SAE AS50881 should be applied. In addition, the requirements of MIL-STD-7080 for the installation of electrical equipment should be considered. The air vehicle structure should be considered as return or ground for primary power distribution where possible. This will provide wiring weight reduction.

Convenient means should be provided for disconnecting ground power from equipment not requiring power during ground operation.

REQUIREMENT LESSONS LEARNED (3.4.8.4)

The power distribution subsystem on some air vehicles has malfunctioned or been improperly designed. The malfunction in the distribution subsystem resulted in partial or total loss of all electrical power.

Automatic load shedding has been shown to be important in the event of a partial loss of the electrical subsystem. This provision has reduced the likelihood of the entire subsystem being lost due to one item failing. The crew cannot be expected to shut down equipment in time to prevent a total electrical subsystem failure. Some air vehicles without load shedding have lost total electrical power due to one small failure that could have been automatically detected and isolated.

Program experience has shown that mission completion success rate has been low because of failures caused by mission-critical loads. The Fail-Op fault tolerance for the mission-critical loads should be extended to the distributed bus (ELMC) level.

H.4.4.8.4 Power distribution.

Compliance with the power distribution requirements shall be verified by analyses and tests as follows: (TBS) .

VERIFICATION RATIONALE (4.4.8.4)

Analyses and tests are the appropriate means of verifying compliance with this requirement.

VERIFICATION GUIDANCE (4.4.8.4)

TBS should be filled in with the appropriate mix of analysis and test. The following items should be considered.

a. Analyses appropriate for this requirement include electrical load analyses per MIL-E-7016, hazard analyses, failure mode and effect analyses, and circuit analyses.

b. Testing should be used to verify distribution subsystem performance in the laboratory and on the vehicle. The laboratory testing should duplicate actual electrical loads and simulate normal and fault conditions.

VERIFICATION LESSONS LEARNED (4.4.8.4)

Experience has shown that the distribution subsystem needs the same careful design and analysis effort as the main electrical subsystem itself.

H.3.4.8.5 Control and protection.

The electrical power subsystem shall provide the following control and protective functions: (TBS) .

REQUIREMENT RATIONALE (3.4.8.5)

Appropriate means of control and protection are necessary for the safe and effective operation of the electrical power subsystem.

REQUIREMENT GUIDANCE (3.4.8.5)

TBS should be filled in with the specific functions necessary for the particular application. Factors that should be considered include crew instrumentation and controls, failure modes and effects, automatic control and protection, reliability, vulnerability, and safety. The following is provided to aid in determining these functions.

a. Routine operations of the electrical power subsystem such as normal start-up, shut-down, paralleling, and voltage and frequency regulation, which require no crew decisions, should be performed automatically. Fault clearing in a list of routine operations should be performed automatically. The control function, if automatic, should allow for anticycling. The crew should be provided with the instruments and manual controls necessary for effective control of the electrical power subsystem for both normal and abnormal operation. These provisions need to include indications of all subsystem faults and malfunctions that affect flight safety or mission effectiveness. Means of controlling the electrical power subsystem should be provided such that mission and safety requirements are met without unnecessarily burdening the crew. On the other hand, the crew should be involved in non-routine situations in which crew action can improve mission effectiveness or control abnormal or hazardous conditions.

b. Automatic protective functions should be provided for abnormal conditions of the electric power subsystem which require a prompt predetermined response and for which no crew decisions are needed. Faults and malfunctions should be detected, isolated, and de-energized in a manner which eliminates the hazardous condition to ensure safety of the air vehicle and minimize performance degradation.

c. All distribution circuits including generator feeders, bus ties, and load circuits should be protected against short circuits and overloads throughout their total length. Each load circuit should be individually protected to prevent a single fault from affecting more than one critical function.

d. Redundant power circuits and components should be routed and located separately to minimize vulnerability. Means should be provided for detecting the failure of each redundant component. The advantages of redundant components are realized only if the components are sufficiently isolated electrically and physically so that multiple failures are improbable. Furthermore, if there is no way to detect the failure of a redundant component, the value of redundancy is lost.

e. For fault protection mechanisms to perform properly, it is important that equipment subject to electrical faults of primary power be properly bonded and grounded to the air vehicle structure. The impedance of the entire fault return path should be low enough such that the available fault current will quickly trip the protective devices (typically, tens of milliseconds).

f. Circuit breakers that are essential for flight safety should be able to be easily re-set by the crew.

REQUIREMENT LESSONS LEARNED (3.4.8.5)

One electrical power generation subsystem was designed to parallel the main generators through bus tie contactors. As originally designed, the bus tie contactors would open to provide isolated generator operation only for certain fault conditions. Opening was automatic. No crew control was provided. During flight testing it was discovered that faults on the parallel subsystem could produce excessive voltage transients on all buses before the bus tie contactors could open. This situation was corrected by automatic control. On the F/A-18C/D air vehicle, the pilot has manual control to reset the bus tie circuitry. However, this control allows the pilot to re-apply both main generators into a fault.

Switching of one essential bus from the emergency generator back to the main generator was changed from automatic to manual to give the crew better control of an abnormal situation.

The multiplexing of control signals for the electrical power subsystem and for the monitoring and control of individual load circuits is a possible option to reduce the amount of wiring required. The use of a multiplexed data bus for load control signals and related data proved to be a successful approach on the B-1 air vehicle. A significant reduction of wiring weight and volume was achieved.

Multiple wire feeders for the essential bus of one air vehicle have been instrumental in maintaining electrical power under emergency conditions. Attempts to remove this capability during modification programs were met with great resistance from the user community.

Power controllers are power switching devices that connect power to the appropriate bus or load. They generally are mechanical devices such as switches, relays, or contactors; but also include solid state devices for various applications. Experience has indicated that the main drivers in selection of a power controller are current requirements and operational voltage. Solid state devices, which have an inherent voltage drop, have been limited to low current applications because of the heat dissipation (P = IV), but can be used at higher ratings if dissipation is not a main concern (that is, short duration or adequate cooling).

Electromechanical contactors are used for high current applications. However, at 270 Vdc, concern exists about breaking the arc on opening, and additional features are required compared to some 115 Vac counterparts that can take advantage of the zero crossing for arc suppression.

Conventional protective devices such as circuit breakers or fuses have been used to protect the distribution subsystems; they are located at appropriate points on the distribution bus. In many remote applications, the switching and protective functions can be combined into one component, thereby reducing weight and volume. Applications of particular types of power controllers include generator bus contactors, cross-tie contactor, remote control circuit breaker, solid state power controller, and vacuum relays.

H.4.4.8.5 Control and protection.

Compliance with the electrical power subsystem control and protection requirements shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.8.5)

Analyses and tests are the appropriate means of verifying compliance with this requirement.

VERIFICATION GUIDANCE (4.4.8.5)

TBS should be filled in with the appropriate mix of analysis and test for the particular application. Initial verification of control and protection requirements can be accomplished by circuit analyses, including analyses of failure modes and effects. Qualification testing should normally be used to verify that the control and protection requirements of individual components are met. Performance of the complete subsystem can be verified by laboratory and vehicle testing.

VERIFICATION LESSONS LEARNED (4.4.8.5)

Verification of the control and protection subsystem to isolate and remove faults is essential. This verification will show subsystem capability to provide power to non-affected areas. One subsystem failed to detect a small fault that eventually grew until the entire electrical subsystem shut down. Adequate fault detection and isolation would have prevented this occurrence.

H.5 PACKAGING

H.5.1 Packaging.

For acquisition purposes, the packaging requirements shall be as specified in the contract or order (see 6.2). When packaging of materiel is to be performed by DoD or in-house contractor personnel, these personnel need to contact the responsible packaging activity to ascertain packaging requirements. Packaging requirements are maintained by the Inventory Control Point's packaging activities within the Military Service or Defense Agency, or within the military service's system commands. Packaging data retrieval is available from the managing Military Department's or Defense Agency's automated packaging files, CD-ROM products, or by contacting the responsible packaging activity.

H.6 NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

H.6.1 Intended use.

The electrical power subsystem descriptions in this appendix are intended for use in air vehicle systems developed to perform combat and combat-support missions in environments unique to military weapon systems.

H.6.2 Acquisition requirements.

Acquisition documents should specify the following:

a. Title, number, and date of the specification.

H.6.3 Component information

H.6.3.1 Wiring.

Electrical power subsystem performance and reliability is dependent to a large extent on the integrity of the wiring that interconnects the subsystem. Consideration should be given with respect to wiring components and their compatibility for the application, with particular attention given to the application environment. Considerations for wiring installation should include maximum reliability, minimum interference and coupling between subsystems, accessibility for inspection and maintenance, and protection against damage. Since the wiring is normally expected to last for the entire service life of the air vehicle, special care is should be considered in its design and installation. The legacy defense specification MIL-W-5088 and its successor, SAE AS50881, provide guidance based on years of experience with air vehicle wiring installations and on the capabilities of wiring components.

Most problems with air vehicle wiring have involved deterioration caused by the environment, aging, improper application of materials and components, and abuse of various kinds. Moisture, heat, vibration, and rough handling are common hazards that should be recognized and guarded against during subsystem design.

In Vietnam, air vehicles experienced a major problem when the potting compound in the electrical connectors reverted to a sticky, gummy mass because of heat and humidity. This cost millions of dollars and extensive downtime to repair. Environmentally-sealed connectors which do not require potting are now preferred for most applications. Where potting is required, use should be restricted to those materials that have been qualified to the service environment.

Short, easy replaceable harnesses to go between the equipment and air vehicle wiring should be considered for use with equipment that is frequently removed (such as liquid oxygen converters). As the equipment is removed and replaced, the connectors become worn and have to be replaced. After a few replacements, the wires are no longer long enough and an entire harness must be replaced.

Aluminum wire is used on some air vehicles to feed power to the load centers from the engine pylons, and from the load centers to points throughout the air vehicle. Loose connections, electrolysis, and galvanic reactions have led to corrosion and arcing at the terminal lugs. Fires and loss of electrical power have resulted. Therefore, aluminum wire should not be approved for use unless solutions to termination problems have been proven.

H.6.3.2 Batteries.

Batteries that are components of the vehicle electric subsystem should be capable of providing the specified battery power under the environmental and operational conditions to which they will be subjected.

A battery relay should be installed in each battery circuit to enable the flight crew to isolate the battery from the rest of the electric subsystem. The battery relay should be controlled by a crew station battery switch. Any circuits that must remain connected to the battery with the battery switch OFF should be connected directly to the battery through suitable fuses or circuit breakers.

On-board charging of sealed battery subsystems with aqueous electrolyte solutions should be controlled to enable the battery to become fully charged without excessive gassing or heating throughout the entire range of specified battery temperatures. The charging rate should be sufficient to maintain the battery in a state of charge that will meet the battery power demands of normal ground and airborne operation of the air vehicle.

Each battery should be located and installed so that it can be readily inspected and easily removed from the air vehicle without removing other components except for a readily opened access panel or door. The location and design of the battery installation should be such that the release of heat, smoke, gases, electrolyte or other products of a severe battery failure will not damage adjacent components or structure, endanger personnel, or adversely affect crew performance. Since all batteries can vent, the battery compartment, and particularly the battery should be ventilated to prevent the accumulation of explosive mixtures of gases. All vent tubes leading to the exterior of the air vehicle should be designed to preclude the collection of rainwater and other liquids for all ground and flight environments.

The installation should provide for maintaining battery temperature within the limits specified for battery operation. Any heater or thermal insulation required for low temperature operation should be provided as an integral part of the battery and not as part of the air vehicle's battery compartment.

Valve-regulated lead-acid (VRLA) and vented nickel-cadmium (VNC) batteries are the two types of secondary rechargeable batteries most used in air vehicles. VRLA batteries are less costly and easier to maintain. Both can be effectively charged from a simple constant-potential source. Nickel-cadmium batteries can provide better high-rate performance, especially at low temperature, and are more resistant to vibration. The disadvantages of VNC batteries include higher cost, and some can require special maintenance procedures. MIL-PRF-81757 and MIL-PRF-8565 are Tri-Service specifications for VRLA and VNC batteries. These standard batteries, which are the product of considerable Tri-Service experience and research, should be used where suitable. They are procured competitively and in quantities that result in lower cost. If none of the MIL-PRF-81757 or MIL-PRF-8565 standard batteries are suitable, the next best choice for a nickel-cadmium battery would be a non-standard battery. Such non-standard batteries should be designed such that cell removal and replacement is separately impeded. For interface reasons, receptacle should meet MIL-PRF-18148/3.

The effects of temperature, charging efficiency, aging, and other derating factors should be considered in the selection of a battery so required ampere-hour capacity and other performance requirements are met.

Battery sizing depends on the degree of non-interruptible power required and assumes that emergency power can be brought online in certain time duration.

There are two cases: the fly-by-wire system for a traditional electro-hydraulic air vehicle and flight control actuation for the more-electric air vehicles. For precise battery estimates, actuator requirements and capabilities need to be known. Also, some actuator schemes involve the utilization of energy extracted from the air stream in the back drive mode to enhance the overall efficiency. This potential regenerative power source may well reduce the battery sizing requirements.

The air vehicle should be provided with an automatic means to disconnect the battery so that it can be electrically isolated in the event of battery failure. It may be necessary, however, for some circuits to remain connected to the battery at all times.

Effective on-board charging is required to keep secondary batteries adequately charged. Batteries are very sensitive to applied voltage. If the voltage is too low, the battery will not become fully charged. If it is too high, the battery will become overcharged with excessive heating and loss of electrolyte. Excessive overcharging can lead to a catastrophic failure when a battery overheats. It is not good practice to float a sealed nickel-cadmium battery directly on a high current DC bus. Better control of the charging current is needed.

A generally accepted procedure for charging sealed nickel-cadmium batteries is to supply a constant-current charge until a predetermined, temperature-compensated battery voltage is reached. At that point charging is terminated or reduced to a small trickle-charge rate. The "constant" current may be a continuous direct current or a series of pulses of a controlled average value. In addition, charging is terminated when battery temperature becomes excessive. This method of charge control requires sensing battery temperature. Temperature sensors should be added to any battery charged by a constant current airborne charger.

The following factors should be given careful consideration in designing the battery installation.

a. Because of the requirement for maintenance, the battery should be readily accessible for inspection and removal. Handles or carrying straps on batteries are desirable. There is no battery in use in any military air vehicle today that will not require maintenance of some type over the life of the air vehicle.

b. The potential hazard of a battery failure should be recognized in subsystem design. Failure effects can range from excessive gassing to complete thermal destruction.

c. The possibility of hydrogen gas evolution, even with "sealed" subsystems, emphasizes the need for adequate ventilation of the battery to prevent explosive concentrations from developing.

d. The sensitivity of batteries to temperature, vibration, and other environmental factors should be considered.

e. Battery electrolyte will corrode many types of materials. Such materials should not be used in nearby areas or components, or else they should be protected against the electrolyte. In addition, consider using snorkel-type electrolyte deflectors, such as those in MIL-PRF-81757/2 for acrobatic applications.

Indication of battery subsystem malfunctions such as over-temperature, battery discharging, and low battery voltage should be provided to the crew as necessary to meet subsystem safety and reliability requirements.

Catastrophic failures and loss of power have resulted in the loss of both air vehicles and personnel. Instances of less severe problems have caused personnel injury, air vehicle damage, mission aborts, poor maintainability and reliability, and high replacement costs.

Some specific lessons learned are:

a. One air vehicle required a non-standard battery because of available space and the need for thermal insulation. Several deficiencies were later discovered in the design and installation of the unit.

    1. A non-standard cell that was much more costly than an equivalent standard cell was originally selected for the battery. It was later found that the standard cell could be substituted without loss of performance.

    2. The thermal insulation was designed as an integral part of the battery case. This not only increased the initial and replacement costs, but also downgraded battery reliability because of susceptibility to cracking and contamination by the electrolyte. Making the insulation (or other thermal conditioning) a part of the air vehicle battery

compartment rather than a part of the battery would have been a better approach. These points also apply to battery heater blankets.

3. The original configuration of the battery vent tube allowed rain water to enter the battery and contribute to corrosion of thermal switches. A redesign of the vent was required to correct this problem.

4. Access to the battery required the removal of a structural fuselage panel secured by approximately 50 stubborn screws. This is unsatisfactory for an item that requires frequent maintenance.

b. Through the 1970's, numerous instances occurred of thermal runaway of VNC batteries directly connected to high current DC generators. The loss of one air vehicle and one of its crew members was attributed to this cause. There has also been a recent history of VRLA battery overheating, leading to mission aborts and air vehicle damage. Safe limitations on charging current and battery isolation capability are needed for all batteries.

c. As a result of its location in the cockpit, the A-7 and SH-60 air vehicle batteries not only required seat removal or movement for battery maintenance, but also subjected the crew to smoke and fumes in the event of a major battery failure. The cockpit is a poor location for the air vehicle main battery or any battery not part of essential life support and survival gear.

d. Because of the weight and space penalties involved, batteries are often selected which are inadequate for the required performance. Insufficient derating for temperature, aging, on-board charge efficiency, and high discharge rates are common pitfalls that cause maintenance effort to be at least 1 order of magnitude greater than they should be.

e. One air vehicle's batteries are installed in fiberglass boxes with attached circuit breakers. The entire assembly (box, battery, circuit breaker, wiring, and connector) must be removed each time the battery is removed for maintenance. Due to the close proximity of components, electrical shorting is reported to be a frequent problem during such maintenance.

f. Sealed lead-acid batteries are now gaining support due to their reduced maintenance factors and cost. Adequate charging subsystems are required and heaters may be needed for cold-temperature use.

g. Improved lithium batteries used in any air vehicle application should be submitted for safety review in accordance with S9310-AQ-SAF-010. (Copies of this document are available at www.marcorsyscom.usmc.mil and https://mercury.tdmis.navy.mil/cert/certtest.cfm.) Such batteries offer several unique performance advantages compared to other batteries. However, lithium batteries may present a severe hazard to crew and air vehicle if venting occurs.

h. Silver-zinc secondary batteries were used in one aircraft because of their very high energy density. However, these batteries have a very limited cycle life and are extremely susceptible to internal shorting. Because of the numerous catastrophic failures that were experienced, this type of secondary battery is not recommended for air vehicles.

H.6.3.3 Generators.

The design and performance of the generator subsystem are essential contributors to the overall performance of the electrical power subsystem. The fundamental subsystem power parameters of voltage, frequency, and capacity are established primarily by the main generators and associated components. Constant frequency 400 Hz power can be obtained from a generator driven directly from a prime mover when the prime mover operates at fixed speed. Generator subsystems of this type should be in accordance with MIL-G-21480 with changes as necessary for the specific application.

When the prime mover operates at varying speeds, either of two types of generator subsystems can be used for producing constant frequency power. One approach is to use a constant speed drive between the prime mover and the generator. The second approach is to drive the generator directly from the prime mover at varying speed and convert the variable frequency produced by the generator to constant frequency by means of an electronic converter. MIL-E 85583 should be specified for subsystems of this type. Generators in accordance with MIL-DTL-6162 are suitable for 28 volt DC subsystems. Generator subsystem capacity is often limited by the amount of cooling available. Therefore, particular attention should be given to this aspect of the installation.

Oil-cooled, oil-lubricated generators have proven to be smaller, lighter and more reliable than their air-cooled, grease-lubricated predecessors.

Constant speed drive oil level has been critical to satisfactory operation on various air vehicles. Furthermore, filling to the proper level has been adversely affected by temperature, air vehicle attitude, and inadequate oil level indication. New designs should be less critical with respect to oil level and should provide for simple and accurate filling and inspection procedures. Consideration should be made with respect to the drive being capable of operation under all specified "g" conditions over the entire range of specified oil levels. When an external oil cooler is used in a generating subsystem, it should be protected against contamination from the generating subsystem. An outlet or scavenge filter can provide this protection. On one air vehicle, when an integrated drive generator had a hardware failure, metal could and did contaminate the oil cooler, which meant the cooler had to be replaced. An engineering change proposal for a scavenge filter was later approved and added to the subsystem.

Due to recent advancements in high power, high temperature, solid-state switching devices, high power density motors and generators; efficient, high power converter topologies; and the evolution of fault-tolerant electrical power subsystems coupled with technology breakthroughs in electrically driven actuators have rekindled interest in the more-electric air vehicles. Thought should be given to 270-volt DC subsystem design and verification in the area of power generators. Experiences have shown that a major air vehicle DC generator design requirement is to maintain a constant voltage over a wide speed range. The magnetic section is sized for maximum load at minimum speed. As speed increases or load decreases, either the magnetic field must decrease accordingly or the resulting higher voltage amplitude waveform must be controlled to maintain a constant output. Three 270-volt DC generator design concepts exist and they should be carefully selected. They include the wire-wound rotor, permanent magnet generator, and the switched-reluctance machine.

H.6.3.4 Converters.

When equipment that is essential for safe flight derives power from an inverter, a spare inverter should be provided. Changeover from the main inverter to the spare should be automatic in the event of main inverter failure. Spare inverters may be used as operative units to supply power to nonessential loads, but these loads should be dropped in the event of main inverter failures.

When the outputs of two or more AC to DC converters are paralleled to supply a common DC bus, no single unit should be loaded beyond its rating for the worst-case load unbalance or failure mode which can occur.

The electrical power subsystem is often required to supply power of a type different from that provided by the primary source. In this event a means of power conversion is needed. Typically, the conversion is from 115-volt, 400 Hz power to 28 volts DC (rectification) or from 28-volt DC to 115-volt, 400 Hz, 3-phase or single-phase (inversion).

Requirements for AC to DC converters (transformer-rectifiers) should be based on MIL-C-7115.

Converters are frequently used in the subsystem to provide voltages other than the ones provided by the main generators. This results in an electrical subsystem that is more efficient overall. Many air vehicles use off-the-shelf equipment which do not operate on normal air vehicle power and converters are the best way to provide the electrical power these equipment need.

H.6.4 Definitions.

Utilization equipment: Utilization equipment is that equipment which receives power from the electrical power subsystem.

Utilization equipment terminals: Utilization equipment terminals provide the interface with the electrical power subsystem. Power interconnections within the utilization equipment or equipment system are excluded.

H.6.5 Acronyms.

The following list contains the acronyms/abbreviations contained within this appendix.

ELMC	Electrical Load Management Center
VNC	Vented Nickel-Cadmium
VRLA	Valve Regulated Lead-Acid

H.6.6 Subject term (key word) listing.

Battery

Capacity

Converter

Power

Wiring

H.6.7 International standardization agreement implementation.

This specification implements NATO STANAG 3109, Symbol Marking of Aircraft Servicing and Safety/Hazard Points; NATO STANAG 7073, Connectors for Aircraft Electrical Servicing Power; and ASCC AIR STD 25/18, Connectors for 28 Volt DC Servicing Power. When amendment, revision, or cancellation of this specification is proposed, the preparing activity must coordinate the action with the U.S. National Points of Contact for the international standardization agreements, as identified in the ASSIST database at https://assist.dla.mil/online/start.

H.6.8 Responsible engineering office.

The office responsible for the development and technical maintenance of this appendix is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL. Requests for additional information on this appendix can be obtained from AFLCMC/ENRS, BLDG 28 RM 118, 2145 MONAHAN WAY, WPAFB OH 45433-7017 USA; DSN 674-5476; COMMERCIAL (937) 904-5476; ENGINEERING.STANDARDS@US.AF.MIL.

H.6.9 Amendment notations.

The margins of this specification are marked with vertical lines to indicate modifications generated by this amendment. This was done as a convenience only and the Government assumes no liability whatsoever for any inaccuracies in these notations. Bidders and contractors are cautioned to evaluate the requirements of this document based on the entire content irrespective of the marginal notations.

APPENDIX I

AIR VEHICLE MECHANICAL SUBSYSTEMS

REQUIREMENTS AND GUIDANCE

I.1 SCOPE

I.1.1 Scope.

This appendix provides the requirements, verifications, tailoring guidance, and background information for the Mechanical Subsystems provided for in Part 1 of this specification. The appendix has been developed and coordinated by technical personnel from the Air Force, Navy, and Army and has been approved as an official guide for use by Government personnel for assistance in tailoring the air vehicle subsystems specification for acquisition and model specifications.

I.1.2 Structure.

The appendix structure replicates the structure of the Air Vehicle Subsystems Specification except it places each corresponding section 3 requirement and section 4 verification together.

I.1.3 Appendix.

This appendix provides tailoring guidance and background information for individual paragraphs of the Air Vehicle Subsystems Specification. Guidance gives recommendations on how to tailor the specification paragraph. Where ___(TBS)___ appears, the guidance paragraph provides recommended values or text that the using service may use to insert in the __(TBS)__. When contractors are expected to complete the _(TBS)__, the Guidance paragraph will so state. The Using Service makes the final decision on whom completes the __(TBS)__ in the specification. Finally, Lessons Learned are provided to give insight to past events that could impact the tailoring of the specification.

I.1.4 Deviations.

Projected designs for given applications which will result in improvement of the system performance, reduced life cycle cost, or reduced developmental cost through deviations from this guidance, or where requirements of the specification results in compromise in operational capability, should be brought to the attention of the using service.

I.1.5 Environmental impact.

Air Vehicle Subsystems will be designed such that their operation, maintenance, and repair may be accomplished without violating the most stringent environmental regulations applicable to locations where subsystems are used or supported. Compliance with environmental regulations will not prevent subsystems from achieving and sustaining mission performance capability. Materials, processes, and environmental control equipment necessary to meet these environmental requirements must currently be available in the Using Service's maintenance and supply system. The design will not use environmentally unsuitable materials such as ozone depleting fluorocarbons, chlorofluorocarbons, and halons, or highly volatile organic compounds in solvents and coatings during development, production, operation, maintenance, or repair. The Environmental Protection Agency maintains an online list of toxic chemicals and hazardous substances on its Ozone Layer Depletion Website at http://www.epa.gov/ozone/snap/ that should be consulted. The Significant New Alternatives Policy (SNAP) Program available thereon identifies substitutes for ozone depleting chemicals.

The contractor will conduct an environmental analysis of air vehicle subsystems.

I.1.6 Responsible engineering office.

The responsible engineering office (REO) for this appendix is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL.

I.2 APPLICABLE DOCUMENTS

I.2.1 General.

The documents listed in this section are specified in sections 3 and 4 of this handbook. This section does not include documents cited in other sections of this guide specification or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3 and 4 of this handbook, whether or not they are listed.

I.2.2 Government documents

I.2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this appendix to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

DEPARTMENT OF DEFENSE SPECIFICATIONS

JSSG-2001	Air Vehicle Joint Service Specification Guide
JSSG-2006	Aircraft Structures Joint Service Specification Guide

DEPARTMENT OF DEFENSE HANDBOOKS

MIL-HDBK-1599	Bearings, Control System Components, and Associated Hardware Used in the Design and Construction of Aerospace Mechanical Systems and Subsystems

(Copies of these documents are available online at http://quicksearch.dla.mil or from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia PA 19111-5094 USA.)

I.2.2.2 Other Government documents, drawings, and publications.

The following other Government documents, drawings, and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

FEDERAL AVIATION ADMINISTRATION

DOT/FAA/AR-MMPDS	Metallic Materials Properties Development and Standardization (MMPDS)

(Information on this document's availability is provided at www.mmpds.org or via e-mail at bcommpds@batelle.org.)

I.2.3 Non-Government publications.

The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

AEROSPACE INDUSTRIES ASSOCIATION OF AMERICA, INC.

NAS 0331	Bearing Installation and Retention by Swagging or Staking
NASM1312	Fastener Test Methods

(Copies of these documents are available via www.aia-aerospace.org; Aerospace Industries Association, 1000 Wilson Boulevard, Suite 1700, Arlington VA 22209-3928 USA.)

AMERICAN SOCIETY OF MECHANICAL ENGINEERS

ASME B1.15	Unified Inch Screw Threads (UNJ Thread Form)

(Copies of this document are available from https://www.asme.org; ASME, Three Park Avenue, New York NY 10016-5990 USA.)

SAE INTERNATIONAL

SAE ARP777	Gas Actuators (Lineary and Vane Rotary Type)
SAE ARP4058	Actuators: Mechanical, Geared Rotary
SAE ARP4255	Electrical Actuation Systems for Aerospace and Other Applications
SAE ARP4386	Terminology and Definitions for Aerospace Fluid Power, Actuation and Control Technologies
SAE AS6038	Bearings, Ball, Bellcrank, Antifriction, Airframe
SAE AS6039	Bearings, Ball, Rod End, Double Row, Self-Aligning

SAE AS7949	Bearings, Ball, Airframe, Antifriction
SAE AS8914	Bearings, Roller, Self-Aligning, Airframe, Antifriction
SAE AS81820	Bearings, Plain, Self-Aligning, Self-Lubricating, Low Speed Oscillation

(Copies of these documents are available from www.sae.org; SAE International, 400 Commonwealth Drive, Warrendale PA 15096-0001 USA; and www.ihs.com to qualified users.)

STANDARDS AUSTRALIA INTERNATIONAL LTD

SAI AS 3990	Mechanical Equipment – Steelwork

(Copies of this document are available from www.standards.com.au; SAI LTD, PO Box 1055; Strathfield, NSW; Australia 2135.)

I.2.4 Order of precedence.

Unless otherwise noted herein or in the contract, in the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

I.2.5 Streamlining.

The Air Vehicle Subsystems Specification has been streamlined. The documents listed in this appendix which are required for acquisition have the same status as those referenced directly in section 2 (first tier). All other documents referenced through tiering, may be used for guidance and information only.

I.3 REQUIREMENTS

I.4 VERIFICATIONS

I.3.1 Definition

I.4.1 Definition

I.3.2 Characteristics

I.4.2 Characteristics

I.3.3 Design and construction

I.4.3 Design and construction

I.3.4 Subsystem characteristics

I.4.4 Subsystem characteristics

I.3.4.1 Landing subsystem

I.4.4.1 Landing subsystem

I.3.4.2 Hydraulic subsystem

I.4.4.2 Hydraulic subsystem

I.3.4.3 Auxiliary power subsystem

I.4.4.3 Auxiliary power subsystem

I.3.4.4 Environmental control subsystem

I.4.4.4 Environmental control subsystem

I.3.4.5 Fuel subsystem

I.4.4.5 Fuel subsystem

I.3.4.6 Aerial refueling subsystem

I.4.4.6 Aerial refueling subsystem

I.3.4.7 Fire and explosion hazard protection subsystem

I.4.4.7 Fire and explosion hazard protection subsystem

I.3.4.8 Electrical power subsystem

I.4.4.8 Electrical power subsystem

I.3.4.9 Mechanical subsystems.

Mechanical subsystems shall consist of (a) doors, hatches, and ramps; (b) airframe bearings; (c) fasteners; and (d) utility actuators.

REQUIREMENT RATIONALE (3.4.9)

Mechanical subsystems are used where securing, fastening, and mechanizing is required.

REQUIREMENT GUIDANCE (3.4.9)

a. Doors, hatches, and ramps. See "Doors, hatches, and ramps" in this appendix.
b. Airframe bearings. See "Airframe bearings" in this appendix.
c. Fasteners. See "Fasteners" in this appendix.
d. Utility actuators. See "Utility actuators" in this appendix.

REQUIREMENT LESSONS LEARNED (3.4.9)

(TBD)

I.4.4.9 Mechanical subsystems.

Mechanical subsystems function and performance shall be verified incrementally by __(TBS)__.

VERIFICATION RATIONALE (4.4.9)

Verification is essential to assure that mechanical requirement are met.

VERIFICATION GUIDANCE (4.4.9)

TBS: Verification should be accomplished incrementally and should include inspection, analysis, demonstration, or test, or a combination of these methods.

VERIFICATION LESSONS LEARNED (4.4.9)

(TBD)

I.3.4.9.1 Air vehicle doors, hatches, hinged access panels, and ramps subsystem.

Air vehicle door, hatch, and ramp mechanical subsystems shall provide latching, locking, door status monitoring, door control, and sealing.

REQUIREMENT RATIONALE (3.4.9.1)

Air vehicles in general require numerous openings in the fuselage to permit access to and escape from the flight and passenger compartments, the cargo and baggage hold, and equipment and subsystem bays. The purpose of the air vehicle door and hatch mechanical subsystems is to provide the mechanization of these functions.

REQUIREMENT GUIDANCE (3.4.9.1)

a. Jamming or blocking of air vehicle doors. The air vehicle doors and hatches should be designed so jamming or blocking by cargo, baggage, or foreign objects in the open or closed position is not possible.

b. Jam loads in the subsystem. The air vehicle doors and hatches should withstand jam loads at any point without detrimental deformation.

c. Holding of air vehicle doors. For ground operation with power off, means should be provided to hold the air vehicle doors in the open or closed position. Subsequent power operation of the doors, with these means left in place, should not result in damage.

d. Main entrance doors. Main entrance doors should permit passage of personnel and necessary equipment. Main entrance doors for patrol, transport, antisubmarine warfare and utility air vehicles should be provided with a lock and key for locking the door from the outside, however, the doors should be operable from the inside when locked.

e. Cargo doors. Special consideration should be given to cargo doors for ease of loading and unloading. Main cargo-loading openings should admit packages of maximum practicable dimensions so that as varied a cargo as possible may be carried. The main side-cargo-loading-opening should be on the left side, unless such openings are symmetrical about the centerline of the air vehicle. Cargo doors should be flush with the floor except where it is required to make them watertight or pressure-tight. Cargo door locations and the manner of opening should render minimum interference to cargo loading and unloading, and should not restrict the use of loading platforms, cranes, fork lift trucks, or such, for transferring cargo. Servicing of the air vehicle should be possible without interference with loading or unloading when done simultaneously.

f. Paratroop doors. Doors for parachute jumping should be operable from the inside in flight and located for safe egress. There should be no projections on which personnel might stumble or foul their clothing or gear in preparing to jump or while jumping. Air vehicles capable of carrying more than 20 troops should be provided with 2 door spaces to permit simultaneous jumping. Doors for parachute jumping should be at least 36 inches wide by 70 inches high and should be flush with the floor.

g. Compartment hinged access panels. Compartment hinged access panels and other openings with covers should be provided as required. The covers and hatches should permit ready securing or opening and should be watertight in flight. All equipment compartments should be accessible without the use of workstands or platforms and should be eye level or lower to permit maintenance personnel access to equipment contained therein. Equipment compartments should be free of structural obstruction and armament recesses.

h. Seaplane and amphibian boarding doors. All seaplane and amphibian air vehicles should have provisions for boarding to and from boats brought along side in choppy water. Doors most suitable for this purpose should be clearly designated. Recessed fittings should be provided forward and aft of entrance doors for steadying or securing a small boat raft. Amphibian air vehicles should have provisions for boarding from the ground when ashore.

REQUIREMENT LESSONS LEARNED (3.4.9.1)

a. Subsystem bearings. Air vehicle door and hatch bearings should be selected in accordance with MIL-HDBK-1599.
b. Mechanical joints. Air vehicle door mechanical joints that do not have standard bushings or bearings should have a life equal to the air vehicle service life with at least one rework. Parts containing friction surfaces subject to wear should be designed for easy repair or replacement. Joints of air vehicle doors and hatches should be smooth with no gaps to cause a breakdown of airflow.
c. Performance requirements. The performance requirements of JSSG-2006 apply to the air vehicle door and hatch mechanical components.
d. Door sills and edges. Door sills, coamings, and lower edges of doors should be so constructed as to provide edges that may not be readily damaged by normal personnel traffic. Additionally, all corners of doors, hatches, panels, or covers should be rounded to preclude injury to maintenance personnel with the doors, hatches, panels, or covers in the open position.

I.4.4.9.1 Air vehicle doors, hatches, hinged access panels, and ramps subsystem.

Testing required to verify the door, hatch, hinged access panels and ramp mechanical subsystems shall be conducted. The design and operating characteristics shall be substantiated by analysis.

VERIFICATION RATIONALE (4.4.9.1)

The design and operating characteristics of the mechanical subsystems to fulfill the functional needs of the air vehicle must be made known prior to operational deployment.

VERIFICATION GUIDANCE (4.4.9.1)

The integration of the mechanical subsystems should be demonstrated in a mock-up simulating the expected loads and structural attachments. Testing should be designed and conducted to establish integrity and durability of the mechanisms. The sizing and operating characteristics should be determined analytically.

VERIFICATION LESSONS LEARNED (4.4.9.1)

(TBD)

I.3.4.9.1.1 Air vehicle door maintenance.

Air vehicle door, hatch, hinged access panels and ramp hinges requiring disassembly for maintenance shall be installed by a method that will prevent damage to all the corrosion protected surfaces.

All door hardware (latches and hinges) and any items mounted to or within the door or hatch structure shall be readily accessible for lubrication, rigging, adjustment, removal, and replacement without disassembly of structure.

REQUIREMENT RATIONALE (3.4.9.1.1)

The purpose of this requirement is to ensure that the installation techniques will not damage the corrosion protected surfaces of bushings and joints during the assembly process, and that the door hardware will be easily serviced.

REQUIREMENT GUIDANCE (3.4.9.1.1)

Hardware should not require lubrication at the organizational or intermediate level. All latches and locks should be accessible without the use of special tools, equipment, or workstands.

REQUIREMENT LESSONS LEARNED (3.4.9.1.1)

(TBD)

I.4.4.9.1.1 Air vehicle door maintenance.

Verify by analysis of the design drawings that air vehicle door bushings and joints requiring disassembly for maintenance will be installed by a method that will prevent damage to all corrosion protected surfaces. Also verify that design can allow easy access for maintenance of door hardware.

VERIFICATION RATIONALE (4.4.9.1.1)

Verification is needed to confirm that the manufacturing process used in the installation of bushings will not induce corrosion in protected surfaces and that door hardware will be easily accessed for maintenance.

VERIFICATION GUIDANCE (4.4.9.1.1)

Analysis of the drawings should include inspection of the installation tolerances of the assembly methods with particular attention to the corrosion protected surfaces. Ease of maintenance for the door hardware should also be inspected.

VERIFICATION LESSONS LEARNED (4.4.9.1.1)

(TBD)

I.3.4.9.1.2 Powered door position.

Powered doors shall not change position due to loss of power in any associated system.

REQUIREMENT RATIONALE (3.4.9.1.2)

The purpose of this requirement is to ensure the loss of a powered door will not cause injury or damage.

REQUIREMENT GUIDANCE (3.4.9.1.2)

A positive mechanical device should be provided to prevent change in selected door positions due to fluid bleeding down after fluid power is shut off or loss of electrical power.

REQUIREMENT LESSONS LEARNED (3.4.9.1.2)

(TBD)

I.4.4.9.1.2 Powered door position.

Powered door position requirements shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.9.1.2)

This verification is necessary to assure continued controlled flight and landing in the event of a door loss or door component failure.

VERIFICATION GUIDANCE (4.4.9.1.2)

TBS should include an inspection of the air vehicle drawings. In addition a failure modes and effects analysis should be conducted to predict the consequence of hydraulic, electrical, or mechanical failures.

VERIFICATION LESSONS LEARNED (4.4.9.1.2)

(TBD)

I.3.4.9.1.3 Latching.

Latches shall keep the doors and hinged access panels secured under all design conditions. The latches shall withstand limit design loads without detrimental deformation or loss of fuselage pressurization and shall withstand ultimate loads without failure.

REQUIREMENT RATIONALE (3.4.9.1.3)

Door latching secures doors to prevent loss in flight.

REQUIREMENT GUIDANCE (3.4.9.1.3)

a. Unlatching due to deflection. Maximum possible relative deflection between the air vehicle structure, doors, and the latches should not cause unlatching under any ultimate design loading condition.

b. Latching cycle. The latches should be incapable of completing the latching cycle under all operating conditions unless the doors are in the fully closed position.

c. Latch installation visibility and accessibility. Latch installations on the doors that affect the safety of flight and are operational in flight should be visible and accessible by ground crew and by air crew members to ensure a fully latched condition by direct visual observation.

d. Latching subsystem independence. The latches should be independent of the locks so that any inadvertent unlatching attempt will not cause unlocking.

e. Flight and pressurization loads. Flight and pressurization loads should not exert an unlatching force.

f. Latch damage or permanent deformations. Damage or permanent deformation to the latches or support structures should not result from the most critical jam load conditions.

g. Latch selection. Single, simple action door latches should be used. Latches on exterior doors should be of the irreversible type. Spring action should not be used to return the latch to the locked position; however, it may be used to hold the latch in the locked position and resist vibration forces tending to unlock the door. Latching mechanisms of hair trigger type should not be used. Latches on interior doors that do not open into water-tight or pressurized compartments may utilize simple spring actuated mechanisms.

REQUIREMENT LESSONS LEARNED (3.4.9.1.3)

(TBD)

I.4.4.9.1.3 Latching.

The security, under all design to conditions, of air vehicle door and hinged access panel latches shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.9.1.3)

The tests are intended to ascertain whether or not door openings could occur subsequent to simulated single latch failure or combination of probable multiple failures.

VERIFICATION GUIDANCE (4.4.9.1.3)

TBS: Testing should be accomplished in conjunction with other tests whenever possible. To accomplish this goal, all suitable latch tests should be coordinated with the structural test program to avoid duplication. Tests should be conducted duplicating the most critical conditions. In conjunction with these tests, all failures should be analyzed for any detrimental after effects caused by the initial failure.

VERIFICATION LESSONS LEARNED (4.4.9.1.3)

(TBD)

I.3.4.9.1.4 Locking.

The door locks shall prevent the door latches from opening unless the door locks are opened.

REQUIREMENT RATIONALE (3.4.9.1.4)

The purpose of this requirement is to ensure that the locks hold the latches closed under all air and ground load conditions and single failure modes.

REQUIREMENT GUIDANCE (3.4.9.1.4)

a. Deflection of lock actuation. Maximum possible deflection of the lock actuator, linkage and support structure should not cause unlocking under any ultimate load conditions.

b. Lock indication. The locks should be incapable of locking or indicating they are locked unless all the latches are properly latched in the fully secured position. This requirement applies to the following door subsystems: __(TBD)__.

c. Lock service life. The locks and their components should have an actuation service life of __(TBD)__ cycles.

d. Visibility of lock installation. The lock installation on the door subsystems should be accessible to the flight and ground crew members to ensure a fully locked condition by direct visual observation. In addition, the lock installation should be visible to the air crew members for doors that are in the pressurized volume; or that affect safety of flight, and are opened and closed in flight.

e. Inadvertent unlocking. The locks should be independent of the latches and inadvertent unlocking should not cause unlatching. Inadvertent latch activation should not cause unlocking or unlatching with the locking subsystem engaged.

f. Unlocking at unsafe pressure levels. The locks should be incapable of unlocking at unsafe pressurization levels.

g. Lock damage or permanent deformation. Damage or permanent deformation to the locks or support structure should not result from the most critical jam load conditions.

REQUIREMENT LESSONS LEARNED (3.4.9.1.4)

(TBD)

I.4.4.9.1.4 Locking.

Verify by analysis and test that the air vehicle door locks shall prevent unlatching under all operating and ultimate load conditions.

VERIFICATION RATIONALE (4.4.9.1.4)

It must be verified that the door latches do not yield due to pressurization loads or single failure modes.

VERIFICATION GUIDANCE (4.4.9.1.4)

All testing should be accomplished in conjunction with the door latch test on the full-scale test model.

VERIFICATION LESSONS LEARNED (4.4.9.1.4)

(TBD)

I.3.4.9.1.5 Pressurization.

All air vehicle pressurized doors, whose inadvertent opening would present a probable hazard to personnel or to continued safe flight and landing, shall have provisions to prevent pressurization of the air vehicle if the doors are not fully closed, latched, and locked.

REQUIREMENT RATIONALE (3.4.9.1.5)

The air vehicle could over pressurize or lose pressurization if a door is not secured properly. The provisions not only must give positive evidence of an improperly locked and latched door, but also guard against unsafe pressurization.

REQUIREMENT GUIDANCE (3.4.9.1.5)

The air vehicle doors should be designed so that the air vehicle cannot be pressurized unless the doors are completely closed, latched and locked. The design of the doors should prevent pressurization of the air vehicle at the maximum airflow rate from the pressurization system.

REQUIREMENT LESSONS LEARNED (3.4.9.1.5)

(TBD)

I.4.4.9.1.5 Pressurization.

Verify by analysis and inspection that doors and hatches are designed to prevent the cabin from being pressurized if they are not properly closed, latched, and locked.

VERIFICATION RATIONALE (4.4.9.1.5)

Analysis and inspection are necessary to verify that door and hatch designs will not permit the cabin to be pressurized if doors and hatches are not properly closed, latched, and locked.

VERIFICATION GUIDANCE (4.4.9.1.5)

Analysis and inspection should cover all the probable failure modes of the subsystem. Demonstrations should be performed on a full-scale article.

VERIFICATION LESSONS LEARNED (4.4.9.1.5)

(TBD)

I.3.4.9.1.6 Unlocking under pressurization.

When the air vehicle is pressurized, the doors and hatches shall not unlock with the locks energized to the open position.

REQUIREMENT RATIONALE (3.4.9.1.6)

The intent of this requirement is to ensure that the pressurization prevention design will hold the locks in the closed position when the fuselage is pressurized and the locks are energized to open.

REQUIREMENT GUIDANCE (3.4.9.1.6)

This requirement primarily applies to the larger doors, whose in-flight loss could cause a safety hazard.

REQUIREMENT LESSONS LEARNED (3.4.9.1.6)

(TBD)

I.4.4.9.1.6 Unlocking under pressurization.

Verify by demonstration that the design shall prevent unlocking when the air vehicle is pressurized with the locks energized to the open position.

VERIFICATION RATIONALE (4.4.9.1.6)

Demonstration is intended to ascertain whether or not unlocking can occur while the air vehicle is pressurized.

VERIFICATION GUIDANCE (4.4.9.1.6)

Demonstration should be accomplished at various fuselage pressure differentials until the pressure is low enough to permit unlocking. A determination should then be made regarding the safety aspects of the door opening at that pressure. All demonstrations should be performed on a full-scale test model.

VERIFICATION LESSONS LEARNED (4.4.9.1.6)

(TBD)

I.3.4.9.1.7 Pressurization prevention device failures.

__(TBS)__ failures of the pressurization prevention device shall not permit the fuselage to be pressurized without air vehicle doors being locked and latched.

REQUIREMENT RATIONALE (3.4.9.1.7)

The purpose of this requirement is to prevent the air vehicle from pressurizing with the locks in the open position. This requirement is included to ensure that in no case will a single or multiple failure permit the fuselage to be pressurized.

REQUIREMENT GUIDANCE (3.4.9.1.7)

TBS should be completed by referring to JSSG-2001, “Reliability”.

REQUIREMENT LESSONS LEARNED (3.4.9.1.7)

(TBD)

I.4.4.9.1.7 Pressurization prevention device failures.

Verify by analysis that a single failure or multiple failures of the pressurization prevention device from permitting the fuselage to be pressurized without the proper positioning of the door locks and latches.

VERIFICATION RATIONALE (4.4.9.1.7)

The analysis is intended to ascertain whether or not hazardous pressurization can occur subsequent to a single pressurization system failure or a combination of probable multiple failures.

VERIFICATION GUIDANCE (4.4.9.1.7)

All failures in the pressurization system, which were identified in the analysis, should be tested to ascertain the severity of the failure. The most critical condition can be identified by structural analysis.

VERIFICATION LESSONS LEARNED (4.4.9.1.7)

(TBD)

I.3.4.9.1.8 Door status monitoring.

The indication subsystem shall continuously monitor and provide an unsafe indication when the doors, latches, or locks are unsecured, and provide a safe indication when they are secured. The following air vehicle doors shall require indicators: __(TBS)__.

REQUIREMENT RATIONALE (3.4.9.1.8)

The purpose of this requirement is to ensure that the safe or unsafe status of the doors is continuously presented to the aircrew members. The indicators also assist in trouble shooting in the event of a malfunction.

REQUIREMENT GUIDANCE (3.4.9.1.8)

TBS should be completed with a listing of all power-operated doors and other doors considered critical to air vehicle safety.

a. The flight status of the pressurized air vehicle doors should be communicated by multiple indicators (mechanical or electrical). Each indicator should be energized by a separate sensor and an independent circuit. At least a single indicator should be considered for unpressurized doors that are operated in flight.

b. Indicator sensors should sense the position of the doors, latches, and locks directly without the use of auxiliary devices such as sensor targets.

c. Mechanical indicators should use positive mechanical linkage for extension and retraction.

d. The indication subsystem should be such that the deflection of the air vehicle structure under all ground and flight load conditions should not cause false indications.

e. Indication that latching is complete should result only from full engagement of the mating latch members.

f. Indication that locking is complete should result only from full engagement of the mating locking members.

g. Remote electrical indication subsystems should incorporate a built-in test capability to test the integrity of the indicator lights and circuits, and should not fail passively for any probable failure modes.

REQUIREMENT LESSONS LEARNED (3.4.9.1.8)

(TBD)

I.4.4.9.1.8 Door status monitoring.

Verify by analysis and demonstration that each indication subsystem will continuously monitor and provide an unsafe indication when either the door, latch, or lock is unsecured; and provide a safe indication when they are secured.

VERIFICATION RATIONALE (4.4.9.1.8)

Analysis and demonstration is intended to confirm that the indication subsystem continuously monitors the door status.

VERIFICATION GUIDANCE (4.4.9.1.8)

Demonstration should be accomplished on the full-scale article in conjunction with other tests, such as the life cycle tests and should include all the malfunctions that could give a false indication determined by the analyses. Particular emphasis should be placed on those malfunctions that could give a safe indication for an unsafe condition.

VERIFICATION LESSONS LEARNED (4.4.9.1.8)

(TBD)

I.3.4.9.1.9 Door control.

Controls shall be provided for all doors and hatches by __(TBS)__.

REQUIREMENT RATIONALE (3.4.9.1.9)

The purpose of this requirement is to ensure that controls are provided for doors in a manner that will enable the crew to open or close the doors quickly and safely.

REQUIREMENT GUIDANCE (3.4.9.1.9)

TBS: The following should be considered:

a. Door control interruption. Control power interruption or a reversal of the door controls during an actuation cycle should not cause subsystem damage. Reversal of the controls during a cycle should cause reversal of the door movement. The controls should be capable of stopping door movement at any time in the cycle at the option of the operator by selecting the control stop position. In the event of a power interruption, the door controls should go to the stop position and it should not require reprogramming upon resumption of power.

b. Manual actuation of door control subsystem. The controls should be designed for emergency operation by means of manual actuation of the door sequence.

c. Inadvertent door actuation. Means should be provided to prevent inadvertent actuation of the doors.

d. Malfunction or failure during cycle. The controls should automatically stop the sequence in the event a malfunction or failure occurs part way through a cycle.

e. Alternate power. An alternate power source should be provided that will operate any door that would require an alternate power source if the main power source is lost. The time to operate the door with alternate power should reasonably approximate the time using main power.

REQUIREMENT LESSONS LEARNED (3.4.9.1.9)

(TBD)

I.4.4.9.1.9 Door control.

Verify by analysis and demonstration that the door controls are provided in a manner such that the aircrew can operate the controls quickly and safely without the danger of damaging the air vehicle.

VERIFICATION RATIONALE (4.4.9.1.9)

Analysis and demonstration is intended to confirm that the door controls can be operated safely and efficiently.

VERIFICATION GUIDANCE (4.4.9.1.9)

Demonstration should be accomplished on the full-scale article in conjunction with other tests, such as the life cycle tests. The door controls should be tested both opening and closing from several points in the actuation cycle. Manual operation of the door and a reversal of door movement should also be tested.

VERIFICATION LESSONS LEARNED (4.4.9.1.9)

(TBD)

I.3.4.9.1.10 Sealing.

All door and hatch seals and their supporting structures shall retain air pressurization during all flight and ground operations when the engines are running.

REQUIREMENT RATIONALE (3.4.9.1.10)

The purpose of this requirement is to ensure that cabin pressurization is not lost as a result of fuselage or canopy deflections.

REQUIREMENT GUIDANCE (3.4.9.1.10)

The seals should retain air pressurization caused by maximum fuselage deflections. Seals should be positively retained by methods other than or in addition to adhesive bonding and should be designed for easy removal and replacement.

REQUIREMENT LESSONS LEARNED (3.4.9.1.10)

(TBD)

I.4.4.9.1.10 Sealing.

Verify by analysis and demonstration that the seals will retain cabin pressurization as a result of expected fuselage or canopy deflections.

VERIFICATION RATIONALE (4.4.9.1.10)

Pressurization tests are intended to demonstrate the canopy and door seals' ability to maintain cabin pressurization.

VERIFICATION GUIDANCE (4.4.9.1.10)

Tests should be performed on a full-scale air vehicle under full load and maximum pressurization.

VERIFICATION LESSONS LEARNED (4.4.9.1.10)

(TBD)

I.3.4.9.1.11 Ramp load cycle time.

The ramp shall be capable of lifting ramp maximum load from the normal open to the fully closed position in __(TBS)__.

REQUIREMENT RATIONALE (3.4.9.1.11)

The purpose of this requirement is to ensure that ramp actuation can be accomplished within the allowable time specified.

REQUIREMENT GUIDANCE (3.4.9.1.11)

TBS: Time should be determined by referring to JSSG-2001.

REQUIREMENT LESSONS LEARNED (3.4.9.1.11)

(TBD)

I.4.4.9.1.11 Ramp load cycle time.

Ramp load cycle time shall be verified by analysis and test.

VERIFICATION RATIONALE (4.4.9.1.11)

The purpose of the analysis and test is to verify that the ramp is designed properly to lift the specified loads in the specified time.

VERIFICATION GUIDANCE (4.4.9.1.11)

All testing should be performed at rated system pressure and voltage and at normal actuation rates. Ground test on the full-scale article should precede flight tests.

VERIFICATION LESSONS LEARNED (4.4.9.1.11)

(TBD)

I.3.4.9.1.12 Extending and holding the cargo ramp.

The ramp shall have the capability of extending and holding full operational load in a position level with the floor during ground and flight operations.

REQUIREMENT RATIONALE (3.4.9.1.12)

The purpose of this requirement is to ensure that the ramp will not drop with its load as a result of a power system failure or interruption. All probable failure modes that may cause a ramp to drop should be considered.

REQUIREMENT GUIDANCE (3.4.9.1.12)

Specify the failure modes which the ramp is expected to withstand in order that it be restrained in the loaded, fixed position. If trapped hydraulic pressure is used to hold the ramp, the trapping valve should be located at the actuator port.

REQUIREMENT LESSONS LEARNED (3.4.9.1.12)

(TBD)

I.4.4.9.1.12 Extending and holding the cargo ramp.

Verify by analysis and test that the ramp will stop and hold its position while loaded to its operational capability in the event of power system failure or interruption.

VERIFICATION RATIONALE (4.4.9.1.12)

Analysis and test are intended to reveal any deficiency that would permit the ramp to drop in the event of a failure.

VERIFICATION GUIDANCE (4.4.9.1.12)

Various hydraulic and electrical power interruptions singularly and in combination should be simulated for the tests. Consult the structure engineers for the maximum ramp loads. All tests should be performed on the full-scale article before testing on test air vehicle. If a hydraulic trapping value is used, verify that it is located at the actuator port.

VERIFICATION LESSONS LEARNED (4.4.9.1.12)

(TBD)

I.3.4.9.1.13 Weapons bay door.

Weapons bay door latches shall be provided with a positive lock to prevent external air loads from moving the weapons bay doors toward their open positions while the air vehicle is in flight with the door controls set in the closed position. Manually operated hold-open latches shall be provided to secure doors in the open position, shall incorporate a lock, and shall be located in an area where personnel can access safely.

REQUIREMENT RATIONALE (3.4.9.1.13)

The purpose of this requirement is to ensure that the weapons bay doors do not open or close unexpectedly due to external air loads.

REQUIREMENT GUIDANCE (3.4.9.1.13)

Hold-open latches should be located away from turbine engine bleed-air exhausts, engine intakes and exhausts, propellers, and such.

REQUIREMENT LESSONS LEARNED (3.4.9.1.13)

(TBD)

I.4.4.9.1.13 Weapons bay door.

Verify by analysis and inspection that weapons bay doors will not open due to external air loads. Verify by analysis and test that latches are in place to secure weapons bay doors in the open position.

VERIFICATION RATIONALE (4.4.9.1.13)

Analysis and test are intended to reveal any design deficiencies that may permit the weapons bay doors to open or close unexpectedly.

VERIFICATION GUIDANCE (4.4.9.1.13)

In flight-testing should be performed under various flying conditions to ensure weapons bay doors do not open or close unexpectedly. Ground testing on the full-scale test model should precede any ground or flight tests on test air vehicle. Tests on the full-scale test model should simulate the wind loads.

VERIFICATION LESSONS LEARNED (4.4.9.1.13)

(TBD)

I.3.4.9.1.14 Weapons bay door performance.

Weapons bay doors shall be designed to travel from fully closed to fully open in __(TBS 1) under a __(TBS 2)__ knot wind.

REQUIREMENT RATIONALE (3.4.9.1.14)

The purpose of this requirement is to ensure the weapons bay door can be opened within the allowable time specified at the speed specified.

REQUIREMENT GUIDANCE (3.4.9.1.14)

TBS 1 and TBS 2: Refer to JSSG-2001.

REQUIREMENT LESSONS LEARNED (3.4.9.1.14)

(TBD)

I.4.4.9.1.14 Weapons bay door performance.

Weapons bay door performance shall be verified by analysis and test.

VERIFICATION RATIONALE (4.4.9.1.14)

The verification is intended to demonstrate that the operation of the weapons bay doors is completed within the established time period under the specified load.

VERIFICATION GUIDANCE (4.4.9.1.14)

The demonstration should be performed on a fully assembled subsystem, preferably on a full-scale article. Ground tests should precede flight tests. In-flight tests should be performed at maximum speed.

VERIFICATION LESSONS LEARNED (4.4.9.1.14)

(TBD)

I.3.4.9.2 Airframe bearings.

Airframe bearings shall be capable of joining mechanical elements; transmitting design loads through the full range of the system operating parameters; permitting rotation, misalignment, or both while maintaining a specified dimensional relationship between the joined elements; reducing friction and wear; and making friction and wear more predictable. Airframe bearings shall be standardized to the maximum extent possible without compromising performance.

REQUIREMENT RATIONALE (3.4.9.2)

Proper selection of airframe bearings will provide structurally efficient joints that are trouble free in service at the lowest possible total cost. Standard bearings are given priority in new design in order to minimize the cost of procurement and testing, reduce schedule and technical risk, and obtain multiple sources of supply.

REQUIREMENT GUIDANCE (3.4.9.2)

MIL-HDBK-1599 should be used for selection, application, and installation of airframe bearings. The information contained within MIL-HDBK-1599 is considered guidance that may be deviated from when adequate technical justification exists. Parts listed in MIL-HDBK-1599 are standard parts and should be given selection priority in mechanical and functional system design.

REQUIREMENT LESSONS LEARNED (3.4.9.2)

The system operating parameters are the basis of selecting what type of bearing should be used for a particular application. Table 201-VII in MIL-HDBK-1599 provides bearing selection parameters. The first step in the selection of an airframe bearing is to determine whether an antifriction or a plain bearing would best fit the needs of the application. Under normal circumstances, the type of bearing that is superior in the greatest number of desirable properties would be the logical choice. However, in some instances one property may be so important that a selection can be made on the basis of this quality alone.

Standard bearings should be used in all possible application because:

a. Nonstandard bearings may be priced from 3 to 20 times the cost of equivalent standard bearings.

b. Due to lack of reliable data on load-life relationships and static limit loads, calculations alone are used on nonstandard bearings by the vendor to determine capacity. No qualifications or service testing has been done, making the performance of the bearing the responsibility of the purchaser.

c. Standard bearings can, in many cases, be obtained from stock or from frequent production runs which should shorten the lead time needed to obtain bearings. Special bearing can require up to one year from the time the order is placed to delivery.

d. It is wise to have a multiple source of supply because strikes, disasters, or material shortages can cause long delays when special bearings are obtained from one vendor. Standards with Qualified Products Lists are required to identify at least two suppliers.

Bushings have been provided for all bolts and pins subject to angular or other motions, which tend to distort or enlarge the hole. Bushings have been economical replaceable elements that protect expensive structural members from wear and galling. Bushings that have been securely installed and assume all of the wear and deformation at the joint have assured that: (1) relative motion, and thus wear, occurred at the intended surface; (2) the bushing have not migrated out of the housing; and (3) proper stresses have been maintained in the bushing and housing.

Bushing installed with a sliding fit have been used as a spacer to eliminate clevis deflection in a clevis-and-lug bearing joint. Bushings have not been necessary in standard items such as fork-end cable terminals and turn buckles.

In previous applications it has been found that only a portion of the shaft will be in contact with the bearing surface due to shaft bending in large length-to-diameter bushings. Therefore, when the effective projected area was computed to determine static capacity, the length used in the computation did not exceed the bushing diameter even though the length of the bushing may have exceeded the diameter.

In the past, design activities prepared a Program Parts Selection List (PPSL). Design selection of parts from a PPSL promoted standardization. All parts introduced in the design of equipment, system or subsystem were listed on the PPSL.

I.4.4.9.2 Airframe bearings.

The airframe bearing shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.9.2)

Analysis and test of the airframe bearing reduces the risk of costly design changes, which would result from the need to increase bearing capability. A design change could also impact surrounding structure design. The risk of bearing replacement becoming a high maintenance item is also reduced.

VERIFICATION GUIDANCE (4.4.9.2)

TBS: MIL-HDBK-1599 should provide guidelines for analysis of airframe bearings. Verify by demonstration that airframe bearings are standardized to the maximum extent possible without comprising performance. Analysis and testing of nonstandard bearings should take into account the nonstandard features of the bearing as well as the design application for which the nonstandard bearing is intended.

VERIFICATION LESSONS LEARNED (4.4.9.2)

(TBD)

I.3.4.9.2.1 Capacity.

Airframe Bearings shall have the highest load capacity rating consistent with space and weight as specified in __(TBS)__.

REQUIREMENT RATIONALE (3.4.9.2.1)

Growth of air vehicle capabilities generally result in bearing design load increases as the air vehicle program matures. Providing the highest capacity bearing that will fit in the available space during the initial design will preclude overloading bearings in future model air vehicles or expensive structural redesign to incorporate larger bearings.

REQUIREMENT GUIDANCE (3.4.9.2.1)

TBS: MIL-HDBK-1599 should be used to provide capacity equations for the most common airframe bearing types. The capacity equations or other analytical tools should be used to compare candidate bearings.

REQUIREMENT LESSONS LEARNED (3.4.9.2.1)

The proper size of the bearing have been determined after choosing what type of bearing best meets the operating parameters. The two primary load conditions that have been considered to properly select a bearing for aerospace vehicle applications were (1) “static” loading, which is concerned with the strength of the bearing and its ability to resist significant deformation and fracture, and (2) “dynamic” loading, which is concerned with the oscillation or rotation of the bearing while under fixed or changing load and is limited by fatigue and wear. After a tentative selection was made on the basis of static capacity, the size selected was reviewed to determine if it had adequate life for the rotation or oscillation desired.

I.4.4.9.2.1 Capacity.

Airframe Bearing capacity shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.9.2.1)

Analysis and test of the airframe bearing capacity reduces the risk of costly design changes, which would result from the need to increase bearing capacity. The risk of bearing replacement becoming a high maintenance item is also reduced.

VERIFICATION GUIDANCE (4.4.9.2.1)

TBS: Verify by test or analysis that the bearing meets the capacity requirements of the application. Analysis of bearing capacity using the capacity equations of MIL-HDBK-1599 should be sufficient to verify the requirement of most airframe bearing applications. When unique applications or nonstandard bearings are used, use of other analytical techniques may be appropriate.

VERIFICATION LESSONS LEARNED (4.4.9.2.1)

An airframe bearing may be subjected to radial, axial and moment loading at the same time. It will be necessary to calculate the equivalent thrust load and to determine the proper size bearing by a comparison of the calculated equivalent load and the limit thrust load using appropriate analytical techniques.

I.3.4.9.2.2 Installation and retention.

Bearings shall be sized to fit within a housing as specified in __(TBS)__. If lubrication of the bearing is required, the bearing shall be lubricated when installed and provisions shall be made for re-lubrication, inspection and replacement.

REQUIREMENT RATIONALE (3.4.9.2.2)

The proper fit of bearings within the housing will preclude adverse effects such as fretting corrosion, unacceptable stress levels in either the bearing or housing, migration of the bearing out of the housing, and reduced bearing fatigue and wear life.

Some bearings require periodic re-lubrication to achieve rated life. Provisions are needed for the maintainer to re-lubricate the bearings with standard tools.

REQUIREMENT GUIDANCE (3.4.9.2.2)

TBS should be filled in with AIA/NAS 0331, MIL-HDBK-1599, or other specifications that provide guidelines for airframe bearing installation, retention, and replacement. Requirement 202 of MIL-HDBK-1599 provides guidelines for establishing engineering criteria and design information relative to the installation and retention of bearings, including recommended shaft and housing fits to mount standard bearings. Requirement 203 of MIL-HDBK-1599 provides guidance for establishing standard practices for the lubrication of the bearings and bearings surfaces. Nonstandard bearings may require special consideration to select the proper fit for the bearing to operate as designed.

REQUIREMENT LESSONS LEARNED (3.4.9.2.2)

Landing gear trunnion bearings require a special fit to ensure the landing gear meets the requirement to drop and lock under its own weight.

I.4.4.9.2.2 Installation and retention.

Compliance with the installation and retention requirement shall be verified by __(TBS)__. Verify by inspection that bearings that require lubrication are lubricated when installed and provisions have been made for re-lubrication, inspection and replacement.

VERIFICATION RATIONALE (4.4.9.2.2)

Verification of installation requirements during the initial design assures that the bearing operates as intended when exposed to the loads, temperatures and contaminants of the design environmental conditions. Verification of lubrication requirements assures that bearings operate as intended when installed and that proper maintenance can be performed.

VERIFICATION GUIDANCE (4.4.9.2.2)

TBS should be filled in with inspection. Inspection of assembly, installation, and fabrication drawings, process specifications confirms that proper provisions have been specified for installing, maintaining, and replacing airframe bearings. AIA/NAS 0331 and MIL-HDBK-1599 provide a basis for evaluating installation and lubrication provisions on engineering drawings. Unique application or nonstandard bearings may require provisions that differ from AIA/NAS 0331 and MIL-HDBK-1599, which is acceptable with adequate justification.

VERIFICATION LESSONS LEARNED (4.4.9.2.2)

(TBD)

I.3.4.9.2.3 Antifriction bearings.

If required, antifriction bearings shall be in accordance with __(TBS 1)__. Design and usage limitations shall be as follows __(TBS 2)__.

REQUIREMENT RATIONALE (3.4.9.2.3)

Standard bearings should be given priority in new design in order to minimize the cost of procurement and testing, reduce schedule and technical risk, and obtain multiple sources of supply. Design and usage limitations reflect accepted design practices within the aerospace industry to provide structurally efficient joints that are trouble free in service.

REQUIREMENT GUIDANCE (3.4.9.2.3)

TBS 1 should be filled in with MIL-HDBK-1599 selection recommendations, SAI AS 3990, and SAE AS6038, AS6039, AS7949, and AS8914.

TBS 2 should be filled in with information from table 201-VII of MIL-HDBK-1599, which provides guidance for design and usage limitations.

REQUIREMENT LESSONS LEARNED (3.4.9.2.3)

Antifriction (or rolling element) bearings have several advantages over plain bearings. A life with essentially no wear, a comparatively small lubricant requirement, and a low starting and dynamic friction coefficient are the principal advantages. Their use results in reduced control system friction and pilot effort. The extremely close internal clearances permit backlash or looseness to be reduced to a minimum.

Caution: antifriction bearings are manufactured to very close tolerances and are adversely affected by contaminants or moisture. Rough and careless handling and installation can seriously reduce the life.

When nonstandard bearings were used they were approved via the program process for inclusion in the PPSL.

I.4.4.9.2.3 Antifriction bearings.

Antifriction bearings shall be verified by inspection.

VERIFICATION RATIONALE (4.4.9.2.3)

Conformance with the specified standards is necessary to achieve required performance.

VERIFICATION GUIDANCE (4.4.9.2.3)

The inspection should verify that the Antifriction Bearing are in accordance with MIL-HDBK-1599, SAI AS 3990, and SAE AS6038, AS6039, AS7949, and AS8914.

VERIFICATION LESSONS LEARNED (4.4.9.2.3)

Additional laboratory testing is not necessary for parts listed on a DOD approved qualified products list as long as the proposed application is well within the loads and conditions established in the associated specification and standards.

I.3.4.9.2.4 Plain bearings.

If required, plain bearings shall be in accordance with ___(TBS 1)___. Design and usage limitations shall be as follows: __(TBS 2)__.

REQUIREMENT RATIONALE (3.4.9.2.4)

Standard bearings should be given priority in new design in order to minimize the cost of procurement and testing, reduce schedule and technical risk, and obtain multiple sources of supply. Design and usage limitations reflect accepted design practices within the aerospace industry to provide structurally efficient joints that are trouble free in service.

REQUIREMENT GUIDANCE (3.4.9.2.4)

TBS 1 should be filled in with MIL-HDBK-1599 selection recommendations and SAE AS81820, AS81934, AS81935, AS81936, and AS8952.

TBS 2: Select one or more of the listed limitation parameters that apply to the air vehicle subsystem and equipment:

a. Table 201-VII of MIL-HDBK-1599 provides guidance for design and usage limitations.

b. Self-aligning bearings should be employed where linkage geometry or structural deflections would induce unacceptable stress levels in rigid bearings.

c. Sintered bearings generally are not suitable for airframe applications. If used the following limitations should be observed:

   1. Design loads should be less than 1000 psi.

   2. The bore should not be reamed since metal can be smeared over the voids in the bearing surface, thus preventing oil from being released from the porous structure.

   3. Use in continuous rotation applications only. Oscillation under unidirectional load does not allow liberated oil to be spread freely on the bearing surface, resulting in accelerated wear.

   4. Do not use where subjected to shock loads.

d. Plain annular and plain self-aligning bearings are generally not suitable in air vehicle primary control systems and other critical applications. They are intended for use where:

   1. Moderate friction and bearing play at low rotational speeds are not objectionable.

   2. Wear is not excessive.

Bearings are not subject to vibratory shocks and alternating loads.

REQUIREMENT LESSONS LEARNED (3.4.9.2.4)

Generally, plain (or sliding surface) bearings have higher friction than antifriction types of the same size but have greatly increased static load capabilities. Dynamic life is a function of the type of lubricant and the imposed load and is the limiting condition for this class of bearing. Dynamic load allowables are much lower than static load allowables, which is a major difference when compared to antifriction bearing values. In general, plain bearings are more rugged than antifriction types and can better tolerate contamination and careless handling.

For SAE AS81820 plain spherical bearings, the radial static limit load is calculated for the capacity of the bearing, housing, and pin. Because the wide series has a greater pin bending, the radial capacity is rated lower than the bearings listed in the narrow series.

Nonstandard plain bearings have been approved via the program process for inclusion in the PPSL may be used.

I.4.4.9.2.4 Plain bearings.

Verify by inspection and test that plain bearings are in accordance with __(TBS)__. Verify by inspection that plain bearing design and usage limitations are followed.

VERIFICATION RATIONALE (4.4.9.2.4)

Inspection of assembly, installation, and fabrication drawings confirms that specified plain bearings conform to the specified standards or have been approved via the PPSL process and that design and usage limitations have been followed.

VERIFICATION GUIDANCE (4.4.9.2.4)

TBS should be filled in with SAE ARP5448, which provides recommended practices for testing plain bearings.

VERIFICATION LESSONS LEARNED (4.4.9.2.4)

Additional laboratory testing is not necessary for parts listed on a DoD-approved Qualified Products List (QPL) (https://assist.dla.mil/online/start) if the proposed application is within the loads and conditions established in the associated specification and standards. Non-standard bearings may require additional testing as recommended in SAE ARP5448 to verify the bearing will meet the performance requirements of the application.

I.3.4.9.3 Fastener subsystem.

The fastener subsystem shall be capable of joining and securing airframe structural members, air vehicle components, access panels and doors while preserving the structural integrity of the elements being joined. The fastener subsystem shall use common fasteners and attributes to the maximum extent possible without compromising performance.

REQUIREMENT RATIONALE (3.4.9.3)

It has been estimated that 20 to 30 percent (20-30%) of the cost of air vehicle procurement and maintenance can be attributed to fasteners and fastening subsystems. The selection of appropriate fasteners is of extreme importance. Standard fasteners should be given priority in new aerospace systems design.

REQUIREMENT GUIDANCE (3.4.9.3)

The design activity should prepare a PPSL. A PPSL inhibits the proliferation of fastener designs used in aerospace applications; and assists in reducing part numbers, lowering procurement cost, utilizing common maintenance practices, and reducing support tool variations. All parts introduced in the design of equipment, system or subsystem should be listed on the PPSL.

Where possible and practical, mating parts (except where flush head bolts or plate nuts are used) should have similar external wrenching configurations.

REQUIREMENT LESSONS LEARNED (3.4.9.3)

(TBD)

I.4.4.9.3 Fastener subsystem.

The fastener subsystems ability to join and secure airframe structural members, air vehicle components, access panels and doors while preserving the structural integrity of the elements being joined shall be incrementally verified by __(TBS)__. Verify by demonstration that the fastener subsystem uses common fasteners and attributes to the maximum extent possible without compromising performance.

VERIFICATION RATIONALE (4.4.9.3)

Standard fasteners and fastener subsystems are expected to be used in most applications. This requirement can be verified through analysis and test of new fasteners and fastener subsystems to determine their mechanical and physical properties. This verification also establishes the methods to demonstrate that the fastener subsystem uses common fasteners and attributes.

VERIFICATION GUIDANCE (4.4.9.3)

TBS should be filled in with analysis, inspection, demonstration, test, or a combination of these methods.

AIA/NASM1312 describes the unified standard methods of testing, analysis of data, and presentation of results.

VERIFICATION LESSONS LEARNED (4.4.9.3)

(TBD)

I.3.4.9.3.1 Fastened joint allowables.

The fastener and joint design allowables shall not exceed those design allowable values specified in __(TBS 1)__. Where the design allowables are nonexistent, they shall be as established in __(TBS 2)__.

REQUIREMENT RATIONALE (3.4.9.3.1)

To determine the strength of mechanical joints, it is necessary to know the strength of the individual fastener, both by itself and when installed in various thicknesses of various materials.

REQUIREMENT GUIDANCE (3.4.9.3.1)

TBS 1 should be filled in with DOT/FAA/AR-MMPDS, Chapter 8, which presents joint design allowable loads for a variety of mechanically fastened joints.

TBS 2 should be filled in with DOT/FAA/AR-MMPDS, Chapter 9, which establishes procedures necessary to develop joint design allowable loads.

REQUIREMENT LESSONS LEARNED (3.4.9.3.1)

(TBD)

I.4.4.9.3.1 Fastened joint allowables.

The fastener and joint design allowable loads shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.9.3.1)

The design allowable loads in DOT/FAA/AR-MMPDS are used in the design of aerospace structures and elements. DOT/FAA/AR-MMPDS is the most authoritative document reflecting the actual properties of the products covered.

VERIFICATION GUIDANCE (4.4.9.3.1)

TBS should be filled in with test or analysis. The joint design allowable loads can be confirmed with the use of DOT/FAA/AR-MMPDS, Chapter 8. Where the design allowable loads have not been predetermined, DOT/FAA/AR-MMPDS, Chapter 9 provides the detailed information on the generation and analysis of joint data that results in the determination of joint allowable loads. The minimum data requirements and analytical procedures are defined in this chapter for the establishment of DOT/FAA/AR-MMPDS design allowable loads. AIA/NASM1312 is the recommended source for the test procedures in developing joint allowable load information.

VERIFICATION LESSONS LEARNED (4.4.9.3.1)

(TBD)

I.3.4.9.3.2 Fastener threads.

Fastener threads shall be as defined __(TBS 1)__. Fastener threads used in safety critical applications shall be as defined __(TBS 2)__. Military engineering cognizant activity for air vehicle subsystem and equipment shall approve designation of a fastener thread as safety critical.

REQUIREMENT RATIONALE (3.4.9.3.2)

Selection of thread geometry should be limited to a single specification to standardize on thread dimensions (preferred diameter-pitch).

REQUIREMENT GUIDANCE (3.4.9.3.2)

TBS 1 should be completed using the following guidance. The UNJ thread form has been adopted by the aerospace industry as the all-purpose thread standard, with the exception of thread sizes .138 inches and smaller, which may use the UN thread form. Within standard UNJ threads, the use of fine threads should be given preference to facilitate the maximum usage of a limited number of threads. For aerospace applications, Classes 3A and 3B should be used. ASME B1.15 contains basic thread data for all standard pitches of threads.

TBS 2 should be filled in with consideration given to the following safety critical applications: (1) thread failure that results in structural failure, or loss of canopy, or landing gear failure, or subsystem failure, or engine ingestion of foreign objects; (2) thread failure that is not the result of multiple failures; and (3) the primary joint failure mode is tension.

It is the responsibility of the design activity of new equipment to identify safety critical applications. The designation of a fastener thread as safety critical indicates that the fastener is used in a safety critical application.

REQUIREMENT LESSONS LEARNED (3.4.9.3.2)

(TBD)

I.4.4.9.3.2 Fastener threads.

Configuration compliance shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.9.3.2)

(TBD)

VERIFICATION GUIDANCE (4.4.9.3.2)

TBS should be filled in with inspection.

VERIFICATION LESSONS LEARNED (4.4.9.3.2)

(TBD)

I.3.4.9.3.3 Fastener usage limitations.

Fastened joint usage limitations shall be as follows __(TBS)__.

REQUIREMENT RATIONALE (3.4.9.3.3)

This requirement provides fastener usage limitations associated with their use. These usage limitations have been developed by the military and aerospace industry, and indicate accepted design practices necessary for air vehicles and subsystems.

REQUIREMENT GUIDANCE (3.4.9.3.3)

TBS should be filled in by selecting one or more of the listed limitation parameters that apply to the air vehicle subsystem and equipment.

a. In the design selection of inserts, consideration should be given to the axial load-carrying capabilities of the installed insert in a specific parent material.

b. Inserts should be installed in accordance with manufacturer's instructions or approved user procedures to insure prevention of their movement during installation or removal of the externally threaded part.

c. Screw thread or screw-locking inserts should not be used in the following applications unless the externally threaded part is held by a positive-locking device that requires shearing or rupture of material before torsion loads would be applied to the externally threaded part in such a manner as to relieve the initial stress of the assembly:

   1. At joints in control systems, at single attachments, or where loss of the threaded member affect safety of flight.

   2. With an externally threaded part that serves as an axis of rotation.

d. Externally threaded fasteners used in conjunction with self-locking inserts should be selected to ensure full engagement of locking device and sufficient thread engagement to guarantee full development of the required design tension load.

e. Silver plated or cadmium plated inserts should not be used in titanium housings.

f. Self-locking inserts require suitable lubricant at thread interface when being mated with titanium or corrosion resistant screws or bolts.

g. When using studs in tapped holes, consideration should be given to eliminating the possibility of stud rotation when installing or removing the mating unit.

h. Stepped studs may be used to provide higher strength capabilities in relatively low strength structural (parent) materials with a shorter length of engagement than required for straight studs (both ends same diameter). In the design selection of studs for structural applications, it is necessary that the proper degree of consideration be given to the axial load carrying capabilities of the installed stud in the specific parent materials at the maximum operating temperature of the assembly. The axial load capability of an installed stud is determined by the lesser value of either the minimum tensile strength of the nut end or by the resistance to pull out from the parent material.

i. Resistance to pull out of the installed stud is the product of the shear engagement area of the stud end thread and the allowable shear stress of the parent material at the maximum operating temperature. It does not represent a dimension of either of the members in an unassembled condition.

j. The allowable shear stress for most metallic materials is listed in DOT/FAA/AR-MMPDS. The shear engagement areas of the stud end thread may be obtained from the stud standard. Most studs are intended to be loaded primarily in tension. Joints carrying shear loads should be designed to preclude subjecting the studs to shear loads or use only those studs whose features allow their use under shear loading.

k. Quick release pins may be of the following types: positive-locking, single-acting, and positive-locking, double-acting. Quick release pins are primarily designed to be used in applications that require double shear strength capabilities combined with quick-disconnect features.

l. The specific shear and tension load capabilities are a function of the material being attached, hole size, and hardness of application material. Typical applications are quick attachment and removal of ground support equipment and attaching warning streamers to critical joints.

m. Plain washers may be used to accommodate variations in grip length, and under a nut to protect surface from damage and to reduce the stress of the joint by increasing the bearing area. Plain washers should be used to avoid electrolytic corrosion by preventing contact of dissimilar metals.

n. Lock washers should not be used in airframe applications.

REQUIREMENT LESSONS LEARNED (3.4.9.3.3)

(TBD)

I.4.4.9.3.3 Fastener usage limitations.

Fastener usage limitations shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.9.3.3)

Inspection and demonstration are considered the most appropriate verification methods to confirm that the fasteners meet the requirements.

VERIFICATION GUIDANCE (4.4.9.3.3)

TBS: Verification of this requirement should be accomplished by an inspection of assembly, installation, fabrication drawings and processing specifications to confirm the fastener adherence to the design and usage limitation requirements.

VERIFICATION LESSONS LEARNED (4.4.9.3.3)

(TBD)

I.3.4.9.3.4 Externally threaded fastener usage limitations.

Externally threaded fastener usage limitations shall be as follows: __(TBS)__.

REQUIREMENT RATIONALE (3.4.9.3.4)

This requirement provides screw and bolt usage limitations associated with their use. These usage limitations have been developed by the military and aerospace industry, and indicate accepted design practices necessary for air vehicles and subsystems.

REQUIREMENT GUIDANCE (3.4.9.3.4)

TBS should be filled in by selecting one or more of the listed limitation parameters that apply to the air vehicle subsystem and equipment.

a. Structural screws and bolts loaded in shear should have sufficient grip length so that no threads are in bearing.

b. Interference between the hole and the head to shank radius should be avoided. It is standard design practice to use countersunk washers or countersunk bolt holes under high-strength (160 ksi and above) protruding head screws and bolts for clearance of the head-to-shank fillet radius.

c. Screws and bolts smaller than .250 inches in diameter should not be used in any single bolted structural connection, including primary control systems, or any application where failure would adversely affect safety of flight.

d. The smallest recommended diameter for 100º reduced flush head screws and bolts is normally .250 inches. However, .190 inches diameter 100º reduced head screws and bolts may be used in panels whose removal is not required for scheduled maintenance.

e. Aluminum alloy threaded screws and bolts should not be used in structural applications.

f. Silver- or cadmium-plated screws and bolts should not be used in contact with titanium structure. Cadmium plated screws and bolts should not be used in temperature probes, electrical or life support space vehicle components or subsystems, portable water supplies, or food processing equipment.

g. Titanium alloy screws and bolts should not be used with silver plated self-locking nuts at temperatures above 600ºF, or cadmium plated nuts at temperatures above 200ºF.

h. Self-locking screws and bolts or screws and bolts utilizing self-locking elements should not be used as follows:

   1. at joints in control systems, at single attachments, or where the loss of the bolt would affect safety of flight;

   2. as an axis of rotation for another part unless the fastener is held in a positive locking device that requires shearing or rupture of material before torsion loads would be applied to the bolt in such a manner as to relieve the internal stress of the assembly or turn the bolt loose;

   3. at any single bolted structural joint that serves as a primary load path, the failure of which would endanger the safety of personnel or would render the equipment inoperative or cause its destruction.

i. Self-locking screws and bolts, or screws and bolts utilizing self-locking elements should not be used to attach access panels or doors, or to assemble any parts that are routinely disassembled at intervals less than 400 flight hours.

j. Self-locking screws and bolts, or screws and bolts utilizing self-locking elements should not be used on jet engine air vehicle locations where a loose fastener could fall or be drawn into the engine intake.

k. For screws and bolts utilizing a self-locking element, the entering end of the threaded holes used in conjunction with the self-locking externally threaded fastener should be countersunk 90º to 120º. This countersink should have a minimum diameter of .015 inches larger than the major thread diameter of the fastener. This is to prevent the first thread from cutting the self-locking element.

l. Unthreaded holes, or portions of holes through which a bolt utilizing a self-locking element must pass, should have a minimum diameter sufficient to clear the locking element.

Self-locking screws and bolts, or screws and bolts utilizing self-locking elements should not be used with castellated nuts or self-locking nuts.

Fasteners of the same diameter having the same grip length, but different shank length; or those having the same shank length, but different grip length; should not be used in the same bolt circle or in proximity where they could be inadvertently interchanged.

REQUIREMENT LESSONS LEARNED (3.4.9.3.4)

(TBD)

I.4.4.9.3.4 Externally threaded fastener usage limitations.

Externally threaded fastener usage limitations shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.9.3.4)

Inspection and demonstration are considered the most appropriate verification methods to confirm that the screws and bolts meet the limitation requirements.

VERIFICATION GUIDANCE (4.4.9.3.4)

TBS should be filled in with consideration given to the following: Verification of this requirement should be accomplished by an inspection of assembly, installation, fabrication drawings, and processing specifications to confirm the screw and bolts adherence to the design and usage limitation requirements.

VERIFICATION LESSONS LEARNED (4.4.9.3.4)

(TBD)

I.3.4.9.3.5 Nut usage limitations.

Nut usage limitations shall be as follows __(TBS)__.

REQUIREMENT RATIONALE (3.4.9.3.5)

This requirement provides nut usage limitations associated with their use. These usage limitations have been developed by the military and aerospace industry, and indicate accepted design practices necessary for air vehicles and subsystems.

REQUIREMENT GUIDANCE (3.4.9.3.5)

TBS should be filled in by selecting one or more of the listed limitation parameters that apply to the air vehicle subsystem and equipment.

a. Self-locking nuts are preferred over non-self-locking nuts in air vehicle applications. Self-locking nuts for use with bolts or studs with a minimum ultimate tensile strength of 160 ksi and designed for high tension fatigue loading should be external wrenching nuts, barrel nuts, or plate nuts which will develop the full tensile strength of the bolt.

b. Plain or self-locking nuts used in:

   1. any joint that serves as an axis of rotation, or

   2. any joint that is designed to transmit motion which may result in relative rotation between components in the joint, or

   3. any bolted structural joint with less than three bolts and serves as a primary load path, the failure of which would endanger the safety of personnel or would render the

air vehicle inoperative or could cause its destruction, should be secured by positive type mechanical locking devices.

c. Bolts, studs or screws should extend through the self-locking nut for a length equivalent of two threaded pitches. This length includes the chamfer.

d. Self-locking nuts that are attached to structure should be attached in a positive manner to eliminate the possibility of their rotation or misalignment when tightening is to be accomplished by rotating the bolts or screws. The manner of attachment should permit removal without injury to the structure, and permit replacement of the nuts. When projection spot-welding is used for attaching plate nuts, control should be maintained in order that removal by drilling out welds permits replacement with drilled plate nuts.

e. Self-locking nuts should not be used:

    1. at joints in control systems at single attachments, or

    2. where loss of the bolt would affect safety of flight, unless the treaded parts are held by a positive locking device that requires shearing or rupture of materials before torsion loads relieve the initial stresses of the assembly.

f. Self-locking nuts should not be used with bolts or screws in locations where the loose nut, bolt or screw could fall or be drawn into an engine air intake duct.

g. Self-locking nuts should not be used with bolts, screws, or studs to attach access panels, doors or to assemble any parts that are routinely disassembled prior to or after each flight.

h. All nuts, except self-locking nuts and nuts for machine screws, should be locked by cotter pins or safety wire.

REQUIREMENT LESSONS LEARNED (3.4.9.3.5)

(TBD)

I.4.4.9.3.5 Nut usage limitations.

Nut usage limitations shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.9.3.5)

Inspection and demonstration are considered the most appropriate verification methods to confirm that the nuts meet the requirements.

VERIFICATION GUIDANCE (4.4.9.3.5)

TBS should be filled in with consideration given to the following: Verification of this requirement can best be accomplished by an inspection of assembly, installation, fabrication drawings and processing specifications to confirm the nuts' adherence to the design and usage limitation requirements.

VERIFICATION LESSONS LEARNED (4.4.9.3.5)

(TBD)

I.3.4.9.3.6 Blind fastener usage limitations.

Blind fastener usage limitations shall be: __(TBS)__.

REQUIREMENT RATIONALE (3.4.9.3.6)

This requirement provides blind fastener usage limitations associated with their use. These usage limitations have been developed by the military and aerospace industry, and indicate accepted design practices necessary for air vehicles and subsystems.

REQUIREMENT GUIDANCE (3.4.9.3.6)

TBS should be filled in by selecting one or more of the listed limitation parameters that apply to the air vehicle subsystem and equipment.

a. Solid rivets or blind fasteners should be used in structural joints only where shear loads are the primary design load consideration.

b. The edge distance (center of hole to edge of sheet) for the location of rivets in sheets should be a minimum of two rivet diameters. The minimum spacing for riveted joints in fuel tight areas should be three rivet diameters; other minimum spacing should be four rivet diameters in the same adjacent rows or in staggered patterns.

c. To minimize galvanic corrosion of the joint, rivets should not be anodic to the most anodic material in the joint.

d. Solid rivets should be driven utilizing tools that conform to acceptable aerospace practices for the rivet size and material being upset. When using rivet material harder than the material to be joined, particular care should be taken to avoid distortion during riveting. Special care is recommended when selecting rivet types and materials for installation through nonmetallic structures. Soft materials may be riveted by using washers under the rivet-upset trail.

e. Spot-facing should be used to provide a flat surface under upset heads when:

   1. the surface slope is greater than 8° under the upset head of the rivets;

   2. a curved surface has a radius less than three times the rivet shank diameter;

   3. and the roughness of the facing surface under the heads is greater than 500 RHR.

f. Solid rivets should not be used where forces required to upset the rivet that could be detrimental to the structure.

g. Blind rivets and fasteners are intended for applications where inaccessibility precludes the use of conventional fasteners, and as a repair fastener for solid rivets.

h. Blind rivets and fasteners should not be used in liquid tight areas. Blind rivets and fasteners should not be used in applications where they are subject to removal during routine servicing and overhaul. Blind rivets and fasteners should not be used on control surface hinges, hinge brackets, flight control actuating systems attachment, wing attach fittings, landing gear fittings, or similar applications.

i. Mechanically locked spindle blind rivets may be used in engine inlet areas. Friction locked spindle blind rivets should not be used in engine inlet areas. Blind rivet holes for dimpled assembly should be drilled to size after dimpling.

REQUIREMENT LESSONS LEARNED (3.4.9.3.6)

(TBD)

I.4.4.9.3.6 Blind fastener usage limitations.

Blind fastener usage limitations shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.9.3.6)

Inspection and demonstration are considered the most appropriate verification methods to confirm that the blind fasteners meet the requirements.

VERIFICATION GUIDANCE (4.4.9.3.6)

TBS should be filled in with consideration given to the following: verification of this requirement can best be accomplished by an inspection of assembly, installation, fabrication drawings and processing specifications to confirm blind fastener adherence to the design and usage limitation requirements.

VERIFICATION LESSONS LEARNED (4.4.9.3.6)

(TBD)

I.3.4.9.3.7 Fastener sizing.

The shank diameter of threaded structural fasteners shall not be less than .190 inches.

REQUIREMENT RATIONALE (3.4.9.3.7)

The rationale for having a fixed minimum fastener diameter for threaded structural applications is to provide structural integrity in the bearing and shear load paths. When a .190-inch minimum diameter for structural fasteners is established, maintainability is greatly aided. Fasteners with diameters less than .190 inches are easily over-torqued by hand-held drivers.

REQUIREMENT GUIDANCE (3.4.9.3.7)

This requirement should apply only to threaded structural fasteners that are torqued or installed by a driving recess in the head of the fastener. This requirement should not apply to rivets, either solid or blind, or pin and collar type fasteners where the driving recess is in the thread end when utilized with the intended or designed mating torque-off collar. When a regular nut or non-torque limiting device is used in conjunction with the point drive threaded fasteners, then the above requirement should apply.

REQUIREMENT LESSONS LEARNED (3.4.9.3.7)

When small diameter fasteners are utilized in long grip length, bolt bending also becomes a problem and joint stiffness is lost.

I.4.4.9.3.7 Fastener sizing.

Fastener sizing shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.9.3.7)

Sizing must be verified to assure adequate strength and fastener life is achieved.

VERIFICATION GUIDANCE (4.4.9.3.7)

TBS should be filled in with inspection and demonstration.

Since some Military, industry, prime contractor and vendor drawings on threaded fasteners allow or call out diameters smaller than .190 inches diameter, it is easy for a weight conscious designer to inadvertently select a smaller than .190 inch diameter. Merely checking a PPSL list, which usually does not go into detail as to diameter or limitations, will not find this problem. Also PPSL's usually do not indicate the mating parts, such as nut or collar with the pin or bolt. Inspection is the only way to determine what parts are mated together. Various shop practices, rework and repair procedures and deviations from design drawings also may change what diameters are actually used from what is called out. Also there are "gray" areas where a designer may believe that his application is not structural or critical and select a smaller than .190 inch diameter.

VERIFICATION LESSONS LEARNED (4.4.9.3.7)

(TBD)

I.3.4.9.3.8 Head angle.

The head angle of countersunk fasteners and the nominal fastener recess angle shall be __(TBS 1)__, except for __(TBS 2)__, whose head angle shall be __(TBS 3)__.

REQUIREMENT RATIONALE (3.4.9.3.8)

To determine the proper fastener head angle or countersink for flush type fasteners, it is necessary to know the joint thickness or top sheet skin thickness as well as the materials physical strength, such as sheet bearing, shear, and compression. The head countersink included angle of 100° has been accepted as an aerospace industry standard to prevent any countersink mismatch and subsequent fastener hole deformation. Also, it provides for cross-servicing of air vehicles between NATO countries. For thin sheet joints, 120° and 130° head angles have been used.

REQUIREMENT GUIDANCE (3.4.9.3.8)

TBS 1 should be completed using a specific value for the head angle of the countersunk fasteners.

TBS 2 should be completed by indicating any exceptions to the value in TBS 1.

TBS 3 should be completed by giving the value(s) for the exceptions indicated by TBS 2. For metallic structure, the 100º countersink head angle has been accepted as an aerospace industry standard to prevent any countersink angle mismatch in assembled joints, and has been determined by test and field service life to be the optimum balance between sheet thickness and fastener strength for air vehicle structural materials. For non-metallic structure, tests have shown that head angles of 130º work satisfactorily. Some solid rivets, which can be used in structural applications, provide head angles of 120º. Fasteners with head angles of 130º and 120º provide the capability of utilizing thinner joint materials.

REQUIREMENT LESSONS LEARNED (3.4.9.3.8)

(TBD)

I.4.4.9.3.8 Head angle.

Head angle shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.9.3.8)

Verification of the proper countersink angle is accomplished by inspection since that is the only positive method of insuring the compliance with this requirement. There are no quick, economical tests that will discern countersink angles with the fastener installed. Inspection of the physical parts and components as well as drawing inspection can accomplish this most readily.(Rewrite)

VERIFICATION GUIDANCE (4.4.9.3.8)

TBS should be filled in with inspection.

Since various countersink-included angles exist, not only on the fasteners but also in the sheet or plate in which the countersink fastener is installed, many inadvertent combinations exist. The wrong countersink fastener may be placed in the correct countersink hole. The correct countersunk fastener may be installed in the wrong countersunk hole, or the wrong countersunk fastener installed in a different but still wrong (per drawing call out) countersunk hole. These misapplications can only be detected by inspection. Inspection of drawings and PPSL will usually indicate the proper head countersink angle and the statistical probability that the physical hardware is per the drawing should be very high.

VERIFICATION LESSONS LEARNED (4.4.9.3.8)

(TBD)

I.3.4.9.3.9 Fasteners used in single point linkages.

In critical single point linkages, such as flight control linkages, the fastener subsystem shall use self-retaining bolts.

REQUIREMENT RATIONALE (3.4.9.3.9)

Single-bolt linkage-joints are used throughout an air vehicle. In many cases, loss of this single bolt could cause catastrophic failure and loss of the air vehicle and life. Examples of such usage are fuel controls, throttle controls, and flight controls. Two types of self-retaining bolts (SRB) have been developed to solve this critical flight safety requirement. These are described below as well as guidance for their selection. Both are equal in overall performance.

REQUIREMENT GUIDANCE (3.4.9.3.9)

Two types of SRB have been developed for critical flight safety applications and are considered of comparable performance. Type I, positive locking bolts, are designed to be installed and removed after the retaining element release button is actuated to allow the locking elements to retract into the bolt body. Type II, impedance type bolts, are designed to be installed and removed by overcoming the frictional force of the retaining elements.

The joint should be designed so that with a self-retaining bolt installed, the joint integrity is not dependent on washers or any other normally removable parts, other than the bolts. A maximum of two washers may be used to adjust for tolerance variation and, when required, they should be used under the head of the bolt, but not under the nut. Bridging spacers may be used on positive-locking bolts only.

Self-retaining bolts should be used in control systems where the bolt serves as an axis of rotation and where separation of the linkage will affect safety of flight. These include controls for flight, fuel, engine air reduction, and propeller systems. The bolts should be additionally locked in position by counterbored-castellated nuts with captive washers. Type II, impedance, self-retaining bolts are less expensive to manufacture, easier to install and remove and have a higher shear and tensile capability, however, the positive loading type I will ensure a positive joint, if installed properly. Corrosion-resistant steel parts are preferred over alloy steel parts.

REQUIREMENT LESSONS LEARNED (3.4.9.3.9)

(TBD)

I.4.4.9.3.9 Fasteners used in single point linkages.

Verify by inspection and demonstration that the fasteners used in critical single point linkages (such as flight control linkages) are self-retaining bolts.

VERIFICATION RATIONALE (4.4.9.3.9)

The type I and II self-retaining bolts specified in the requirements section have been developed specifically to solve the critical flight safety problem and have done so successfully whenever applied. Only by physical inspection and demonstration that all single bolt linkage joints actually contain a SRB can this requirement be met.

VERIFICATION GUIDANCE (4.4.9.3.9)

Many means of insuring linkage integrity or connections exists. There are double and triple redundant systems, permanent fasteners whereby a piece or part has to be destroyed to be removed, cotter pining or safety wiring, and directives mandating that safety inspections should be rigorously complied with. However, none of these methods are practical or reasonable from the life cycle maintenance standpoint. Joints need to be periodically removed. Ground functional checks and inspections will only determine that a bolt is in the linkage joint and nut or cotter pin (or both) is installed. Therefore, because of the criticality of this item, inspection and demonstration methods of verification compliance are essential.

VERIFICATION LESSONS LEARNED (4.4.9.3.9)

(TBD)

I.3.4.9.3.10 Fastener drive and wrenching element configuration.

Fastener drive and wrenching elements, installation and removal tooling, and torque control shall be as defined __(TBS)__.

REQUIREMENT RATIONALE (3.4.9.3.10)

This requirement provides for the selection of drive and wrenching elements for use with aerospace structure fastener subsystems. The fastener recess design selected should influence maintenance manpower, maintenance cost and driver inventory requirements.

In all applications of internal drive configuration fasteners, loads are applied in both torsional directions for removal and installation. If the recess cannot withstand or transmit sufficient torsional force in the installation direction, the desired pre-load is not reached and clamp up is not sufficient, which could result in failure. If the torsional strength of the recess is insufficient in the removal direction, then either the recess cams out or the driver bit breaks (or both), resulting in the fastener having to be drilled out, which increases both maintenance cost and the mission down time of the weapon system.

REQUIREMENT GUIDANCE (3.4.9.3.10)

TBS should be filled in with consideration given to the following:

Hexagon drive external wrenching elements should be limited to use for fasteners up to 180,000 psi maximum ultimate tensile stress. All externally and internally threaded fasteners heat treated to 180,000 psi minimum ultimate tensile stress and higher should have spline drive or 12-point external wrenching element. Preference should be given to spline drive external wrenching element on high-strength fasteners. Fasteners less than 180,000 psi may use spline drive external wrenching element.

The cruciform recess may be used in fastener heat treated up to 160,000 psi maximum ultimate tensile stress. Fastener heat treated above 160,000 psi maximum ultimate tensile stress with cruciform recess may be used in secondary structure. Six lobe drive, offset cruciform and offset cruciform-ribbed recesses should be used in fastener heat treated to 160,000 psi minimum ultimate tensile stress and higher. These recesses may be used in fasteners below 160,000 psi in order to reduce the recess types used in each system. The use of dovetail slot recesses should be avoided.

Internal hexagon recesses, should be limited to the threaded end of pins without a head driving recess.

Care should be exercised to ensure that the correct size bit or wrench is identified, particularly for internal drives, so that specified installation torque requirements are not exceeded.

REQUIREMENT LESSONS LEARNED (3.4.9.3.10)

(TBD)

I.4.4.9.3.10 Fastener drive and wrenching element configuration.

Fastener drive and wrenching elements shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.9.3.10)

Inspection is the most suitable verification method to confirm the selection drive elements and compatibility with the wrenching elements.

VERIFICATION GUIDANCE (4.4.9.3.10)

TBS should be filled in with inspection of installation, assembly and fabrication drawings.

VERIFICATION LESSONS LEARNED (4.4.9.3.10)

(TBD)

I.3.4.9.3.11 Fasteners used in doors and access panels.

Except for captive fasteners, fasteners used to retain access panels and doors shall be of equal diameter and length. Formed-in-place gasket material shall not be used as a spacer or in place of a counterbore for the retaining rings.

REQUIREMENT RATIONALE (3.4.9.3.11)

This requirement defines the basic design and engineering requirements for panel fastener assemblies for attaching structural load-carrying and non-structural panels, inspection doors, quickly detachable plates, control and instrument panels, and equipment rack systems.

REQUIREMENT GUIDANCE (3.4.9.3.11)

Fasteners used in doors and access panels should be classified as fully-captive screws and semi-captive screws. Fully captive screws should be inseparable assemblies incapable of removal either from their retainer or from their associated panels without the use of special tools. Semi-captive screws should be capable of removal from their retainers or the retainers should be capable of removal from their associated panels without special tools. Semi-captive screws are single lead threads only.

Captive and semi-captive screws should be used to secure any panel, door, or other fastener retained device that must be routinely opened or released for maintenance, service, or equipment adjustment. These fasteners should be used where loss of attaching hardware could cause loss of system integrity, whether structural or electronic, or could endanger system operating personnel. These fasteners should be used where extensive equipment tear down for the retrieval of ordinary attaching hardware would be required.

The performance criteria for these fasteners should be indicated by requirements of individual applications. Consideration should be given to each application for fastener tensile and shear load carrying capabilities, clamp-up capabilities, and resistance to axial push-out forces.

REQUIREMENT LESSONS LEARNED (3.4.9.3.11)

(TBD)

I.4.4.9.3.11 Fasteners used in doors and access panels.

Fasteners used in doors and access panels shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.9.3.11)

(TBD)

VERIFICATION GUIDANCE (4.4.9.3.11)

TBS should be filled in with inspection and demonstration.

VERIFICATION LESSONS LEARNED (4.4.9.3.11)

(TBD)

I.3.4.9.4 Utility actuation subsystem.

Mechanical actuation subsystems shall provide motion and position locking functions for stowable and deployable surfaces such as folding wing panels, folding rotor blade systems, folding tail rotors/pylons, air scoops, air vents, and weapons bay doors in ground and air applications for both operational and maintenance purposes. The mechanical actuator subsystem shall be capable of providing these functions via air vehicle or ground power and shall provide for manual operation as well in applications necessary for maintenance, accessibility enhancement, or stowage or folding.

REQUIREMENT RATIONALE (3.4.9.4)

Mechanical actuation systems are necessary to provide motion to various stowable and deployable surfaces such as folding wing panels, folding rotor blade systems, folding tail rotors and pylons, air scoops, air vents, and weapons bay doors in ground and air applications for both operational and maintenance purposes.

REQUIREMENT GUIDANCE (3.4.9.4)

a. Motive/locking functionalities. Motion is typically of a limited (2 position) nature and may require positive locking in either one or all positions; locking and motive functions should not be susceptible to extraneous interference causing inadvertent commands or motion (such as electromagnetic interference (EMI)).

b. Aerodynamic induced load effects. Actuation subsystems should be capable of operating normally through all points of the flight envelope where the subsystem in question may be used; including manual and automatic operation.

c. Oscillating loads effects. Irreversible-gearing should not be used as the sole means of position retention due to oscillating load effects.

d. High actuator case temperature/combustible environment separation. Actuator subsystems should not exhibit external case temperatures sufficient to provide a source of ignition for fuels or hydraulic fluid in the event of an actuator stall.

e. Motive source thermal protection. Means of ensuring subsystem shutdown, rather than a hiatus in subsystem operation, should be incorporated into the integration of safety/mechanism protection devices, such as thermal overheat switches, to prevent continued subsystem operation where such operation could result in an inadvertent deployment.

f. Externally-applied-load backdrive protection. All actuation subsystems should incorporate positive means of preventing backdriving of the motive source (motor, hand crank, or such.) caused by loads being carried by the surface or device being actuated; these means should be in addition to the positive locking mechanism.

g. Maintainer-induced overload protection. Provisions should be made to prevent damage to actuation subsystems in case of over-torque or over speed conditions during improper manual operations (for example, using a high-power rotary tool instead of speed wrench).

h. Integration of cycle requirements between related systems: The cycle requirements of systems that operate in conjunction with each other, such as blade and wing stow subsystems on the same air vehicle, should be integrated with a common overall cycle requirement in mind.

i. Possibly applicable industry standards and recommended practices: Some Industry documents which may prove beneficial for background information include SAE ARP4058, “Actuators, Mechanical, Geared Rotary, General Specification For”; SAE ARP4255, “Electrical Actuation Systems for Aerospace and Other Applications”; SAE ARP777, “Gas Actuators”; and SAE ARP4386, “Terminology and Definitions for Aerospace Fluid Power, Actuation and Control Technologies”.

j. Design life cycles: The actuation system should be designed, in fracture or flight critical cases, to a minimum of 4 lives as measured in actuation cycles and flight hours to ensure a statistically robust system.

REQUIREMENT LESSONS LEARNED (3.4.9.4)

a. Oscillating loads effects. A no-back mechanism was used on an example air vehicle subsystem when irreversible-gearing mechanism failed to operate as designed. The cause of the failure was a “ratchet-type” effect, induced by oscillating loads.

b. Aerodynamic induced load effects. Example air vehicle ECS auxiliary scoop mechanism experienced several problems related to aero-induced loads that were poorly understood at the time. Conservative approaches should have been used in estimating the loads.

c. Motive source thermal protection. Means of ensuring subsystem shutdown, rather than a hiatus in subsystem operation, should be incorporated into the integration of safety/mechanism protection devices, such as thermal overheat switches, to prevent continued subsystem operation where such operation could result in an inadvertent deployment. Example air vehicle experienced inadvertent deployment of the boarding ladder due to thermal switch activation. Command was generated, actuator thermal protection engaged, actuator stopped (actually in mid-operation), then re-engaged later during ground engine runs when thermal switch cooled, allowing actuator to continue in motion. If this had happened just prior to flight, the weight-on-wheels switch would have disconnected power on takeoff, creating the condition of a “live” boarding ladder ready to deploy as soon as the air vehicle hit the runway. The actuator command logic path didn’t adequately address this situation; it was also misidentified in the failure mode effects analysis as a “Failure” (which creates the impression of a fully-nonfunctional/subsystem-off situation). It really was a “hesitant operation” scenario instead. The command path was changed to utilize a regular switch as opposed to the momentary “depress-and-walk-away” switch used earlier.

d. Special accessibility. All actuation subsystems that can conceivably be performed on the deck should have their design closely coordinated with the fleet supportability and carrier suitability areas. An air vehicle blade-fold system was designed to accommodate the requirement that one side of the rotor system, due to deck spacing, would not be accessible on a carrier. This same system also required careful accessibility planning due to the possible dangers to maintainers and equipment from nearby APU exhaust during manual fold operations.

e. Integration of cycle requirements between related systems: The cycle requirements of blade and wing stow subsystems on the same example air vehicle were not readily integrated into a common overall cycle requirement. The existence of two, stand-alone, requirements had the potential to cause confusion.

I.4.4.9.4 Utility actuation subsystem.

The function of the utility actuation subsystem shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.9.4)

Verification of utility actuation subsystems is necessary to validate performance and envelope derived requirements. Verification, dependent on the specific system, may be required by analysis, testing, or by similarity to existing, prequalified systems.

VERIFICATION GUIDANCE (4.4.9.4)

TBS should be completed by considering the following:

a. Oscillating loads effects. The ability to meet this constraint should be validated by test, analysis, and inspection as follows: Analysis, Qualification Testing.

b. Aerodynamic induced load effects. The ability to meet this constraint should be validated by test, analysis, and inspection as follows: Analysis, Qualification Testing.

c. High actuator case temperature/combustible environment separation. The ability to meet this constraint should be validated by test, analysis, and inspection as follows: Analysis, Qualification Testing.

d. Oscillating loads effects. The ability to meet this constraint should be validated by test, analysis, and inspection as follows: Analysis, Qualification Testing (Vibration, Cyclic Loading, Backlash measurements).

e. Motive source thermal protection. The ability to meet this constraint should be validated by test, analysis, and inspection as follows: Analysis, Qualification Testing (Load/Repetitive Cycling).

f. Externally-applied-load backdrive protection. The ability to meet this constraint should be validated by test, analysis, and inspection as follows: Analysis, Qualification Testing.

g. Maintainer-induced overload protection. The ability to meet this constraint should be validated by test, analysis, and inspection as follows: Analysis, Qualification Testing.

h. Special accessibility. The ability to meet this constraint should be validated by test, analysis, and inspection as follows: Analysis, Qualification Testing, Maintainability Demonstrations.

i. Integration of cycle requirements between related systems: The ability to meet this constraint should be validated by test, analysis, and inspection as follows: Analysis, Qualification Testing.

j. Test life cycles: The actuation system should be tested, in fracture or flight critical cases, to a minimum of 2 lives as measured in actuation cycles and flight hours to ensure a statistically robust system.

VERIFICATION LESSONS LEARNED (4.4.9.4)

a. Aerodynamic induced load effects. Example air vehicle ECS auxiliary scoop mechanism experienced several problems related to aero-induced loads. Laboratory equipment that could not reproduce transition between externally induced ECS airflow and Engine-Inlet airflow during testing was significant cause of incorrect analysis validation.

b. Motive source thermal protection. Example air vehicle boarding ladder actuation motor testing failed to reveal possible consequences of thermal protection engagement to control circuit; also actual operating environment should be as fully emulated as possible

c. Similarity based verification & testing. Use caution when using verification and testing based on similarity. An example air vehicle boarding ladder actuator was tested in an orientation 90° from its air vehicle installation orientation. This caused problems related to limit switch travel requirements on the air vehicle ("sagging" of components that did not appear in tested orientation).

I.3.4.9.4.1 Ground wind environment.

All actuation subsystems shall be able to:

a. be locked and unlocked;

b. provide for folding, unfolding, and deploying; and

c. be folded, unfolded, and deployed

within a wind environment that shall encompass both atmospheric and weather-induced conditions, wind-over-deck from carrier vessel movement, and downwash and jetwash conditions from other vehicles on or near the carrier vessel deck.

REQUIREMENT RATIONALE (3.4.9.4.1)

The actuation subsystems are intended to operate in, and therefore withstand, an environment that includes loads caused by atmospheric conditions (weather and sea states), wind-over-deck from carrier vessel movement, and downwash and jetwash conditions from other vehicles on or near the carrier vessel deck.

REQUIREMENT GUIDANCE (3.4.9.4.1)

a. Wingfold-wing pivot wind environment. Air vehicle: wingfold-wing pivot systems should be able to withstand:

1. 60 Kt winds from any horizontal direction in the unlocked and folding condition,
2. 60 Kt winds from any horizontal direction in the unlocked and folded condition, and
3. 100 Kt winds from any horizontal direction in the locked and folded condition.

It should also be possible to fold and unfold the wings in winds up to 60 Kts from any direction.

b. Bladefold wind environment. Rotorcraft: bladefold systems should be able to withstand:

1. 45 Kt winds from any horizontal direction in the unlocked and folding condition,
2. 45 Kt winds from any horizontal direction in the unlocked and folded condition,
3. 100 Kt winds from any horizontal direction in the externally secured and unfolded condition, and
4. 100 Kt winds from any horizontal direction in the locked and folded condition.

It should be possible to fold and unfold the blades repeatedly in winds up to 45 knots from any direction.

c. Tailboom-tailrotor wind environment. Tailboom-tailrotor systems should be able to withstand:

1. 60 Kt winds from any horizontal direction in the unlocked and folding condition,
2. 60 Kt winds from any horizontal direction in the unlocked and folded condition,
3. 100 Kt winds from any horizontal direction in the locked and folded condition, and
4. 100 Kt winds from any horizontal direction in the externally secured and unfolded condition.

It should be possible to repeatedly fold and unfold the tailboom-tailrotor in winds up to 60 knots from any direction.

d. Boarding ladder wind environment. Boarding ladder systems should be able to withstand:

1. 60 Kt winds from any horizontal direction in the unlocked and deploying condition,
2. 60 Kt winds from any horizontal direction in the unlocked and deployed condition, and
3. 100 Kt winds from any horizontal direction in the locked and deployed condition.

It should be possible to deploy and stow the boarding ladder repeatedly in winds up to 60 knots from any direction.

REQUIREMENT LESSONS LEARNED (3.4.9.4.1)

Experience with large rotorcraft in the vicinity of other air vehicles with folding-surfaces indicates those downwash-induced loads from such vehicles, whether from incidental overflight conditions or normal landing/takeoff/hover operations in the vicinity of the folded air vehicles may induce damage.

Jet blast loads are a particular concern with respect to fixed-wing air vehicle and their associated deployable and folding devices and surfaces.)

I.4.4.9.4.1 Ground wind environment.

The ability to meet this constraint shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.9.4.1)

The ability of the specific system to withstand the specific wind environment for its specific application must be verified to ensure a robust and reliable actuation system.

VERIFICATION GUIDANCE (4.4.9.4.1)

TBS should be completed with consideration of the following:

a. Wingfold-wing pivot wind environment. The ability to meet this constraint should be validated by test, analysis, and inspection as follows: Analysis, Qualification Testing.

b. Bladefold wind environment. The ability to meet this constraint should be validated by test, analysis, and inspection as follows: Analysis, Qualification Testing.

c. Tailboom-tailrotor wind environment. The ability to meet this constraint should be validated by test, analysis, and inspection as follows: Analysis, Qualification Testing.

d. Boarding ladder wind environment. The ability to meet this constraint should be validated by test, analysis, and inspection as follows: Analysis, Qualification Testing.

VERIFICATION LESSONS LEARNED (4.4.9.4.1)

(TBD)

I.3.4.9.4.2 Positive locking features.

Mechanisms that provide a structural load path shall incorporate redundant means of locking the mechanism in position. Locking mechanisms shall incorporate a means of operational command interrupt to prevent in-flight actuation of ground-only operating systems.

REQUIREMENT RATIONALE (3.4.9.4.2)

Safety of Flight concerns necessitate the use of redundant means of securing & locking a mechanism in position. Operational command interrupts are necessary because of the hazard inherent in operation a system not intentionally designed for aerodynamic loads (such as boarding ladder systems, and access door actuation systems) in a flight condition which might cause damage or departure of the system from the air vehicle.

REQUIREMENT GUIDANCE (3.4.9.4.2)

Generally applicable positive locking features. Provisions should be made for locking folding wings, blades or other folding/stowing surfaces in the folded/stowed position. Locks should be an integral part of and operate in the sequence of the folding mechanism. Locks should be positive and should not depend on any power source to remain engaged. The control and lock subsystem should be shielded against EMI, and the “fold” sequence should require two separate deliberate pilot actions in the case of flight critical surfaces such as wings/rotor blades. All mechanical and powered locks and actuators should be designed to prevent ground-type system (such as a boarding ladder) deployment in flight or undesired deployment during ground operations. Provisions should be incorporated to prevent inadvertent actuation following the activation and subsequent relief of safety devices such as thermal switches, or fuses. The locking arrangement should be positive and easily operable by maintenance personnel providing rapid engagement and disengagement of the locking mechanism. Locks should be capable of withstanding forces created by 100-knot winds from any horizontal direction. All mechanical and powered locks and actuators should be designed to prevent undesired surface positioning in flight. A positive identification of engagement should be provided by the mechanism.

Warning flag and locking feature ice layer penetration. Actuation subsystems that require ground operation should be able to operate successfully with a coating of ice covering any locking mechanism or locked/unlocked indicating mechanism.

REQUIREMENT LESSONS LEARNED (3.4.9.4.2)

Braking devices. Various subsystems have incorporated electromechanical brakes to "lock" actuator/linkage in place when actuator is not in motion. Experience with air vehicle ECS Auxiliary Scoop Actuator subsystems has shown care must be taken to design the brake to accommodate any uncertainty in loads (such as aerodynamic and friction); existing brake design had difficulties when aerodynamic loads were higher in actual operation.

In-flight actuation command interrupts. Most air vehicle applications utilize a "weight-on-wheels" (WOW) switch to prevent operation of ground-only actuating subsystems, such as a bladefold and wingfold, while in-flight or above a certain ground speed.

Detachable handles, props, struts for deployment and locking. An example air vehicle boarding ladder system initial design had a detachable handle to allow maintainers of different height extremes to actuate the ladder, but it was found that the ladder's close proximity to an engine intake presented too much of a possibility for foreign object damage (FOD), for example, placing the handle on the intake after use and inadvertently leaving it there.

I.4.4.9.4.2 Positive locking features.

The ability to meet this constraint shall be validated by test, analysis, and inspection as follows: (TBS) .

VERIFICATION RATIONALE (4.4.9.4.2)

The ability of the specific system to provide positive locking for its specific application must be verified to ensure a robust and reliable actuation system.

VERIFICATION GUIDANCE (4.4.9.4.2)

TBS should be completed with consideration of the following:

a. Generally applicable positive locking features. The ability to meet this constraint should be validated by test, analysis, and inspection as follows: Analysis, Qualification Testing.

b. Warning flag and locking feature ice layer penetration. Actuation subsystems that require ground operation should demonstrate the ability to operate successfully with a coating of ice covering any locking mechanism or "locked/unlocked" indicating mechanism. The ice should be applied as a mist of water under freezing conditions to allow penetration and subsequent freezing in areas normally accessible to rainwater. The mechanism should then be subjected to low temperatures as specified.

c. Braking devices. The ability to meet this constraint should be validated by test, analysis, and inspection as follows: Analysis, Qualification Testing.

d. In-flight actuation command interrupts. The ability to meet this constraint should be validated by test, analysis, and inspection as follows: Analysis, Qualification Testing.

VERIFICATION LESSONS LEARNED (4.4.9.4.2)

Built-in-test: Several example air vehicle programs have demonstrated the need to include postulated lifetime Built-In-Test cycles into the aggregate Lifetime cycles used for Qualification Testing. These seemingly innocuous cycles sometimes cause relatively high loading over a short period of time, even though the actual actuation unit is under low or zero load conditions itself.

I.3.4.9.4.3 Cockpit positive engagement indication.

The locked-or-unlocked condition of mechanisms used during ground operations or in the interior of the vehicle (cargo or cockpit spaces) shall be displayed in the cockpit.

REQUIREMENT RATIONALE (3.4.9.4.3)

The indication of the locked/unlocked condition is of high importance for both ground and flight safety concerns as well as mission integrity.

REQUIREMENT GUIDANCE (3.4.9.4.3)

Cockpit positive engagement indication systems should be closely coordinated with the parties responsible for cockpit display design.

REQUIREMENT LESSONS LEARNED (3.4.9.4.3)

The use of Indicating sensors linked to the actual surface being operated is preferable to having the sensor mounted on the actuating unit itself; experience with an existing air vehicle has shown that a failed kinematic linkage but operating actuator caused a surface to fail open yet the cockpit indication showed a “closed” condition since it was receiving a signal from the “healthy” actuator. Such failures are relatively rare and may be mitigated by linkage designs, but they can still occur.

I.4.4.9.4.3 Cockpit positive engagement indication.

Cockpit positive engagement indication shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.9.4.3)

The ability of the specific system to provide proper cockpit indication of its operation for its specific application must be verified to ensure a robust and reliable actuation system.

In some cases, subsystems may be activated from some other area than the actual pilot location (for example, cargo bay). Demonstration of visibility from a crew viewpoint (pilot or crew chief) in areas around the interior of the air vehicle is very important, especially with regards to night operations.

VERIFICATION GUIDANCE (4.4.9.4.3)

TBS should be filled in with Analysis, Qualification Testing, and Ergonomic Evaluation.

VERIFICATION LESSONS LEARNED (4.4.9.4.3)

(TBD)

I.3.4.9.4.4 Actuation control.

Where applicable, a means shall be provided for controlling utility actuation. Where possible, a separate means for “Motion” and “Locking” control may be desired.

REQUIREMENT RATIONALE (3.4.9.4.4)

It is necessary to maintain control over the actuation system for mission success as well as flight and ground safety concerns.

REQUIREMENT GUIDANCE (3.4.9.4.4)

(TBD)

REQUIREMENT LESSONS LEARNED (3.4.9.4.4)

Example air vehicle Wingfold control had to be redesigned during the course of the flight test effort to accommodate need to fold wings independently in certain carrier hangar stowage/maintenance accessibility situations. Better communication with shipboard R&M team would have led to this being in design from outset.

Example air vehicle had nosewheel steering gain-control connected to wingfold control handle with separate “unlock” and “fold/unfold” positions; when wingfold control changed to single unlock/motion position this caused adverse crew comments; there was a desire to engage higher-gain steering with “unlocked” but not necessarily “folding” wings.

I.4.4.9.4.4 Actuation control.

The ability to meet this constraint shall be validated by test, analysis, and inspection as follows: Analysis, Qualification Testing, Ergonomic Evaluation, EMI Analysis.

VERIFICATION RATIONALE (4.4.9.4.4)

The ability of the specific system to provide proper cockpit control of its operation for its specific application must be verified to ensure a robust and reliable actuation system.

VERIFICATION GUIDANCE (4.4.9.4.4)

Any means used to prevent inadvertent actuation of a control (such as guards) should be evaluated by actual pilots to determine suitability as soon as possible in the design process. This also applies to visibility of those controls.

VERIFICATION LESSONS LEARNED (4.4.9.4.4)

(TBD)

I.3.4.9.4.5 Maintainer safety.

Actuation subsystems that have provision for manual operation shall include safety devices to prevent injury to maintainers in case of inadvertent application of power during a manually powered operation. Actuated devices shall also be evaluated with respect to possible APU exhaust impingement hazards during actual use and maintenance operations (for example, built-in-test operations and pre-flight checks). Possible hazards include overheat and overpressure of structural components as well as high temperature hazards to personnel.

REQUIREMENT RATIONALE (3.4.9.4.5)

The safety of the maintainer as well as the equipment and air vehicle itself needs to be safeguarded during operation of the actuation system.

REQUIREMENT GUIDANCE (3.4.9.4.5)

Actuation subsystems such as boarding ladders that require the maintainer to be in very close proximity during stowage or deployment should incorporate some means of controlling deployment speed to a specified safe rate.

REQUIREMENT LESSONS LEARNED (3.4.9.4.5)

This is based on experience with several helicopter programs: the relatively small size of a helicopter fuselage makes APU exhaust routing an important concern during operations such as Blade-Fold.

I.4.4.9.4.5 Maintainer safety.

The ability to meet this constraint shall be validated by test, analysis, and inspection.

VERIFICATION RATIONALE (4.4.9.4.5)

The ability of the specific system to provide maintainer safety features in its operation for its specific application must be verified to ensure a safe, robust and reliable actuation system.

VERIFICATION GUIDANCE (4.4.9.4.5)

Analysis, Qualification Testing, and Ergonomic Evaluation should be conducted. Thermal and acoustic analyses of areas necessary for maintainer/crew positioning during actuation processes during various operating conditions (for example, the APU on, main power plant on, or ground carts on) should be performed to validate personnel safety.

VERIFICATION LESSONS LEARNED (4.4.9.4.5)

(TBD)

I.3.4.9.4.6 Ground power operability.

Utility actuation subsystems shall be capable of operating from the ground power supplied to the air vehicle as well as air vehicle supplied power.

REQUIREMENT RATIONALE (3.4.9.4.6)

Utility Actuation systems need to operate safely and properly when using ground power to facilitate system checkout and maintenance functions.

REQUIREMENT GUIDANCE (3.4.9.4.6)

Utility Actuation subsystems should be designed to accommodate air vehicles and ground power and to safely accommodate transitions between the two states.

REQUIREMENT LESSONS LEARNED (3.4.9.4.6)

(TBD)

I.4.4.9.4.6 Ground power operability.

The ability to meet this constraint shall be validated by test, analysis, and inspection.

VERIFICATION RATIONALE (4.4.9.4.6)

The ability of the specific system to provide proper ground power operability for its specific application must be verified to ensure a robust and reliable actuation system.

VERIFICATION GUIDANCE (4.4.9.4.6)

Analysis, Qualification Testing, and Ergonomic Evaluation should be conducted. Analysis or testing should be performed to verify that transitions from ground to air vehicle power could be safely performed without harm to personnel or equipment.

VERIFICATION LESSONS (4.4.9.4.6)

(TBD)

I.3.4.9.4.7 Actuation time.

All actuation subsystems shall be able to perform their specified function within __(TBS)__ time and cycle. Allowable intervals between actuation cycles shall also be specified as well as total cycles expected during the application lifetime.

REQUIREMENT RATIONALE (3.4.9.4.7)

Specific mission requirements will require a system perform within a specified band of time.

REQUIREMENT GUIDANCE (3.4.9.4.7)

TBS: Example fixed-wing air vehicle wingfold system had actuation time of 10-14 seconds. Example air vehicle wingstow system had total actuation time of 90 seconds (12 seconds to Index rotors, 30 seconds to fold blades, 12 seconds to rotate nacelles, and 45 seconds to actually rotate wings to stowed position). Example air vehicle boarding ladder system had actuation time of 7 seconds (3.6 second actuation cycle time plus 3 second ladder deployment time). Example air vehicle bladefold system had powered actuation time of 42 seconds (12 seconds to index rotors; 30 seconds to fold blades).

REQUIREMENT LESSONS LEARNED (3.4.9.4.7)

(TBD)

I.4.4.9.4.7 Actuation time.

The ability to meet this constraint shall be validated by test, analysis, and inspection as follows: Analysis, Qualification Testing.

VERIFICATION RATIONALE (4.4.9.4.7)

The ability of the specific system to provide proper actuation time performance during its operation for its specific application must be verified to ensure a robust and reliable actuation system.

VERIFICATION GUIDANCE (4.4.9.4.7)

Actuation time should be validated by test in an environment that is representative of the actual air vehicle installation and air vehicle loads; if the loads change during the actuation process this should be accounted for also.

VERIFICATION LESSONS LEARNED (4.4.9.4.7)

(TBD)

I.3.4.9.4.8 Surface interference prevention.

Utility actuation subsystems shall incorporate some means to prevent damage to adjacent movable surfaces (for example, flaps) during folding and unfolding operations. Also, means shall be incorporate to allow any movable control surface to be in any position on the panel being folded/unfolded.

REQUIREMENT RATIONALE (3.4.9.4.8)

Damage to adjacent surfaces or to the system itself are not acceptable during system operation because of safety and maintainability/reliability concerns.

REQUIREMENT GUIDANCE (3.4.9.4.8)

(TBD)

REQUIREMENT LESSONS LEARNED (3.4.9.4.8)

Most existing air vehicle wingfold systems utilize some mechanical interlock to prevent ailerons on the outer, folding, wing panel from interfering with the flaps on the inner, non-folding portion of the wing during the wingfold process.

Example air vehicle required aileron interlock to prevent damage to inboard flaps during wingfold operations.

I.4.4.9.4.8 Surface interference prevention.

The ability to meet this constraint shall be validated by test, analysis, and inspection.

VERIFICATION RATIONALE (4.4.9.4.8)

The ability of the specific system to provide proper surface interference prevention through design or specific features for its specific application must be verified to ensure a robust and reliable actuation system.

VERIFICATION GUIDANCE (4.4.9.4.8)

Analysis, Qualification Testing, and Ergonomic Evaluation should be conducted. It is important to consider adjacent structural areas during the design of the actuation subsystem to prevent damage during operation; verification by demonstration may provide results too late to be of much benefit.

VERIFICATION LESSONS LEARNED (4.4.9.4.8)

(TBD)

I.3.4.9.4.9 Replaceable attachments.

The actuation subsystem attachment shall not be an integral part of the air vehicle structure, such as wing rib, but shall be a replaceable attachment which shall be designed so that, in case of an overload or fatigue failure event, failure of the attachment shall occur in lieu of air vehicle primary structural component failure.

REQUIREMENT RATIONALE (3.4.9.4.9)

Damage to the primary air vehicle structure itself is usually not acceptable during system operation because of safety and maintainability/reliability concerns. Damage to the actuation system is preferable to air vehicle structural damage because of cost, flight safety, and ground safety concerns.

REQUIREMENT GUIDANCE (3.4.9.4.9)

It is desirable to have the attachment point of the actuation subsystem function as a “structural fuse,” an overload/jam condition would fail the attachment prior to the much more costly air vehicle primary structure.

REQUIREMENT LESSONS LEARNED (3.4.9.4.9)

(TBD)

I.4.4.9.4.9 Replaceable attachments.

Replaceable attachments shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.9.4.9)

The inclusion of replaceable attachments in the specific system must be verified to ensure a robust, maintainable, and reliable actuation system.

VERIFICATION GUIDANCE (4.4.9.4.9)

TBS should be filled in with test, analysis, and inspection.

VERIFICATION LESSONS LEARNED (4.4.9.4.9)

(TBD)

I.3.4.9.4.10 Folded and stowed position clearance.

Clearance shall be provided in the deployed or stowed position and during the deployment operation to prevent damage to the surface, attached equipment, and to other areas of the air vehicle.

REQUIREMENT RATIONALE (3.4.9.4.10)

Damage to adjacent surfaces or to the system itself are not acceptable during system operation because of safety and maintainability/reliability concerns. Therefore positive clearance values must be maintained for a variety of conditions.

REQUIREMENT GUIDANCE (3.4.9.4.10)

Conditions that include special maintenance positions or equipment location should be examined. Unsymmetrical landing gear deflections, in the case of one surface such as a wing or rotor blade being folded before the others, should be combined with a flat tire or compressed landing-gear-ground-interface-device (skid, air cushions) on the low side in determining critical clearances. With the surfaces folded or swept or stowed it should be possible to retract and extend the landing gear for maintenance purposes. Except when the landing gear retracts into the folded portion of the wings, a complete retraction and extension cycle, including up-lock operation, should be possible.

REQUIREMENT LESSONS LEARNED (3.4.9.4.10)

(TBD)

I.4.4.9.4.10 Folded and stowed position clearance.

Folded and stowed position clearance shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.9.4.10)

The ability of the specific system to provide proper deployed and stowed position clearance during its operation for its specific application must be verified to ensure a safe, robust, and reliable actuation system.

VERIFICATION GUIDANCE (4.4.9.4.10)

TBS should be filled in with test, analysis, and inspection.

VERIFICATION LESSONS LEARNED (4.4.9.4.10)

(TBD)

I.3.4.9.4.11 Manual deployment and drive input.

Utility actuation mechanisms used during ground operations shall have a purely manual backup available for motive power and locking/unlocking purposes if the primary mode of operation is automatic or powered (or both). Subsystems used for purely in-flight applications shall also have means incorporated to allow cockpit controlled activation for ground maintenance actions.

REQUIREMENT RATIONALE (3.4.9.4.11)

Manual backup for deploying and stowing an actuated surface or device is necessary for maintenance power-off conditions as well as to accommodate emergency conditions in situations where the operation of other air vehicles may also be impacted as well (such as hangar deck obstructed by air vehicle(s) with spread wings/rotor blades with failed power units).

REQUIREMENT GUIDANCE (3.4.9.4.11)

Wing folding and spreading operation should be accomplished by both manual and powered means. Wings folded/pivoted by power should permit decoupling of the wing locking mechanism and should have manual or other alternate provision for folding and spreading the wings. Provisions should be made to prevent hazards to maintenance personnel, wing-mounted equipment (such as pylons), or damage critical components that could cause wing/tail control surface damage as well as control loss or damage to electrical connectors, control lines, or such during normal, manual, or externally powered wing-folding and spreading.

Blade folding should be accomplished by manual or powered means. Provisions should be made to prevent hazards to maintenance personnel or damage critical components that could cause blade/wing/tail surface control loss or damage to electrical connectors, control lines, or such during normal, manual, or externally powered blade-folding and spreading.

REQUIREMENT LESSONS LEARNED (3.4.9.4.11)

Manual operation of example air vehicle folding mechanism caused damage through the use of unauthorized, but frequently used, ammunition-loading power tools. A torque-limiting mechanism was later incorporated to address this problem.

I.4.4.9.4.11 Manual deployment and drive input.

The ability to meet this constraint shall be validated by test, analysis, and inspection.

VERIFICATION RATIONALE (4.4.9.4.11)

The inclusion within the specific system of manual deployment and drive input features and their operation for its specific application must be verified to ensure a robust and reliable actuation system.

VERIFICATION GUIDANCE (4.4.9.4.11)

Wingfold-wing pivot manual deployment and drive input should be validated by test, analysis, and inspection as follows: Analysis, Qualification Testing.

Bladefold manual deployment and drive input should be validated by test, analysis, and inspection as follows: Analysis, Qualification Testing.

VERIFICATION LESSONS LEARNED (4.4.9.4.11)

(TBD)

I.3.4.9.4.12 External securing.

Removable Surface securing devices shall only be used in lieu of integral locks when specifically authorized by the Government. These devices shall be capable of withstanding rough handling without damage and shall have strength equal to or exceeding that of the air vehicle. The removable devices shall be such that one man can secure the surface in winds up to 60 knots from any horizontal direction.

REQUIREMENT RATIONALE (3.4.9.4.12)

External securing provisions are necessary to accommodate situations where high wind/sea state conditions occur and it is not feasible to move the air vehicle to a safer location or within a hangar.

REQUIREMENT GUIDANCE (3.4.9.4.12)

Actuation subsystem external securing devices should be designed to reduce or eliminate the possibility of FOD during removal/installation.

Due to the nature of rotorcraft operations, it is desirable that external bladefold securing devices be transportable within the air vehicle to remote staging and operating areas.

REQUIREMENT LESSONS LEARNED (3.4.9.4.12)

An example air vehicle boarding ladder system initial design had a detachable prop to lock the ladder in place and also function as a deployment assistance handle. It was found that the ladder's close proximity to an engine intake presented too much of a possibility for FOD. For example, placing the handle on the intake after use and inadvertently leaving it there.

I.4.4.9.4.12 External securing.

The ability to meet this constraint shall be validated by test, analysis, and inspection as follows: Analysis, Qualification Testing.

VERIFICATION RATIONALE (4.4.9.4.12)

The ability of the specific system to provide proper external securing during operation for its specific application must be verified to ensure a robust and reliable actuation system.

VERIFICATION GUIDANCE (4.4.9.4.12)

Wingfold-wing pivot external securing should be validated by test, analysis, and inspection as follows: Analysis, Qualification Testing.

Bladefold external securing should be validated by test, analysis, and inspection as follows: Analysis, Qualification Testing.

Detachable Securing Devices should be tested with regard to maintainer induced loads (including potential jam/forcing conditions) as well as normal environmental loads, such as wind, or shipboard movement.

VERIFICATION LESSONS LEARNED (4.4.9.4.12)

Example air vehicle wingfold system suffered component failures due to excessive force applied during manual fold operations. The design did not take into account normal usage induced increase in friction creating temporary high load conditions at manual input location.

I.3.4.9.4.13 Visual positive engagement identification.

The locked-unlocked condition of mechanisms used during ground operations or in the interior of the vehicle (cargo or cockpit spaces) shall be displayed visually, externally, internally, or both if required, by purely mechanical, non-electric means. This is in addition to the "cockpit positive engagement indication" in this appendix.

REQUIREMENT RATIONALE (3.4.9.4.13)

Indication of positive engagement of locking mechanisms is necessary to ensure safe operation of an actuating system.

Cockpit and external indication means are both necessary because of the possibility of purely manual deployment, such as when no one is in the cockpit.

REQUIREMENT GUIDANCE (3.4.9.4.13)

Engagement identification devices should be designed to allow visibility during day or night conditions. These devices should be visible from any area that a maintainer could be expected to be during the actuation cycle; they should not become occluded during any portion of the actuation cycle. Flags, distinctively colored cylinders, and distinctively-colored portions of the air vehicle surface that are revealed by the actuating mechanism itself are suitable means of external indication.

REQUIREMENT LESSONS LEARNED (3.4.9.4.13)

Several different means of positive engagement Identification are in use including mechanical striped "barber poles", rotating colored or uncolored discs, and exposed or covered brightly-painted areas.

I.4.4.9.4.13 Visual positive engagement identification.

The ability to meet this constraint shall be validated by test, analysis, and inspection as follows: Analysis, Qualification Testing.

VERIFICATION RATIONALE (4.4.9.4.13)

The ability of the specific system to provide proper positive engagement identification during its operation for its specific application must be verified to ensure a robust and reliable actuation system.

VERIFICATION GUIDANCE (4.4.9.4.13)

Positive engagement identification should be verified my maintainer demonstrations as early in the program as possible; including the use of partial mockups (real or virtual) when available.

VERIFICATION LESSONS LEARNED (4.4.9.4.13)

(TBD)

I.5 PACKAGING

I.5.1 Packaging.

For acquisition purposes, the packaging requirements shall be as specified in the contract or order (see 6.2). When packaging of materiel is to be performed by DoD or in-house contractor personnel, these personnel need to contact the responsible packaging activity to ascertain packaging requirements. Packaging requirements are maintained by the Inventory Control Point's packaging activities within the Military Service or Defense Agency, or within the military service's system commands. Packaging data retrieval is available from the managing Military Department's or Defense Agency's automated packaging files, CD-ROM products, or by contacting the responsible packaging activity.

I.6 NOTES.

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

I.6.1 Intended use.

The mechanical subsystem descriptions in this appendix are intended for use in air vehicle systems developed to perform combat and combat-support missions in environments unique to military weapon systems.

I.6.2 Acquisition requirements.

Acquisition documents should specify the following:

a. Title, number, and date of the specification.

I.6.3 Acronyms.

The following list contains the acronyms/abbreviations contained within this appendix.

PPSL	Program Parts Selection List
QPL	Qualified Products List
SRB	Self-retaining Bolt

I.6.4 Subject term (key word) listing.

Bearing

Door

Fastener

Latch

Lock

Seals

Weapons bay

I.6.5 Responsible engineering office.

The office responsible for the development and technical maintenance of this appendix is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL. Requests for additional information on this appendix can be obtained from AFLCMC/ENRS, BLDG 28 RM 118, 2145 MONAHAN WAY, WPAFB OH 45433-7017 USA; DSN 674-5476; COMMERCIAL (937) 904-5476; ENGINEERING.STANDARDS@US.AF.MIL.

I.6.6 Amendment notations.

The margins of this specification are marked with vertical lines to indicate modifications generated by this amendment. This was done as a convenience only and the Government assumes no liability whatsoever for any inaccuracies in these notations. Bidders and contractors are cautioned to evaluate the requirements of this document based on the entire content irrespective of the marginal notations.

APPENDIX J

AIR VEHICLE CARGO, AERIAL DELIVERY, AND SPECIAL OPERATIONS SUBSYSTEM

REQUIREMENTS AND GUIDANCE

J.1 SCOPE

J.1.1 Scope.

This appendix provides requirements, verifications, tailoring guidance, and background information for the Cargo, Aerial Delivery, and Special Operations Subsystem provided for in Part 1 of the Air Vehicle Subsystems Specification. The appendix has been developed and coordinated by technical personnel from the Air Force, Navy, and Army and has been approved as an official guide for use by Government personnel for assistance in tailoring the air vehicle subsystems specification for acquisition and model specifications. This appendix is a mandatory part of the specification. The information contained herein is intended for compliance.

J.1.2 Structure.

The appendix structure replicates the structure of the Air Vehicle Subsystems Specification except it places each corresponding section 3 requirement and section 4 verification together.

J.1.3 Appendix.

This appendix provides tailoring guidance and background information for individual paragraphs of the Air Vehicle Subsystems Specification. Guidance gives recommendations on how to tailor the specification paragraph. Where ___(TBS)___ appears, the guidance paragraph provides recommended values or text that the Using Service may use to insert in the __(TBS)__. When contractors are expected to complete the _(TBS)__, the Guidance paragraph will so state. The Using Service makes the final decision on whom completes the __(TBS)__ in the specification. Finally, Lessons Learned are provided to give insight to past events that could impact the tailoring of the specification.

J.1.4 Deviations.

Projected designs for given applications which will result in improvement of the system performance, reduced life cycle cost, or reduced developmental cost through deviations from this guidance, or where requirements of the specification results in compromise in operational capability, should be brought to the attention of the Using Service.

J.1.5 Environmental impact.

Air Vehicle Subsystems will be designed such that their operation, maintenance, and repair may be accomplished without violating the most stringent environmental regulations applicable to locations where subsystems are used or supported. Compliance with environmental regulations will not prevent subsystems from achieving and sustaining mission performance capability. Materials, processes, and environmental control equipment necessary to meet these environmental requirements must currently be available in the Using Service's maintenance and supply system. The design will not use environmentally unsuitable materials such as ozone depleting fluorocarbons, chlorofluorocarbons, and halons, or highly volatile organic compounds in solvents and coatings during development, production, operation, maintenance, or repair. The Environmental Protection Agency maintains an online list of toxic chemicals and hazardous substances on its Ozone Layer Depletion Website at http://www.epa.gov/ozone/snap/ that should be consulted. The Significant New Alternatives Policy (SNAP) Program available thereon identifies substitutes for ozone depleting chemicals.

The contractor will conduct an environmental analysis of air vehicle subsystems.

J.1.6 Responsible engineering office.

The responsible engineering office (REO) for this appendix is AFLCMC/EZFC (ATTLA), BLDG 28 RM 118, WPAFB OH 45433-7017 USA; DSN 986-9849, COMMERCIAL (937) 656-9849; AFLCMC.EZF.MAILBOX@US.AF.MIL.

J.2 APPLICABLE DOCUMENTS

J.2.1 General.

The documents listed in this section are specified in sections 3 and 4 of this handbook. This section does not include documents cited in other sections of this guide specification or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3 and 4 of this handbook, whether or not they are listed.

J.2.2 Government documents

J.2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this appendix to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

INTERNATIONAL STANDARDIZATION AGREEMENT

AIR AND SPACE INTEROPERABILITY COUNCIL

AIR STD AM 1048	Restraint Factors for Fixed Wing Aircraft

(Copies of this document are available at http://quicksearch.dla.mil, www.airstandards.org, and www.ihs.com to qualified users.)

DEPARTMENT OF DEFENSE SPECIFICATIONS

JSSG-2001	Air Vehicle Joint Service Specification Guide

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-1791	Designing for Internal Aerial Delivery in Fixed Wing Aircraft

(Copies of these documents are available online at http://quicksearch.dla.mil or from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia PA 19111-5094 USA.)

J.2.2.2 Other Government documents, drawings, and publications.

The following other Government documents, drawings, and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

U.S. ARMY

Field Manual 4-20.103 (FM 10-500-3)/ Marine Corps Reference Publication MCRP 4-11.3C/ Air Force Technical Order T.O. 13C7-1-11	Airdrop of Supplies and Equipment: Rigging Containers

(Copies of this document are available online at https://rdl.train.army.mil for access by qualified users.)

U.S. MARINE CORPS

FMFLant OP3000.3	Standard Operating Procedure

(Requests for this document should be made via http://www.marines.mil.)

U.S. NAVY

NAVAIR Instruction 13100.15	Engineering Technical Review of Commercial-Derivative Aircraft Programs

(Copies of this document are available online at https://mynavair.navair.navy.mil/portal/server.pt/community/directives/1595 to qualified users.)

J.2.3 Non-Government publications.

The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

SAE INTERNATIONAL

SAE AS8905	Fittings and Cargo Rings, Tiedown, Aircraft Floor
SAE AS21234	Fitting, Tiedown, Cargo Ring (5,000 LB) and Seat Stud, Type I
SAE AS21235	Fitting, Tiedown, Cargo Ring (10,000 LB) and Seat Stud, Type II
SAE AS21236	Ring, Cargo Tiedown (10,000 LB), Type III
SAE AS21237	Ring, Cargo Tiedown (25,000 LB), Type IV

(Copies of these documents are available from www.sae.org; SAE International, 400 Commonwealth Drive, Warrendale PA 15096-0001 USA; and from www.ihs.com to qualified users.)

J.2.4 Order of precedence.

Unless otherwise noted herein or in the contract, in the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

J.2.5 Streamlining.

The Air Vehicle Subsystems Specification has been streamlined. The documents listed in this appendix which are required for acquisition have the same status as those referenced directly in section 2 (first tier). All other documents referenced through tiering may be used for guidance and information only.

J.3 REQUIREMENTS

J.4 VERIFICATIONS

J.3.1 Definition

J.4.1 Definition

J.3.2 Characteristics

J.4.2 Characteristics

J.3.3 Design and construction

J.4.3 Design and construction

J.3.4 Subsystem characteristics

J.4.4 Subsystem characteristics

J.3.4.1 Landing subsystem

J.4.4.1 Landing subsystem

J.3.4.2 Hydraulic subsystem

J.4.4.2 Hydraulic subsystem

J.3.4.3 Auxiliary power subsystem

J.4.4.3 Auxiliary power subsystem

J.3.4.4 Environmental control subsystem

J.4.4.4 Environmental control subsystem

J.3.4.5 Fuel subsystem

J.4.4.5 Fuel subsystem

J.3.4.6 Aerial refueling subsystem

J.4.4.6 Aerial refueling subsystem

J.3.4.7 Fire and explosion hazard protection subsystem

J.4.4.7 Fire and explosion hazard protection subsystem

J.3.4.8 Electrical power subsystem

J.4.4.8 Electrical power subsystem

J.3.4.9 Mechanical subsystems

J.4.4.9 Mechanical subsystems

J.3.4.10 Cargo, aerial delivery, and special operations.

The cargo, aerial delivery and special operations subsystem shall provide ease of loading and unloading of the air vehicle, accommodate and secure internal and external loads such as bundles and palletized cargo, facilitate the safe aerial delivery of personnel and cargo, and be compatible with essential equipment for Special Operations.

REQUIREMENT RATIONALE (3.4.10)

The cargo subsystem must be designed to minimize the time required for loading and unloading operations. The cargo subsystem design should facilitate the loading and unloading to the maximum extent possible; thereby minimizing the delivery mission turn-around times. The cargo subsystem design must be able to support the unique mission defined Special Operations requirements while not jeopardizing the safety of personnel or airworthiness of the air vehicle.

REQUIREMENT GUIDANCE (3.4.10)

JSSG-2001 should be used as a primary reference to ensure all performance capabilities are included in the cargo subsystem specification. The mission stated in JSSG-2001 should determine the range of performance capabilities and functions required of the cargo subsystem.

REQUIREMENT LESSONS LEARNED (3.4.10)

Cargo subsystems need to be Tri-Service interoperable. Past challenges have been and will continue to be the size and performance capability of cargo subsystems. The cargo subsystem's design needs to consider the range of cargo compartment sizes and interfaces. In addition to interface compatibility problems, air vehicles have not always been designed for efficient conversion to accommodate multiple cargo delivery missions. Often, lengthy conversion times are needed to accommodate various cargo loads as in the case of air vehicles that have only a drive-on floor or a strictly roll-on floor. These types of designs require considerable time to convert to other cargo requirements; such as the KC-10 which has to place pallets on top of the rollers in order to drive vehicles on board the air vehicle.

J.4.4.10 Cargo, aerial delivery, and special operations.

The capability of the cargo subsystem to provide for ease of loading and unloading of the air vehicle; securing of required cargo loads; safe aerial delivery of personnel, bundles and palletized cargo; and essential equipment for Special Operations shall be verified incrementally by ___(TBS)___.

VERIFICATION RATIONALE (4.4.10)

Verification is necessary to confirm those cargo subsystems operational procedures, load capacity, and flight envelope performance is compatible with the air vehicle.

VERIFICATION GUIDANCE (4.4.10)

TBS should be filled in with the demonstrated capability of the cargo subsystems to operate throughout their intended flight envelope and at the required operating conditions. Individual components should be certified as airworthy through test and analysis. Analyses should include test data that proves the subsystem meets all stress levels, environmental conditions, and failure modes. However, individual tests need not be repeated during demonstration when integrated as a system with the air vehicle. The demonstration tests should consist of several completed operations of the subsystem in accordance with the operator's manual in normal modes; electrical, hydraulic and manual as applicable. Alternate modes or emergency procedures are typically demonstrated during one operation.

VERIFICATION LESSONS LEARNED (4.4.10)

Although component testing should verify strength and stress levels; testing as an integrated system is still required to verify component interfaces and operational performance as an integrated system. Several individual components may be designed and constructed by individual manufacturers. Although each vendor manufacturer should have demonstrated their individual components and parts qualification through test, it does not guarantee operational performance as an integrated system. Several interface and performance problems have occurred in the past when components were integrated as a complete system.

J.3.4.10.1 General cargo requirements

J.4.4.10.1 General cargo requirements

J.3.4.10.1.1 Cargo restraints.

The restraint system shall be ___(TBS 1)____ to restrain unpalletized and palletized cargo loads to prevent forward, aft, vertical, and lateral load movement under all air vehicle flight conditions, including severe turbulence and crash. The restraint system crash load factors for the attachment hardpoints and carry-through structure shall be ___(TBS 2)___.

REQUIREMENT RATIONALE (3.4.10.1.1)

Cargo must be restrained to maintain safe operation of the air vehicle and must be secured in the event of the crash to allow safe exit of personnel and to prevent further personnel injury or air vehicle damage.

REQUIREMENT GUIDANCE (3.4.10.1.1)

TBS 1 should be filled in with one or a combination of the following options ("a." through "c.") dependent upon the air vehicle's cargo mission (see JSSG-2001, "Cargo and Payload"):

a. Floor and sidewall tiedowns. Selection and placement of tiedown devices should be based on a pattern that permits maximum flexibility in the application of tiedown devices and quantity required for maximum cargo payload. Ensure identified tiedown fittings are compatible with the identified tiedown devices, to include the rated load capacities, and that they can provide the rated restraint capacity throughout the hemisphere of action above the mounting surface. Tiedown fitting selection is dictated by matching the interface size openings and load capacities to the intended tiedown devices. Historically, the 463L cargo system has used the cargo ring load capacities shown in table J-I.

TABLE J-I. Cargo ring load capacities.

TYPE	DESIGN LOAD (RATED CAPACITY)	PROOF LOAD	ULTIMATE LOAD
I - Cargo Ring and Seat Stud	5,000 lb.	5,000 lb.	7,500 lb.
II - Cargo Ring and Seat Stud	10,000 lb.	10,000 lb.	15,000 lb.
III - Ring	10,000 lb.	10,000 lb.	15,000 lb.
IV - Ring	25,000 lb.	25,000 lb.	37,500 lb.

(extracted from SAE AS8905)

Rated capacity is the proof load and should be used in the calculations for restraint.

1. Typical tiedown ratings and dimensions. Tiedown number and pattern selection needs to consider the intended cargo mission of the air vehicle as stated in the operational requirement document. As an example, there are established medical evacuation missions that require the modification of air vehicle. These modifications need an adequate number and correct rating of tiedown fittings to support the installation of a medical evacuation kit which typically consists of a seat and converter assembly unit and a litter support unit. An example in rotary-wing air vehicles is the UH-60, a general purpose utility air vehicle, which uses 5,000 lb. tiedown fittings in the floor with 3,500 lb. rated cargo restraint net rings on the walls and ceiling. Medium to large transport rotary-wing air vehicles, such as the CH-47D Chinook, use eighty-three 5,000-lb. capacity tiedown fittings in the cargo floor, equally spaced in five rows 20 in. apart longitudinally. There are also eight 10,000-lb. tiedown fittings that can be installed only when necessary by screwing the fittings into the threaded receptacles at the fitting locations. The primary objective in selecting the tiedown numbers and pattern is to ensure the air vehicle's maximum flexibility in performing its operational mission requirement. Further detailed information regarding floor tiedown fittings may be found in SAE AS8905.

   The proposed design should have the minimum clear openings and maximum cross-sectional diameters shown in table J-II to maintain compatibility with currently-fielded 463L cargo subsystem components.

TABLE J-II. Tiedown fittings dimensions.

TYPE	YIELD STRENGTH - LBS.	MIN. CLEAR OPENING DIAMETER - IN.	MAX. DIAMETER OF RING CROSS SECTION - IN.
I - Cargo Ring and Seat Stud	5,000	1.5	.375
II - Cargo Ring and Seat Stud	10,000	1.5	.375
III - Ring	10,000	2.5	.500
IV - Ring	25,000	2.5	.750

(extracted from SAE AS21234, AS21235, AS21236, and AS21237)

   The proposed tiedown fittings and devices should not project above the floor when not in use and should not have any openings by which dirt, dust, or debris can pass through to the space below the floor. Protective coating treatments which might crack, chip, or scale should be avoided.

2. Typical tiedown devices and load limiters. Tiedown devices have traditionally consisted of two chain types for the 10,000 lb. and 25,000 lb. capacity tiedowns and fabric strap types for the 5,000 lb. capacity tiedowns. Each type consists of two components: 1) a primary hook and tensioner unit and 2) a secondary hook attached to a length of chain or strap. The strap devices are generally designed as one assembly, whereas the chain devices can usually remove and stow the chain

separately from the tensioner. The tiedown devices should be designed for easy operation by personnel wearing heavy gloves.

Dynamic cargo restraint tiedowns, enclosures, and barrier nets should incorporate load-limiting energy absorbing type devices. The resulting controlled cargo displacement under a crash load condition should be considered when evaluating the safety of occupants and their subsequent post crash egress from the air vehicle. During take-off, flight, and landing, for both normal and turbulent flight conditions, cargo restraint systems should not permit cargo to shift. When load limiters are used, tiedown straps should be of a material with low elongation characteristics.

Cargo restraint enclosures or floor-to-ceiling low-elongation barrier nets used in conjunction with load limiters may be considered for palletized or other bulk cargo. High stretch materials, such as nylon, are not acceptable for use as primary load restraints.

Secure storage for cargo restraint equipment should be provided and should ensure easy and efficient access and removal.

b. Bundle cargo restraint. For airdrop of A-7A, A-21, and A-22 type cargo secured to appropriate sized skidboards a system of restraint should be provided to achieve vertical and lateral restraint through sufficient interface with the conveyor rail system. For further guidance, see Army Field Manual 4-20.103 (FM 10-500-3)/Marine Corps Reference Publication MCRP 4-11.3C/Air Force Technical Order T.O. 13C7-1-11. A-7A and A-21 bundles should be securable for flight through direct tiedown to the air vehicle floor tiedown fittings. Forward restraint for heavy bundles should be provided through the use of a barrier or buffer assembly. The barrier should provide all necessary forward restraint for the entire complement of bundles to be carried on the air vehicle. The barrier should be moveable or convertible to accommodate smaller numbers of bundles. Aft restraint for heavy bundles should be provided with a means that can be readily released to permit dropping the bundles on command from the cockpit.

c. Pallet cargo restraint. Cargo pallets and airdrop platforms should be restrained through a system of indent locks compatible with the 463 system of detents in the platform siderails. For logistics missions, the system locks should provide all forward and aft load restraint. For airdrop missions, the system should have the capacity to release aft restraint when a set level of aft force is achieved on the platform. The release force should be selectable and settable for each lock and individual locks should be capable of use in parallel or in series. The interface of the pallet and platform lips under the air vehicle's rail system provides the necessary lateral and vertical upward restraint.

TBS 2 should be filled in by specifying the forward, aft, vertical, and lateral load factors as a "g" number. The "g" force is the resultant force exerted on an object by gravity or by reaction to acceleration or deceleration. The "g" is an acceleration ratio (a/g) of the item's acceleration (a) to the acceleration of gravity (g). When multiplied by an item's weight the ratio gives the force experienced by the item due to acceleration or deceleration. The changes in velocity (ΔV) or rate of onset, of the air vehicle floor in the directions of up and down should also be specified. For tactical airdrop missions the g-force is dependent upon the type of extraction: Low Altitude Parachute Extraction System (LAPES) or Low Velocity Airdrop (LVAD). The LAPES is a type of airdrop for platform loads wherein the load is extracted from a C-130 or C-17A aircraft, flying at approximately 130 knots, and at a ramp height of up to 15 feet above ground level (AGL). Recovery parachute systems are not used. NOTE: LAPES is not currently in use by the US Air Force (USAF) or the US Army (USA). The LVAD is a type of airdrop for platform loads where the load is extracted from a C-130 aircraft flying at 140 knots or from C-5 and C-17A aircraft flying at 150 knots by extraction parachutes at an altitude of 700 feet or more. Recovery parachutes are attached to the load to slow the descent and to allow an impact velocity of less than 28.5 ft/sec.

The LAPES restraint computations are based on the required longitudinal restraint criteria of 12g forward restraint for platform extraction and 8g forward restraint for an item extraction. The LVAD computations are based on the required longitudinal restraint criteria of 3g forward for either platform or item based extraction. Typical restraint of cargo for both LAPES and LVAD applies a 10,000 pound load on each tiedown provision, based on the minimum breaking strength of the tiedown strap being utilized, with the straps oriented at an angle of 30° from the longitudinal centerline of the load and 34.4° from the horizontal plane.

Each Service has established different restraint criteria for current and future acquisitions and upgrades. Tailor the TBS 2 in accordance with the unique service program restraint requirements and by the type of air vehicle as shown in tables J-III and J-IV.

The restraint factors for fixed-wing aircraft are the subject of international standardization agreement Air and Space Interoperability Council Air Standard AIR STD AM 1048. When different crash load factors are chosen for the design of attachment hard points and carry-through structure of the restraint system than as listed in the referenced air standard, the preparing activity of the program-unique specification will take appropriate reconciliation action through international channels including departmental standardization offices, as required.

TABLE J-III. U.S. Air Force fixed-wing restraint criteria.

DIRECTION	STATIC	DYNAMIC
	Load Factor	Pulse Duration or Rate of Onset - ΔV
Forward	3.0	10.0 ft/sec
Aft	1.5	5.0 ft/sec
Lateral	1.5	5.0 ft/sec
Up	2.0	10.0 ft/sec
Down	4.5	11.5 ft/sec

(extracted from MIL-STD 1791)

TABLE J-IV. Cargo restraint criteria for U.S. Navy/Marine Corps fixed-wing aircraft.

TYPE/CATEGORY OF AIRCRAFT	FWD G's	AFT G's	LAT G's	UP G's
Helo/Tiltrotor	4	3	3	3
C-130	3	2	1.5	2
Fixed Wing Cargo-Transport	3	2	2	2
Carrier Onboard Delivery (C-2)	20	7	7	4
Commercial Derivatives[1]				

[1] Use G-Levels above for applicable type/category or the FAA requirement, whichever is higher. For FAA requirements lower than the values above, approval will be based on guidelines set forth in NAVAIR Instruction 13100.15.

REQUIREMENT LESSONS LEARNED (3.4.10.1.1)

Cargo restraint is a trade-off between theoretical values and operational practice. In theory, most previous pressurized cargo air vehicle fuselages could achieve a deceleration force of up to 8 or 9g before rupturing and losing structural integrity. However, restraint of internal cargo to 8g became unworkable with the advent of current air vehicles because the payload capacity exceeded the practical limits for the application of tiedowns and because most large items of cargo could not withstand this magnitude of loads. Weight considerations limit the number of tiedown devices, which the air vehicle carries and most vehicles will not remain integral under the application of high forces. Based on statistical data from past years of operation, the USAF adopted a policy that limits the applied restraint to the values shown in table J-III, above. The 3g maximum forward is considered to be a survivable condition encountered in a take-off or landing accident wherein the air vehicle is virtually intact afterward. Accidents having g forces between 3g and 20g while carrying cargo are statistically rare. Accidents resulting in g loads in excess of 20g are non-survivable.

Caution should be taken to ensure the correct selection of the tiedown fittings, which is accomplished by matching the fittings' rated strength to the payload weight of the intended cargo. The correct selection can be determined by verifying the weight range of the intended cargo payloads stated in the air vehicle's operational requirements document. Also ensure the tiedown fittings are compatible with the selected tiedown devices. Current cargo air operations use devices rated (working) at strengths of 5,000 lbs., 10,000 lbs., and 25,000 lbs. Additionally, misapplications of the proof versus ultimate loads can also result in incorrect installations and require expensive retrofit operations. Proof load ratings should be used to ensure a greater margin of safety in cargo operations. In addition to verifying compatibility, the stated load of the tiedown fitting should be for the full range of motion at all angles of restraint. If it is not possible to attain the stated load throughout the full range of motion; angle specifications of load restraint for tiedown applications should be identified.

Another example of incorrect fitting installation occurred with detent locks. Detent locks are not symmetrical; typically forward restraint capacity is greater than aft. Incorrect installation (in the reverse direction) will result in system failure.

J.4.4.10.1.1 Cargo restraints.

Cargo restraints shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.10.1.1)

Proper operation of all cargo restraint provisions requires verification of load and strength capacity to ensure safe performance of the air vehicle. Verification is also needed to ensure the subsystem's capability to meet stated operational requirements in cargo, aerial delivery, and special operations missions.

VERIFICATION GUIDANCE (4.4.10.1.1)

TBS: Verification of cargo restraint provisions consists of analyzing the system capability to restrain the load in accordance with JSSG-2001. The analysis should require both functional demonstration and laboratory testing. Typical internal cargo restraint provisions include tie-down fittings and secure inter-locking floor designs. Proper operation of all tie-down fittings and devices should be demonstrated. Representative demonstration cargo should be made up and secured in the air vehicle using the procedures defined in the cargo-loading manual. Particular emphasis should be placed on accessibility and ease of operation of tie-down provisions.

Laboratory strength tests of cargo furnishings, pallet lock mechanisms, attachments, and fittings to the air vehicle structure (cargo floor) should be completed prior to demonstration tests. Palletized loads may require that pallets be used as load input devices to test the restraint lock system and demonstrate functioning in all required modes. Typically, these tests are accomplished not only for flight but also for crash landing conditions as cargo tie-down provisions, but should also meet emergency restraint requirements. Crashworthiness structural requirements are identified in JSSG-2001, or as emergency landing conditions in the FAA standards. It should also be demonstrated that the cargo restraint provisions maintain the air vehicle center of gravity position within the approved limits and the subsequent center of gravity movement associated with the cargo airdrop is within limits.

VERIFICATION LESSONS LEARNED (4.4.10.1.1)

Qualification tests should be extended to the attachment hardware, such as the fitting bolts. Attention should be given for all components as incorrect selection of bolts has occurred and resulted in lost test time and dollars. Incorrect substitutions will also cause invalid test results or failure.

J.3.4.10.1.2 Ease of loading and unloading.

___(TBS)___ shall be provided to facilitate ease of loading and unloading the air vehicle for both logistical and aerial delivery missions.

REQUIREMENT RATIONALE (3.4.10.1.2)

Efficient loading and unloading equipment must be integrated into the cargo subsystem to ensure mission operational turn around times are met.

REQUIREMENT GUIDANCE (3.4.10.1.2)

TBS should be filled in with one or a combination of the following state of the art equipment, dependent upon the air vehicle's stated Operational Requirements Document (ORD) cargo mission requirements (See JSSG-2001, "Cargo and Payload"):

a. guide rails and rollers
b. cargo winch and snatch-block pulleys
c. treadway flooring
d. ramp extenders
e. stabilizing struts.

REQUIREMENT LESSONS LEARNED (3.4.10.1.2)

Refer to section J.6 "Component information" in this appendix, for background information on items "a." through "e.", stated above.

J.4.4.10.1.2 Ease of loading and unloading.

The means of easily loading and unloading the air vehicle for both logistical and aerial delivery missions shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.10.1.2)

The ease of loading and unloading must be verified as a functional capability of the cargo subsystem.

VERIFICATION GUIDANCE (4.4.10.1.2)

TBS should be filled in with a demonstration that exercises all subsystem components to assess their effectiveness in loading and unloading operations.

VERIFICATION LESSONS LEARNED (4.4.10.1.2)

Analyses and subsystem component testing will not adequately verify subsystem capabilities. It is necessary to demonstrate fully all operations which pertainto loading and unloading the air vehicle to ensure compatibility and interoperability with currently-fielded cargo systems.

J.3.4.10.1.3 External cargo capability.

Rotary-wing and Vertical Take-off and Landing (VTOL) air vehicles shall be provided with ___(TBS 1)___ to meet air vehicle mission requirements to secure external loads. The air vehicle shall have a rated external cargo lifting capacity of ___(TBS 2)___. The external cargo system shall be equipped with a ___(TBS 3)___ fail safe mechanism to prevent sudden shifts in the aircraft center of gravity.

REQUIREMENT RATIONALE (3.4.10.1.3)

Air vehicles require external cargo attachment devices to meet the external air transport operational requirements. The determination of the size, quantity, and capacity is defined by the lifting capability of the air vehicle.

REQUIREMENT GUIDANCE (3.4.10.1.3)

TBS 1 should be filled in with the number and capacity of external cargo attachment points. A thorough analysis of the air vehicle's ORD needs to identify the types of cargo not only in terms of weight, but also design of the end items. This has a direct impact upon the number and the spacing of attachment points required.

TBS 2 should be filled in with the external cargo lifting weight capacity required of the air vehicle. A means to control the external cargo-securing device should be provided to the appropriate crewmembers.

TBS 3 should be filled in with a type of fail-safe mechanism for the external cargo design selected. As an example, multiple load attachment point installations require automatic jettisoning capability in the event of one attachment point failing. Means of controlling the external cargo-securing device should be provided to the appropriate crewmembers. Typically, the pilot has priority control from the cockpit.

REQUIREMENT LESSONS LEARNED (3.4.10.1.3)

The incorrect number and location of external cargo attachment points negatively impact the aeroelastic stability and control of the air vehicle. Past designs have resulted in air vehicle control problems due to an inadequate number or installation location of attachment points. In addition, the external cargo subsystem's design needs to consider the range of cargo compartment sizes and interfaces. As an example, the Army 25-lb. nylon apex-fitting roller is too large to fit a standard 10K external cargo hook. In order to use the system, the apex-fitting roller must be removed before attachment to the hook can be made.

J.4.4.10.1.3 External cargo capability.

The ability of the air vehicle to secure external loads shall be verified by ___(TBS 1)___. The rated capacity shall be verified by ___(TBS 2)___.

VERIFICATION RATIONALE (4.4.10.1.3)

External cargo systems require in-flight demonstration to ensure complete functional integration into the air vehicle as a complete air delivery system. Demonstration needs to show that externally carried loads can be safely transported from one location to another within extremes of the flight envelope without adversely affecting the air vehicle.

VERIFICATION GUIDANCE (4.4.10.1.3)

Verification for external cargo delivery systems is needed at the component, subsystem, and system levels.

TBS 1 should be filled in with component-level testing and flight testing for all conditions that are critical to strength, maneuverability, stability and control, and aeroelastic stability. All components within the external cargo load path should undergo strength and fatigue testing prior to subsystem and system-level testing. Test loads should be increased at incremental levels up to the maximum air vehicle rated load. The maximum subsystem rated load is to be used for these tests unless a lesser load is more critical for demonstrating dynamic stability. Typical measurements are structural, dynamic, aeromechanical, aeroelastic, and electrical test parameters; to include combined system and cargo weight, sling loads, aerodynamic forces, vibrations, and airspeed.

TBS 2 should be filled in with testing the hoist and installation with maximum rated loads. Other measurements include proof load, acceleration forces, and quick-disconnect forces. All release modes should be demonstrated. All release modes including normal, automatic, and semi-automatic hook engagements; automatic touchdown; manual ground; and emergency releases should be demonstrated. Emergency release should be demonstrated during turns at the maximum allowable bank angle and speed and while carrying maximum rated loads. Quick disconnect devices and cable cutters should be actuated at the most critical load conditions.

Re-latch features are to be operated, and proper operation of safety or warning devices, such as unlatched load beam indicator lights, should be verified. Operating procedures defined in the operator's manual should be followed throughout the demonstration. These tests may be carried out jointly with the test of the hoist subsystem. Airworthiness and crashworthiness of the host air vehicle should not be degraded.

VERIFICATION LESSONS LEARNED (4.4.10.1.3)

The U.S. Army Natick Research, Development, and Engineering Center (NRDEC) is the Department of Defense (DoD) executive agent in external air transport certification. As such, the center is an excellent source of technical expertise in the analysis of dynamic vibration, helicopter and load mass differential, and rotor wash patterns. NRDEC, in coordination with each Service's aeronautical engineering program office, provides test and evaluation guidance to individual acquisition and development programs.

External loads are classified as either single-point or dual-point loads depending upon the number of cargo hooks. Traditional guidelines for external load verification include:

a. The load should be within the lifting capability of the desired air vehicle.

b. The load is rigged in accordance with the certified rigging procedures.

c. The maximum stable airspeed limitation specified for the load in the applicability section of the rigging procedure should be maintained.

There are certain items of equipment that are prohibited from external air transportation and which would not be used for verification testing. These items have either structural deficiencies or have exhibited unstable flight characteristics during previous flight-testing. Each Service transmits this information by a separate list once identified. In addition, item selection of previously certified equipment (either single or dual point loads) is not an acceptable method. Loads should not be selected and cannot be certified for dual-point lift based on previously certified dual-point rigging procedures because of the differences in dual-hook air vehicles, such as the distance between the two cargo hooks. Each load needs to be evaluated with the intended air vehicle. Avoid selecting low-density equipment with low weight and large surface area (flat surfaces) such as shelters, empty trailers, pallet loads, and empty fuel or water drums. These items are likely to become extremely unstable when externally air transported, even at low airspeeds.

J.3.4.10.2 Aerial delivery

J.4.4.10.2 Aerial delivery

J.3.4.10.2.1 Static line capability.

The cargo subsystem shall be equipped with a means to permit airdropping of personnel or cargo bundles using static line deployed parachutes. The system shall be compatible with the $^{3}/_{8}$-in. opening of the static line snap hook.

REQUIREMENT RATIONALE (3.4.10.2.1)

Currently, both fixed-wing and rotary-wing air vehicles deploy anchor systems designed to $^{3}/_{8}$-in. anchor cable system. Fixed-wing air vehicle have static-line-deployed systems designed to attach to a $^{3}/_{8}$-in. diameter anchor cable system. Rotary-wing air vehicles utilize modified anchor line cable systems consisting of fabric webbing anchor strap with eight D-rings arranged in a rectangular loop attached to tiedown rings which also requires $^{3}/_{8}$-in. compatibility with static lines.

REQUIREMENT GUIDANCE (3.4.10.2.1)

In air vehicles equipped with anchor line cables, the system should permit multiple sticks or rows of paratroopers to use each designated jump exit. Adjustable stops and intermediate supports should be used to allow one cable to serve as the anchor for both side door and rear ramp exits on each side of the air vehicle. Intermediate support should not impede the motion of the static line snap hook along the anchor line cable when these supports are not required, as in the case of ramp exits. The anchor line cable should be at a height to allow for the range of population sizes of all designated jumpers to attach the static line snap hook of their parachute to the anchor line cable. The system should be stowable and removable when not in use.

In certain air vehicles, the parachutists are seated at or near the exit, such as in rotary-wing air vehicles. These air vehicles are equipped with anchor points that only allow limited motion, the anchor points should be located in such a way that:

a. The parachutist or jumpmaster should be able to attach the static-line.
b. The static-line should have a clear path to the exit point and will not interfere with or impede other parachutists or crew.

The static-line anchor cable and all supporting structure and stops should be stronger than the static-line itself. If the anchor cable or other supporting structure fails then the towed jumper and all subsequent jumpers would have a total malfunction that would result in a catastrophic event. Therefore, the anchor line cable needs to withstand forces at least equal to the strength of the static-line plus an appropriate safety factor. Installation strength should support a minimum defined load applied over the range of expected angles to include: parachutist exits, parachute deployment, towed jumper, and towed jumper retrieval. Surfaces that the static-line and anchor cable or anchor points can come into contact with should not reduce the effective strength to the point that there are premature failures or damage to the system during normal or abnormal operation such as the towed jumper scenario. The main factors are edge radius, roughness, and material. Good practice is to have smooth, well-radiused surfaces on all air vehicle parts, which the static line could contact.

REQUIREMENT LESSONS LEARNED (3.4.10.2.1)

In an effort to increase interoperability and improve the safety of airborne soldiers, the USA and USAF set up an Integrated Concept Team which met and formulated the requirements for a single static-line, called the Universal Static Line (USL). The USL will potentially replace the existing 15-foot static line. The proposed design for the static line capability will have to interface with the new USL and be suitable for static line operations in all current air vehicles. The USL will require that the static-line strength not exceed 3,600 lbs. but with the 1.5 safety factor, the anchor line cable needs to withstand an ultimate load of 5,400 lbs.

J.4.4.10.2.1 Static line capability.

The cargo subsystem's ability to permit airdropping of personnel or cargo bundles using static line deployed parachutes shall be verified by ___(TBS 1)___. System compatibility with the static line snap hook, clevis, or other hardware used to attach the static line to the anchor line cable or anchor point shall be verified by ___(TBS 1)___.

VERIFICATION RATIONALE (4.4.10.2.1)

Static line capability is a crucial function in personnel airborne missions and the safe performance and equipment interoperability needs to be verified to assure a very high system reliability required of personnel parachutes and to assure there is no risk to the air vehicle.

VERIFICATION GUIDANCE (4.4.10.2.1)

TBS 1 should be filled in with component-level test and demonstration with the air vehicle. Parachute performance and reliability should also have to be evaluated for complete system verification. This would include all current static-line parachutes, such as the T-10C, T-11, MC1-1B/C, and MC-5. Performance and reliability should be evaluated over the range of operating conditions during an airdrop. The following elements should be covered in the verification:

a. Ground testing to assure adequate strength of air vehicle components.

b. Ground testing to assure compatibility with parachute systems, both personnel and cargo static deployed parachute systems.

c. Flight safety verification for personnel and cargo static deployed parachute systems (will the static-line interfere with flight control surfaces). This includes ground and air testing.

d. Static line and deployment bag trailing characteristics.

e. Static line and deployment bag retrieval, to include back-up retrieval procedures when applicable.

f. Strength of air vehicle components and static-line with maximum weight towed jumper at maximum achievable distance along static line.

g. Trailing and retrieval of minimum and maximum weight jumper, to include normal and emergency procedures (This is normally not done with rotary-wing air vehicles where the jumper will be retrieved.)

h. The air vehicle influences initial parachute testing with dummies. All aspects of parachute performance should be addressed, including:

   1. Jumper and deployment bag contact

   2. Potential for hazards and collisions resulting from the tendency of parachutes from opposite sides of the air vehicle to move towards each other (cross-over, or centerlining)

      (a.) Execute live jumps to address the parachutist, jumpmaster, and aircrew actions to include safety and static-line control. Begin the demonstration with a number known as a safe condition. Incrementally increase the number of parachutists up to the stated maximum capacity to demonstrate reliability for operational use.

VERIFICATION LESSONS LEARNED (4.4.10.2.1)

The strength of a static line and anchor cable system under actual operating conditions is difficult to define. Loads depend upon jumper weight, elasticity of the static-line material, and additional load attenuation resulting from the anchor line cable deflection under load. Strength can be negatively impacted from the static-line being in contact with the edge of the door or ramp. The US Army NRDEC is the DoD Executive Agent for technical evaluations of static-line personnel parachuting and related system issues. NRDEC is considered the engineering focal point for test evaluation of static-lines, parachute deployment, trailing deployment bags, deployment bag retrieval, and towed jumpers.

J.3.4.10.2.2 Static line retrieval.

The cargo subsystem shall provide a means of retrieving all static lines deployed outside of the air vehicle during flight.

REQUIREMENT RATIONALE (3.4.10.2.2)

An air vehicle closes its exit openings as soon as jump operations are completed. Efficient retrieval of deployed static lines is necessary to close exit openings and resume normal flight operations.

REQUIREMENT GUIDANCE (3.4.10.2.2)

The retrieval assist system should permit a single loadmaster to retrieve a hung paratrooper completely into the air vehicle. The system should have the capability to retrieve a fully combat-loaded paratrooper, weighing a minimum of 400 lb, including the additional aerodynamic loads placed on the hung jumper. The retrieval assist should have a backup or alternate capability to provide high reliability and confidence levels.

REQUIREMENT LESSONS LEARNED (3.4.10.2.2)

Ineffective static line retrieval equipment and recovery measures result in loadmaster and jumper injuries, in addition to air vehicle and equipment damage. It is imperative to retrieve a hung paratrooper to eliminate the additional load placed upon the static-line and anchor cable system. The average weight of a fully combat-loaded soldier has steadily increased over time; therefore it is necessary to start with a minimum weight of 400 lb. as stated in the requirement guidance. Additional coordination with the U.S. Army NRDEC is advised as paratrooper weight and resulting proof load has shown itself to be a fluctuating factor in the past.

J.4.4.10.2.2 Static line retrieval.

The means of retrieving all static lines deployed outside of the air vehicle shall be verified by ___(TBS___.

VERIFICATION RATIONALE (4.4.10.2.2)

Static line retrieval is an essential function of the cargo subsystem that is crucial to the safe performance of the air vehicle and personnel.

VERIFICATION GUIDANCE (4.4.10.2.2)

TBS should be filled in with component-level test and demonstration with the air vehicle. Data should be provided to demonstrate the capability of the retriever's motor throughout the intended flight envelope. Also verify during the demonstration that the retriever's cable should be at least 4 in. above the anchor line for safety purposes.

VERIFICATION LESSONS LEARNED (4.4.10.2.2)

Past demonstrations in static line retrieval emphasize verifying that the retriever spools are secured forward of the intermediate cable support and are tied to supports with webbing.

J.3.4.10.2.3 Aerial delivery go – no go indication.

An indication of go or no go upon reaching the computed aerial delivery release point shall be provided throughout the air vehicle cargo compartment so that it is visible to all personnel and loadmasters during paratroop or cargo aerial delivery missions.

REQUIREMENT RATIONALE (3.4.10.2.3)

The release point must be clearly understood through a visual signal by all crew members and jump personnel to ensure successful mission completion. Visual signals are required as the primary indicators even if aural systems are available. The signals are tied to the jump window such that personnel or cargo exiting the air vehicles during the jump or release phase (green light) are assured to be within the Computed Air Release Point (CARP) envelope for drop accuracy. Generally, the release point's signal for personnel jumps is the same one used to initiate a heavy airdrop of cargo.

REQUIREMENT GUIDANCE (3.4.10.2.3)

Jump indications should also be located at or in the door exits to be visible to the jumper just before departure from the air vehicle.

Jump indicators should be controllable from the cockpit and linked to the air vehicle navigational system and tied into the air vehicle CARP. Jump indicators should be dimmable from full bright to off, and be compatible with night vision mission requirements and equipment.

The indicators should provide an unambiguous, symbology-based indication for "approaching the release point" (red light), "prepare to jump or release" (yellow), and "jump or release" (green). This may be followed at any time by the "stop" indicator (usually a return to the red light). Indicators should have the equivalent of a red light, yellow light, and green light system.

REQUIREMENT LESSONS LEARNED (3.4.10.2.3)

Indicators should be symbology-based as opposed to strictly color due to night vision goggle (NVG) operations.

J.4.4.10.2.3 Aerial delivery go – no go indication.

The visibility of the indication for go or no go upon reaching the CARP shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.10.2.3)

The effectiveness and accuracy of the subsystem's delivery capability needs verification as part of an integrated system with the air vehicle.

VERIFICATION GUIDANCE (4.4.10.2.3)

TBS should be filled in with analysis and demonstration as part of the air vehicle's performance.

VERIFICATION LESSONS LEARNED (4.4.10.2.3)

Effectiveness of the go-no go indicators (jump signals) have been verified via demonstrations with test jumpers aboard the air vehicle. Test flights are made during various lighting conditions ranging from full daylight to dark and with the air vehicle flying in the most adverse conditions for viewing the signals (for example, looking into the sun). Jump personnel with full equipment packs are seated in all possible locations and are asked to fill out a questionnaire during the flight and again after the jump that reflects how well they could see the signals. Jump personnel are also queried on how well they could see the jump signals when they were poised in or near the jump exits awaiting the initial command. All personnel should be able to see the signals at all times, because these may be the only commands given and each individual is personally responsible for jumping or staying in the air vehicle, based on the jump signals. The loadmaster and jumpmaster are prohibited from physically intervening in the jumper's progress throughout the jump. Past efforts to stop a jumper physically after the stick was in progress have resulted in injury and death.

J.3.4.10.2.4 Bundle release.

A means shall be provided to release single or multiple large cargo bundles (A-22 type) when given a go indication. Hardware shall be provided to perform the operations required for the gravity-based airdrop of heavy equipment at altitude, equipment and cargo at low altitude (LVAD) and containers. Capability to release bundles and equipment shall be provided to the crew.

REQUIREMENT RATIONALE (3.4.10.2.4)

Large heavy weight bundles require a quick release capability to initiate gravity-based airdrops. Although this is a gravity-based extraction, this requires an equally precise release point. As these bundles cannot be automatically released, a quick and safe manual release capability is necessary to meet target objective.

REQUIREMENT GUIDANCE (3.4.10.2.4)

The aft restraint gate should be designed with a means of being mechanically released or severed on a signal coinciding with the green light.

The release system should be capable of being rigged at any station within the cargo compartment and provide for release of multiple gates simultaneously or in sequence, and should be designed to easily accommodate missions involving multiple drop sites.

All airdrop mission equipment should be stowable onboard the air vehicle outside the cargo compartment envelope and without interference with other mission configurations.

REQUIREMENT LESSONS LEARNED (3.4.10.2.4)

Increased airdrop accuracy to the present day delivery capability is needed to resupply deployed ground forces effectively. A reliable bundle release mechanism is needed to ensure accurate delivery throughout the range of delivery altitudes, which is determined by the anti-air vehicle threat.

J.4.4.10.2.4 Bundle release.

The means of providing for the release of single or multiple large cargo bundles (A-22 type) when given a go indication shall be verified by ___(TBS)___. The capability of the crew to initiate the release of bundles shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.10.2.4)

An accurate and reliable bundle release mechanism is a critical element for precise air delivery missions.

VERIFICATION GUIDANCE (4.4.10.2.4)

TBS should be filled in with analysis and demonstration as part of the air vehicle's performance. Ideally, service personnel perform the demonstration test as part of the air vehicle's performance utilizing the system manuals. The bundle sequence is determined before loading. If single bundles are to be dropped, a restraint strap and release lanyard are required for each bundle. If multiple bundles are to be dropped in units of two or three, a restraint strap and release lanyard are required for the aft bundle in each unit. Before demonstration test, ensure the bundle release mechanism (currently release plates and lanyards) are correctly installed in accordance with proposed design.

VERIFICATION LESSONS LEARNED (4.4.10.2.4)

Past experience has placed an emphasis upon verifying that the effects of the bundle release operations upon the air vehicle's center of gravity position are within the approved limits associated with cargo airdrop operations. Changes in the host air vehicle's control forces' yaw rates need to be measured throughout bundle release operations.

J.3.4.10.3 Special operations

J.4.4.10.3 Special operations

J.3.4.10.3.1 Search and rescue operations.

The air vehicle shall incorporate a rescue hoist to conduct search and rescue missions relating to personnel extraction and rescue. The rescue hoist shall have the ___(TBS)___ operational capability.

REQUIREMENT RATIONALE (3.4.10.3.1)

Search and rescue designated air vehicles must have the means to conduct rescue missions effectively.

REQUIREMENT GUIDANCE (3.4.10.3.1)

TBS should be filled in with the following minimum operational capabilities:

a. Performance and cooling. A rescue hoist should be provided that has an operating capacity of at least 600 lbs. at a continuously variable speed range up to 200 feet per minute. A circulating fan is a desired safety factor to provide cooling for the motor. The rescue hoist should include a corrosion and rotation resistant cable with the free end terminated with a SAE AS8905 Helicopter Rescue Hook attached through the means of ball-bearing swivel.

b. Safety measures. The Helicopter Rescue Hook should have a means to prevent cable payout under any load up to 1.5 times operating capacity when not in the payout condition or when inoperative. It should sustain a minimum of 5-lbs. tension at no load during all extending operations. A fail-safe mechanism is desired to limit the induced loading weight to the hoist to a pre-determined weight. Typical systems use 1,200 lbs. as a maximum weight. The rescue hoist should have normally employed limit and safety controls and sustain operation at up to 45° bank angles. The rescue hoist should also contain a cartridge-actuated cable cutter mounted on or near the hoist.

c. Modes of operation. The rescue hoist should be operable by both the cabin operator and the pilot (to include pilot capability to override cabin operator control). Additional safety measures should include a manual method of controlling hydraulically powered hoists in the event of failure of the air vehicle electrical systems. An additional safety factor is the location of the hoist to permit maximum clearance and safety for both the hoist operator and the rescued personnel being retrieved into the cabin, to include provisions for a safety belt for the hoist operator.

REQUIREMENT LESSONS LEARNED (3.4.10.3.1)

Not all branches of the Services currently have dedicated air vehicle assets equipped with the necessary search and rescue equipment. Therefore, it is necessary to ensure the air vehicle has the capability to perform the rescue operations or possess the capability of being modified to accept specialized equipment. Search and rescue operations include the following tactical insertion and extraction methods: aerial insertion and extraction by fixed-wing assault landings, parachute (static line, free fall), rotary-wing landings, hoists, rappelling, fast ropes, Stabilized Tactical Airborne Operation (STABO), Special Patrol Insertion and Extraction (SPIE), and rope ladder.

J.4.4.10.3.1 Search and rescue operations.

Search and rescue operations capability shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.10.3.1)

Search and rescue operations are one of the most time-sensitive missions that require a high readiness posture and fast response capability. This requires early verification of the air vehicle's search and rescue capability so that necessary improvements in performance can be made before deployment.

VERIFICATION GUIDANCE (4.4.10.3.1)

TBS should be filled in with analysis and demonstration of each rescue component as part of the air vehicle's performance. There is a high degree of risk involved during rescue hoist operations.

Therefore, demonstrations should occur after the air vehicle design has been verified through flight tests. The proposed design may include both internal and external mount positions. Both mount positions need to be tested. The hoist also needs to be demonstrated with all associated equipment to evaluate the full range of performance. Current rescue hoist systems' associated items include:

a. forest penetrator

b. litters (sked and stokes)

c. survivor sling (horse collar).

The full range of performance includes operation in all modes of operation. The pilot and hoist operator's controls and all safety measures are verified in the demonstration.

VERIFICATION LESSONS LEARNED (4.4.10.3.1)

Past experience indicates a greater emphasis is needed on verifying that the subsystem is not adversely affected by a specified electromagnetic field. This includes verifying the various human factor performance requirements.

J.3.4.10.3.2 Rope suspension operations compatibility.

The cargo subsystem shall be capable of meeting special operation mission requirements by providing air vehicle attachments points and compatible interfaces for ___(TBS)___. When specified, special operations subsystem functions shall include a means to conduct Rotary-wing and VTOL air vehicle rope suspension operations. Rope suspension operations include rappelling, fast roping, SPIE, and Jacob’s ladder which require air vehicle attachment and interface points.

REQUIREMENT RATIONALE (3.4.10.3.2)

Air vehicles must have cargo subsystems that can support the unique operation requirements of rope suspension special operations missions. In particular, rope suspension operations enables combat equipped troops to negotiate obstacles or terrain that would be otherwise non-negotiable by allowing insertion and extraction from areas which restrict helicopter landings. Secure anchor points that are easily accessible and readily rigged for usage on the air vehicle are essential in assuring troop safety during these operations.

REQUIREMENT GUIDANCE (3.4.10.3.2)

TBS should include fast rope, Jacob's ladder, SPIE rigging, rappelling and other operations as required. Attachment points for required rope suspension operations should make use of existing cargo rings, fittings, and hooks to the maximum extent possible. Additional attachment points to accommodate specific rigging equipment should be provided when necessary. Refer to Fleet Marine Force, Altantic Operating Procedure FMFLant OP3000.3 for Standard Operating Procedures for specific attachment information. Whenever possible, hand holds should be provided to assist ropers' movement to the rope stations. Positioning of the attachment point(s) should permit combat equipped troops to safely access the ropes. Location points above the end of the cargo ramp should permit ropes to hang vertically with no interference from the ramp, but remain easily accessible by personnel on the ramp. Location points above the cabin entry door(s) may take advantage of support structure already included from a rescue hoist. All anchor points may make use of existing cargo tiedown rings or the external cargo hooks to provide secure attachment of special rigging hardware (for example gantry, Schlomer frame). Each rope system should include a safety pin to secure the rope to prevent accidental release and a quick release mechanism that will allow release once the safety pin is removed. The following design criteria formula for the structural attachment point ultimate load is normally used:

N (Number of Troops) x 240 lbs.

(Estimated weight of an equipped military person) x 1.5 F.S. x a limit load factor of 2.

REQUIREMENT LESSONS LEARNED (3.4.10.3.2)

The priority for special operations compatibility in air vehicle design is to ensure limited conversion time. Consequently, the necessary attachment points should be designed into the basic structure of the air vehicle.

J.4.4.10.3.2 Rope suspension operations compatibility.

Compatibility of the cargo subsystem attachment points and interfaces with rope suspension operations equipment shall be verified by ___(TBS)___.

VERIFICATION RATIONALE (4.4.10.3.2)

In order to insure safe operation and meet mission requirements, it is necessary to verify the cargo subsystem's interoperability with the rope suspension operations equipment.

VERIFICATION GUIDANCE (4.4.10.3.2)

TBS should be filed in with coordinated analysis from the appropriate organizations in each Service's Special Operations branch.

VERIFICATION LESSONS LEARNED (4.4.10.3.2)

Emphasis should be placed upon the identification through analysis of the following required interfaces: sufficient number and placement of tiedown devices and the capability to receive or mount the required rope suspension operations rigging.

J.5 PACKAGING

J.5.1 Packaging.

For acquisition purposes, the packaging requirements shall be as specified in the contract or order (see 6.2). When packaging of materiel is to be performed by DoD or in-house contractor personnel, these personnel need to contact the responsible packaging activity to ascertain packaging requirements. Packaging requirements are maintained by the Inventory Control Point's packaging activities within the Military Service or Defense Agency, or within the military service's system commands. Packaging data retrieval is available from the managing Military Department's or Defense Agency's automated packaging files, CD-ROM products, or by contacting the responsible packaging activity.

J.6 NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

J.6.1 Intended use.

The cargo subsystem descriptions in this appendix are intended for use in air vehicle systems developed to perform combat and combat-support missions in environments unique to military weapon systems.

J.6.2 Acquisition requirements.

Acquisition documents should specify the following:

a. Title, number, and date of the specification.

J.6.3 Component information

J.6.3.1 Guide rails and rollers.

In the past, air vehicles with a cargo mission requirement have utilized a system of lateral and longitudinal cargo guide rails and rollers in the air vehicle to ease in the loading and unloading of palletized logistical cargo and aerial delivery missions. Historically, for logistical cargo missions the guide rails and rollers have been compatible with the 463L system of pallets. For aerial delivery, the guide rails and rollers have been compatible with aerial delivery platforms and skidboards. In the design of past cargo subsystems, the following has also been considered when guide rails and rollers have been used in the air vehicle:

a. Palletized cargo. Interface of the guide rails with the platform and pallet side rails should be designed to space rollers close enough to accommodate all types of pallets. Pallet runner size, spacing, and orientation should be considered in the selection and design of conveyors. Guide rollers height should accommodate over-hang of the pallets. Guide rails have had a bumper or stop at the forward end and have been flared at the aft end to permit easy entry of palletized loads. Provisions have also been made for the continuity of the rail where it traverses the hingeline of the air vehicle ramp.

b. Cargo aerial delivery. For interface with the Type V platform runners, the lateral spacing of the rollers has provided contact between butt lines 10.6 and 21.75 L&R for the inboard runners and butt lines 36.75 and 53.5 L&R for the outboard runners. Roller contact width has been a minimum of 3 in. and roller height above the floor has not been less than 1 in. Longitudinal spacing of individual rollers combined with individual roller capacities has also provided a load capacity at least equal to that of the airdrop platform (2500 lb. per linear ft. for the Type V). Heavy-duty teeter rollers provided at the end of the cargo ramp have had a capacity to support the maximum weight airdrop platform (60,000 lbs. for the Type V) during ground loading and airdrop. Intermediate teeter rollers have been provided at the conveyor ends to support logistic pallet loads of at least 10,000 lbs. cresting the junction of the ramp and floor when the ramp is not coplanar with the floor.

c. Bundle aerial delivery. Lateral and longitudinal roller spacing has been compatible with the skidboard dimensions and center of gravity locations of cargo bundles as contained in Army Field Manual NO. 4-20.103 (FM 10-500-3)/Marine Corps Reference Publication NO. 4-11.3C/Air Force Technical Order NO. 13C7-1-11. Historically, minimum skidboard width for A-7A and A-21 bundles has been 42 in. For airdrop of A-22 bundles, the air vehicle has had a guide rail system which should accommodate skidboard widths of 48 in. and thickness of 1 in. For vertical restraint, the guide rails have been designed with lateral edges (lips) that overhang the plywood skidboard by at least ¾-in. on each side.

J.6.3.2 Cargo winch.

In the past, air vehicles with a cargo mission requirement have utilized a winch in the cargo compartment with ancillary devices to enable pulling the maximum designated cargo into and out of the air vehicle. The winch has been controllable in both speed and direction and from any point in the compartment or outside the air vehicle to just beyond the point where the cargo would begin loading. High-speed operation for payout and rewind without loads has been utilized to assist loadmasters in spooling out cable quickly. Variable speed operation under load has been demonstrated to be very useful for moving large objects under exacting conditions. To prevent the winch from exceeding cable design limits, a load limiting feature is provided that prevents application of loads greater than a predetermined limit based on the known cable strength. Historically, pulling force has been limited to half the minimum breaking strength of the cable and the load limit feature is set for 65 percent (65%) to 70 percent (70%) of the minimum breaking strength.

J.6.3.3 Treadway floor.

The air vehicles need to have a treadway area on the cargo floor and any ramp surface to enable drive-on loading of wheeled or tracked vehicles. The treadway width should be dictated by the tread widths of the largest and smallest vehicles to be accommodated. If the air vehicle is designed to carry dual rows of vehicles, the treadway width would extend across the entire cargo floor. The treadway area, including any integral hardware for palletized cargo or any imbedded tiedown provisions, should be specified to support the required wheel and axle loads (single and dual axles) at maximum pneumatic tire pressures (usually 100 psi). It should also track loads, hard wheels, or skid mounted bulk cargo requirements based on actual contact area. The treadway area should be equipped with an antiskid treatment effective under all conditions of mud, oil, water, grease, or combinations thereof.

J.6.3.4 Cargo ramp extensions (ramp toes).

For drive on loading of rolling stock, the air vehicle should be equipped with extensions to the cargo floor and ramp such that a smooth and shallow transition is provided. End loading air vehicles should have one or more hinged ramps that can be lowered to make ground contact, with removable or deployable ramp toes that extend the treadway surface of the ramp to the ground line and bridge the vertical drop-off at the structural end of the ramp. When deployed, the ramp extensions or toes should be long enough to provide approximately the same approach angle as the cargo ramp. These ramp extensions or toes should accommodate the entire range of wheel tracks for all envisioned cargo but should be easily removed or folded away to permit the ramp and cargo door closure and to support airdrop operations from a coplanar ramp. Ramp extensions or toes should support the same loads as the treadway floor, but only at ground loading conditions.

J.6.3.5 Stabilizer struts.

The cargo floor and ramp should have the capability to be stabilized as necessary during loading such that there should be no significant change in air vehicle position, ramp angles, and floor height as the cargo is moved into the required compartment(s). The amount of movement to be allowed may be expressed as a function of floor or ramp height changes during the loading process. The stabilizer system should function primarily when the ramp does not make contact with ground (as when coplanar loading of platforms). The stabilizer system should be equipped with a load limiter feature to prevent damage to the air vehicle if the designed load limits are exceeded. The stabilizer system should be readily deployable and removable by the loadmaster.

J.6.3.6 Passenger seats.

A mixed cargo and troop capability is normally stated in an air vehicle's ORD, and usually states a minimum of installed inboard facing seats along each side of the air vehicle. The seats should be compatible with paratroop jumping operations. In stowage the seats should not interfere with normal full floor cargo. While in use, the seats should not reduce the original cargo floor space by more than 25 percent (25%), or as stated in the ORD. The seat components should be interchangeable from one side of the air vehicle to the other by the loadmaster while in flight without the use of special tools. The seats should be designed to accommodate combat equipped troops. The seat base should be a minimum of 18 in. wide and laterally adjacent seats should be minimum of 24 in. on the center. The seat bottoms should move out of the way for paratrooper jumps and should be easily operable by combat-equipped paratroopers. Seat backs and bottoms should provide space and support for the seated individual's parachute and any other condition stated in the ORD. Passenger seat restraint requirements should be in accordance with the ORD.

J.6.4 Definitions.

A-7A Airdrop Cargo Sling Assembly: The A-7A consists of four identical sling straps, each 188 in. in length. Each strap is fitted with a parachute harness adapter (friction adapter) and a floating D-ring. The straps are placed around cargo loads up to 500 lbs in either a two, three, or four strap configuration, in a manner to support and suspend the load under the recovery parachute, which can be either one to three 68-in. pilot chutes or one G-13 or G-14 cargo parachutes.

A-21 Cargo Bag Assembly: The A-21 cargo bag is an adjustable size container consisting of a sling assembly with scuff pad, fixed quick-release strap and assembly, two O-ring straps, three quick release straps, and a 97 x 115 in. canvas cover. The A-21 cargo bag assembly has a 500-lb load capacity and is typically used with one G-13 or G-14 cargo chute for low velocity drops. Three 68-in. pilot chutes, one 12-foot high velocity cargo chute, or one 15-ft cargo extraction chute can be used with the A-21 for high velocity drops.

A-22 Cargo Bag Assembly: The A-22 cargo bag assembly is an adjustable cotton duck and nylon webbing container. It consists of a sling assembly, a cover, and four suspension webs. The load may be rigged with or without the cover. The rigged load size may be up to 48-in. x 48-in. x 83 in. high with the G-12 recovery parachute. All A-22 containers are secured to ¾-in. or 1-in. thick plywood skidboards, atop varying thickness of paper honeycomb depending on the type of drop. Weight capacity is 501 to 2200 lbs. For cargo items which exceed the 48-in. length limitation, double A-22 configurations may be made by linking two sling assemblies together and using a 48 x 96-in. sheet of plywood for the skidboard.

A-23 Cargo Bag Assembly: The A-23 cargo bag assembly is a reinforced version of the A-22 used primarily for high altitude high velocity airdrops.

J.6.5 Acronyms.

The following list contains the acronyms/abbreviations contained within this appendix.

AGL	Above Ground Level
ATTLA	Air Transportation and Test Loading Activity
CARP	Computed Air Release Point
LAPES	Low Altitude Parachute Extraction System
LVAD	Low Velocity Airdrop
NRDEC	Natick Research, Development, and Engineering Center
ORD	Operational Requirements Document
SPIE	Special Patrol Insertion and Extraction
STABO	Stabilized Tactical Airborne Operations
USL	Universal Static Line
VTOL	Vertical Takeoff and Landing

J.6.6 Subject term (key word) listing.

Passenger

Ramp

Restraint

Static line

Tiedown

J.6.7 Responsible engineering office.

The office responsible for the development and technical maintenance of this appendix is AFLCMC/EZFC (ATTLA), BLDG 28 RM 118, WPAFB OH 45433-7017 USA; DSN 986-9849, COMMERCIAL (937) 656-9849, AFLCMC.EZF.MAILBOX@US.AF.MIL. Requests for additional information on this appendix can be obtained from AFLCMC/ENRS, BLDG 28 RM 118, 2145 MONAHAN WAY, WPAFB OH 45433-7017 USA; DSN 674-5476; COMMERCIAL (937) 904-5476; ENGINEERING.STANDARDS@US.AF.MIL.

J.6.8 Amendment notations.

The margins of this specification are marked with vertical lines to indicate modifications generated by this amendment. This was done as a convenience only and the Government assumes no liability whatsoever for any inaccuracies in these notations. Bidders and contractors are cautioned to evaluate the requirements of this document based on the entire content irrespective of the marginal notations.

APPENDIX K

AIR VEHICLE VERTICAL TAKEOFF AND LANDING (VTOL) — SHORT TAKEOFF AND LANDING (STOL) POWER DRIVE SUBSYSTEMS

REQUIREMENTS AND GUIDANCE

K.1 SCOPE

K.1.1 Scope.

This appendix provides the requirements, verifications, tailoring guidance, and background information for the VTOL — STOL Power Drive Subsystems provided for in Part 1 of this specification. The appendix has been developed and coordinated by technical personnel from the Air Force, Navy, and Army and has been approved as an official guide for use by Government personnel for assistance in tailoring the air vehicle subsystems specification for acquisition and model specifications. This appendix is a mandatory part of the specification. The information contained herein is intended for compliance.

K.1.2 Structure.

The appendix structure replicates the structure of the Air Vehicle Subsystems Specification except it places each corresponding section 3 requirement and section 4 verification together.

K.1.3 Appendix.

This appendix provides tailoring guidance and background information for individual paragraphs of the Air Vehicle Subsystems Specification. Guidance gives recommendations on how to tailor the specification paragraph. Where ___(TBS)___ appears, the guidance paragraph provides recommended values or text that the Using Service may use to insert in the __(TBS)__. When contractors are expected to complete the _(TBS)__, the Guidance paragraph will so state. The Using Service makes the final decision on whom completes the __(TBS)__ in the specification. Finally, Lessons Learned are provided to give insight to past events that could impact the tailoring of the specification.

K.1.4 Deviations.

Projected designs for given applications which will result in improvement of the system performance, reduced life cycle cost, or reduced developmental cost through deviations from this guidance, or where requirements of the specification results in compromise in operational capability, should be brought to the attention of the Using Service.

K.1.5 Environmental impact.

Air Vehicle Subsystems will be designed such that their operation, maintenance, and repair may be accomplished without violating the most stringent environmental regulations applicable to locations where subsystems are used or supported. Compliance with environmental regulations will not prevent subsystems from achieving and sustaining mission performance capability. Materials, processes, and environmental control equipment necessary to meet these environmental requirements must currently be available in the Using Service's maintenance and supply system. The design will not use environmentally unsuitable materials such as ozone depleting fluorocarbons, chlorofluorocarbons, and halons, or highly volatile organic compounds in solvents and coatings during development, production, operation, maintenance, or repair. The Environmental Protection Agency maintains an online list of toxic chemicals and hazardous substances on its Ozone Layer Depletion Website at http://www.epa.gov/ozone/snap/ that should be consulted. The Significant New Alternatives Policy (SNAP) Program available thereon identifies substitutes for ozone depleting chemicals.

The contractor will conduct an environmental analysis of air vehicle subsystems.

K.1.6 Responsible engineering office.

The responsible engineering office (REO) for this appendix is AFLCMC/EZFP, WPAFB OH 45433-7017 USA; DSN 986-9916, COMMERCIAL (937) 656-9916; AFLCMC.EZF.MAILBOX@US.AF.MIL.

K.2 APPLICABLE DOCUMENTS

K.2.1 General.

The documents listed in this section are specified in sections 3 and 4 of this handbook. This section does not include documents cited in other sections of this guide specification or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3 and 4 of this handbook, whether or not they are listed.

K.2.2 Government documents

K.2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this appendix to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

DEPARTMENT OF DEFENSE SPECIFICATIONS

JSSG-2001	Air Vehicle Joint Service Specification Guide
MIL-PRF-7808	Lubricating Oil, Aircraft Turbine Engine, Synthetic Base
DOD-PRF-85734	Lubricating Oil, Helicopter Transmission System, Synthetic Base

DEPARTMENT OF DEFENSE STANDARDS

MS3325	Drive Pad - Accessory, 2.653 BC Square, Design Standard
MS3326	Drive Pad - Accessory, 5,000 BC Square, Design Standard
MS3327	Drive Pad - Accessory, 5,000 BC Round, Design Standard
MS3328	Drive Pad - Accessory, 8,000 BC Round, Design Standard
MS3329	Drive Pad - Accessory, 10,000 BC Round, Design Standard
MS3336	Accessory Drives, Aircraft Engine, Reference Chart for
MS9948	Cover - Accessory Drive, 10,000 BC Round, QAD
MS9949	Cover - Accessory Drive, 8,000 BC Round, QAD
MS9950	Cover - Accessory Drive, 5,000 BC Round, QAD

(Copies of these documents are available online at http://quicksearch.dla.mil or from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia PA 19111-5094 USA.)

K.2.3 Non-Government publications.

The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

AMERICAN NATIONAL STANDARDS INSTITUTE/
AMERICAN BEARING MANUFACTURERS ASSOCIATION

ANSI/ABMA 9:1990	Load Ratings and Fatigue Life for Ball Bearings
ANSI/ABMA 11:1990	Load Ratings and Fatigue Life for Roller Bearings

(Copies of these documents are available from http://webstore.ansi.org; ANSI, 25 West 43rd Street, 4th Floor, New York NY 10036-7422 USA; and from www.ihs.com to qualified users.)

SAE INTERNATIONAL

SAE AMS2430	Shot Peening, Automatic

(Copies of this document are available from www.sae.org; SAE International, 400 Commonwealth Drive, Warrendale PA 15096-0001 USA; and from www.ihs.com to qualified users.)

SOCIETY OF TRIBOLOGISTS AND LUBRICATION ENGINEERS

STLE Life Factors for Rolling Bearings, 1992

(Copies of this book may be ordered from www.stle.org; STLE, 840 Busse Highway, Park Ridge IL 60068-2302 USA; Information@stle.org).

K.2.4 Order of precedence.

Unless otherwise noted herein or in the contract, in the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

K.2.5 Streamlining.

The Air Vehicle Subsystems Specification has been streamlined. The documents listed in this appendix which are required for acquisition have the same status as those referenced directly in section 2 (first tier). All other documents referenced through tiering may be used for guidance and information only.

K.3 REQUIREMENTS

K.4 VERIFICATIONS

K.3.1 Definition

K.4.1 Definition

K.3.2 Characteristics

K.4.2 Characteristics

K.3.3 Design and construction

K.4.3 Design and construction

K.3.4 Subsystem characteristics

K.4.4 Subsystem characteristics

K.3.4.1 Landing subsystem

K.4.4.1 Landing subsystem

K.3.4.2 Hydraulic subsystem

K.4.4.2 Hydraulic subsystem

K.3.4.3 Auxiliary power subsystem

K.4.4.3 Auxiliary power subsystem

K.3.4.4 Environmental control subsystem

K.4.4.4 Environmental control subsystem

K.3.4.5 Fuel subsystem

K.4.4.5 Fuel subsystem

K.3.4.6 Aerial refueling subsystem

K.4.4.6 Aerial refueling subsystem

K.3.4.7 Fire and explosion hazard protection subsystem

K.4.4.7 Fire and explosion hazard protection subsystem

K.3.4.8 Electrical power subsystem

K.4.4.8 Electrical power subsystem

K.3.4.9 Mechanical subsystems

K.4.4.9 Mechanical subsystems

K.3.4.10 Cargo, aerial delivery, and special operations

K.4.4.10 Cargo, aerial delivery, and special operations

K.3.4.11 VTOL-STOL Power drive subsystems.

The power drive subsystem shall transmit, on an "as required" basis, the power from the engine(s) to all load absorbers (main rotor(s), tandem rotors, tail rotor, accessories), without destructive and/or undesirable vibrations, at the appropriate torque and speed for all allowed environments, loads, attitudes, and misalignments at all air vehicle ground, flight and emergency operations for which the power drive subsystem is required to function. The power drive subsystem shall provide for disengagement and engagement of the load absorbers from the engines for purposes of autorotation, one engine inoperative (OEI) conditions, and other applicable modes of operation. The power drive subsystem may also be required to perform the separate functions of braking, holding and, if needed, locking the rotor system for the purposes of shut down, initial start up, storage, or other defined phases of operation.

REQUIREMENT RATIONALE (3.4.11)

This requirement defines the critical function of reliably transmitting mechanical power from the main engine to the main propulsor (for example the air vehicle rotors or lift fan). It also establishes the basis from which other functional or performance requirements are derived.

REQUIREMENT GUIDANCE (3.4.11)

The power drive subsystem should be of a robust design capable of operating beyond its maximum rated condition for those instances where excursions may occur such as autorotation, other emergency conditions and defined transients. Excursion capabilities should be defined as:

a. An input torque of at least 20 percent (20%) greater than the input for the subsystem maximum rating.

b. An output shaft speed of at least 20 percent (20%) greater than the maximum operating speed of the power absorber.

The contractor should also define the load limits of the system in terms of torque.

A detailed description of the entire drive subsystem, including all related subordinate systems such as gearboxes, shafting, and torque control; should include the configuration, arrangement, weight, system interfaces, design margins, and ratings. Appropriate schematics should depict bearings, gears, rotor brake, clutches, shafts, couplings, cooling systems, accessories, and APU and engine input drives. The design of the power drive subsystem should be supported by extensive analyses including, but not limited to, structural, dynamic, and thermal and should address maintenance concepts, producibility, reliability, safety, survivability, and corrosion resistance.

Each gearbox of the power drive subsystem and associated components should be rated at the most severe input power condition (torque and speed) for all allowed operating modes (OEI included) exclusive of transient conditions. Transient capability of the power drive subsystem should be defined by the contractor relative to the specific application. The rating should be based on the durability, dynamic response, and structural integrity requirements specified.

REQUIREMENT LESSONS LEARNED (3.4.11)

Sealant. Sealants have been successfully used at parting planes of gearbox housings to prevent intrusion of moisture into faying surfaces, therefore helping to reduce corrosion. Sealants of a low adhesion type with low peel strength to facilitate easy removal during disassembly have been preferred. Sealant should be applied to prime painted surfaces prior to topcoat.

Gear meshes. In the past, under certain circumstances associated with manufacturing or design tolerances, gear meshes with whole number gear ratios (for example non-hunting gear meshes) have caused vibration problems in other subsystems such as the engine. However, new technology manufacturing may keep errors to a level where vibration is not a problem.

K.4.4.11 VTOL-STOL power drive subsystems.

Verification shall be performed incrementally by analysis and a series of bench and system-level tests to insure structural integrity, endurance, performance, and capability to withstand all specified transient excursions, and operational and environmental conditions including emergency conditions and autorotation.

VERIFICATION RATIONALE (4.4.11)

This requirement is needed to verify that the power drive subsystem can continuously and reliably transmit the necessary power to meet air vehicle mission requirements. The extent and timing of the testing is intended to reasonably ensure that the power drive subsystem is ready for each phase of the development program. The requirement is also used to control and identify production parts for official tests prior to flight testing.

VERIFICATION GUIDANCE (4.4.11)

Analysis should consist of a detailed description with associated schematics, drawings, and calculations for the entire power drive subsystem and all related modules and components (gearboxes, shafting, bearings, gears, clutches, accessories, rotor brakes, couplings, and oil cooling systems). The analysis should identify the arrangements, functional relationships, weight, system interfaces, design margins, and associated structural, vibration, and cooling analysis. In addition, the analysis should address maintenance concepts, producibility, safety, survivability, and corrosion resistance.

a. Bench and system-level testing: In the tests described below, the gearbox configuration should reflect the latest changes as documented in the gearbox drawings and should ideally represent the configuration intended for production. The contractor should document all gearbox components being tested for each specific test, including component part and serial number, vendor, and total test time. If a component is replaced during testing, the reason for replacement should be annotated. The gearbox lubrication system should not be augmented or bypassed. Accessory drives should impose maximum loading and overhung moments and should be configured to impose maximum angular misalignment if specified. Additional tests may be required if production configuration tests are not successful.

   What constitutes a “system level” test should be defined. At a minimum, it represents all the components associated with the propulsion system, which includes the entire power train including the engines, power drives, accessories, and a load absorbing system. In many cases, it also includes the rotor system, rotor and engine control, hydraulic and pneumatic systems, starter system, fire detection and extinguishing system, auxiliary power units, electrical system and fuel system. It is quite often represented by a ground test vehicle as in a rotary-wing air vehicle tie down test.

   The gearbox bench test stands should be capable of operating at variable speeds (up to a minimum of 125 percent (125%)) and imposing all power and load (thrust and bending) parameters (up to a minimum of 130 percent (130%) of the maximum load) encountered under any rotor speed and flight condition allowed by the air vehicle flight spectrum (including autorotation). The test stand should provide for monitoring of all gearbox operating parameters. A means of cleaning and flushing debris accumulated due to manufacturing and assembly prior to power rotation should be provided. The bench stand should be able to accommodate all main power train gearboxes and interconnecting shafting and coupling. However, due to space limitations, shortened shafts or abbreviated shafting trains are often used. Normally, a regenerative (back-to-back) torque load system is employed for economy and ease of applying controlled conditions over a range of speed and torque. A separate bench test for the tail take-off shafting and gearboxes is usually used for rotary-wing air vehicle applications.

   Bench and system-level tests that should be conducted are described in the following sub-paragraphs:

   1. Integrity bench test: It is important that an integrity test be conducted on each gearbox design early in the program and before the Production Configuration Verification Bench Test in order to evaluate its capability to operate satisfactorily beyond the rated torque and speed but within its mechanical limits. Over torque and

over speed excursions can be expected to occur as a result of emergency conditions and autorotation. The test should also serve to identify the need for configuration changes. The test should be conducted after completion of the gear tooth bending test and should incorporate the optimized gear pattern developed during pattern development tests (see "Durability" verification in this appendix) and optimized lubrication from the "Oil Management Test" (see "Lubrication" verification in this appendix). A minimum 200-hour test is recommended in a test stand which integrates the gearboxes and shafting in the main power train and with a loading spectrum consisting of the distribution shown in table K-I.

TABLE K-I. Test stand loading spectrum distribution.

INPUT POWER LEVEL	DURATION
120% gearbox rated power	100 hours
100% of gearbox rated power	60 hours

The time at 120 percent (120%) rated power should be predominately above rated torque but should include some time at overspeed condition.

If applicable, the tail takeoff should be tested for a minimum of 60 hours at 120 percent (120%) of tail takeoff rating. Power level for any remaining time is discretionary. When component design changes are made during the test, the test duration should be increased until the new component is tested for the duration and power levels required by the test plan. The testing should verify operation with each lubricant selected. A tear-down inspection, along with resolution of all discrepancies, should be conducted before initiation of further verification testing.

2. Production configuration verification bench test: For each production source, a 200-hour test is recommended for each transmission and gearbox configuration proposed for production. The configuration should be audited prior to test to verify that essential production configurations are incorporated with all design configuration changes. A loading spectrum should be established which reflects mission profile and verifies the latest design changes. An intermediate tear down inspection should be conducted after 60 hours of testing and should occur prior to the 50-hour Preliminary Flight Acceptance Test (PFAT) at the system level as described below. A resolution of all discrepancies should be required before continuation of the bench test and initiation of the 50-hour PFAT. The recommended criteria for successful completion of this test are that the gearbox is operating satisfactorily and tear-down inspections do not reveal failure, impending failure, or undue wear which would compromise safety-of-flight or reliability.

3. System level PFAT: A 50-hour, system-level test should be completed without component replacement before first flight using a missionized test cycle that simulates projected use of the air vehicle. The configuration of the propulsion components such as engines, should be equivalent to the flight test air vehicle

configuration. Tear-down inspection results should be used to establish inspections, limitations, and restrictions for flight release.

4. System level verification test: A 200-hour test should be run without component replacement using the PFAT test cycle. The test hours should accrue at a rate to lead the flight hours of the lead flight test vehicle by at least a 2 to 1 ratio until that high time air vehicle attains 100 flight hours. The intent is to expose the propulsion components to actual powers and loads as part of an integrated air vehicle system before they are encountered in the air vehicle. This serves to reduce the flight test risk. During all phases of testing, degraded modes of operation should be investigated. A complete tear down inspection of all systems should be conducted. The recommended criteria for successful completion of this test are that the gearbox is operating satisfactorily and tear-down inspections do not reveal failure, impending failure, or undue wear which would compromise safety-of-flight or reliability.

5. Long-term reliability maintainability system-level test: This test should commence following completion of the 200 hour system level verification test. The test spectrum should consist of a composite of the mission profile of the air vehicle. The intent of the test is to reveal any possible long-term endurance component problems. A duration of 1,250 hours is recommended using a missionized test cycle.

6. Special or Additional Tests: Testing such as the rotor brake engagement test, clutch tests, environmental tests, or testing of some special feature should be integrated into the bench or system-level test program where practical.

VERIFICATION LESSONS LEARNED (4.4.11)

The Test Plan: Successful tests have contained the following elements that were reflected in the test plan:

a. Oil servicing. The oil system was drained and filled with new oil at the start of the specific transmission system or component test with the specified lubricant. Provisions were also made to document the amounts of lubricants drained. An oil consumption log was maintained during testing that reference oil servicing, test time, seal drain leakage and leakage locations.

b. Oil temperature and pressure. It was recommended to run a portion of the test at conditions of maximum specified oil temperature (measured at the location monitored by cockpit temperature indicator) with the pressure adjusted to minimum steady state value. The remaining test time was recommended at nominal conditions.

c. Test data.

   1. Accuracy of data. All instruments and equipment were calibrated as necessary to assure that the required degree of accuracy was maintained. Typical accuracies are as follow:

      (a.) Rotational speeds: ±0.5 percent (±0.5%) of the value obtained at maximum rating.

      (b.) Shaft torque: ±2.0 percent (±2.0%) of the value obtained at maximum rating.

(c.) Displacement and strain: ±5 percent (±5%) of the value obtained at maximum rating.

(d.) All other data: ±2.0 percent (±2.0 %) of the value obtained at maximum rating.

2. Data acquired. The data to be recorded and maintained was specified by the user. The serial number of the components on test, test condition, and the desired power, torque, and rotational speed was recorded on each log sheet. Gearbox oil consumption was recorded at specified intervals of operation (10 hours was typical). The following test data were recorded at specified intervals (normally less than 30 minutes or once during each test condition, whichever is shorter):

(a.) total test time

(b.) actual time of day

(c.) revolutions per minute of the gearbox input shaft

(d.) ambient air temperature

(e.) oil temperature out of each gearbox or in the sump

(f.) oil temperature into each gearbox

(g.) oil pressure gearbox

(h.) gearcase pressure (frequency of measurements defined in the test plan)

(i.) loads: torques, thrusts, moments.

Notes were placed on the log sheets describing all incidents of the test, such as special lubrication, leaks, vibrations, noise changes, oil filter bypass indications and any other irregular functioning of the component or the test equipment, and the corrective measures taken.

3. Quality evidence inspections. Evidence of the quality of materials, parts, and components was based on physical inspection and process control data. The inspections and process data were sometimes supplemented by physical and chemical tests to determine the extent of conformance to requirements of the contractor's specifications and drawings. They included sampling plans, magnetic particle inspection, fluorescent penetrant inspection of nonmagnetic parts, nital etch, and visual inspection.

4. Calibration: Prior to initiation and after completion of the verification tests, the transmission system components were calibrated to establish, within the instrumentation limits, the efficiency characteristics of the transmission system components.

5. Inspection procedure. The inspection procedure following official tests was defined. Typically the procedure was divided into two phases. The first phase was a "dirty" inspection of all parts immediately after disassembly to inspect for evidence of leakage, oil coking, unusual heat patterns and other abnormal conditions. The "dirty" inspection was conducted before any part cleaning processes were initiated. The second phase consisted of a "clean" inspection following a complete detailed analytical inspection by the contractor. The user inspection team participated in both "dirty" and "clean" inspections and prepared discrepancy reports for action and

disposition by the contractor. Inspection techniques for the analytical inspection have included, but was not limited to: visual, dimensional, magnetic particle, fluorescent, penetrant, X-ray, and ultrasonic. Upon completion of the "clean" inspection, the user was provided all results of nondestructive tests, and recommendations for modification or redesign of deficient parts.

A coating applied to the gear prior to test has aided in the inspection of teeth for pattern definition and identification of surface distress. However, the coating has, in some gear teeth, hindered the inspection for surface distress.

In the past, the gearboxes have been flushed with lubricating oil to clean debris prior to power rotation using externally driven lubrication pumps. An electric motor was used to slowly rotate the drive system during the flushing process.

K.3.4.11.1 Vibration and dynamics.

The power drive subsystem and individual components shall be free of destructive and/or undesirable vibration at all operating speeds and powers, including steady-state, autorotation and transient operation. When the engine, engine accessories, rotor, propeller, or fan system(s), and all power drive subsystem dynamic components are operated as a combined dynamic system, there shall be no dynamic coupling modes that are destructive or limit the air vehicle for all permitted ground and flight modes. Critical speeds shall be at least __(TBS) percent from air vehicle operating speeds, including idle, all flight conditions and autorotation.

REQUIREMENT RATIONALE (3.4.11.1)

Absence of destructive vibration and dynamic response is essential to maintain good structural and mechanical integrity of the power drive subsystem. The intent of this requirement is to obtain a power drive subsystem with acceptable levels of vibration and margin by describing general design considerations for the manufacturer. Rotary-wing air vehicle power drive subsystems have had a history of special vibration problems and the associated stresses can shorten the fatigue life of components or even become destructive. Emphasis on all components operating as a combined system recognizes the fact that one component can induce destructive vibrations in another component through interconnecting shafting. Also, a thorough understanding and definition of the dynamics of the system are needed to insure that the system responds properly (such as without torsional instabilities) to engine power demands.

REQUIREMENT GUIDANCE (3.4.11.1)

TBS: The margin from critical speeds should be in the range of 20 to 30 percent (20 - 30%) above applicable speed. The margin should be both above and below critical speed for supercritical shaft operation.

If supercritical shafting is used during transient operation, damping should be provided to the extent necessary to prevent stress and deflection amplitudes from exceeding design allowables.

Range of vibratory characteristics at the power drive system interfaces should be defined. Vibration limits should be defined.

Close cooperation with the engine control system designer is necessary to insure adequate gain and phase margins to avoid torsional instabilities. In some cases, it may be necessary to limit torsional spring rate within the power drive subsystem.

REQUIREMENT LESSONS LEARNED (3.4.11.1)

In the past, shafts were either balanced in production or provisions were made for balancing as part of the maintenance procedures. Some manufacturers balanced to a level such that maximum imbalance did not exceed 25 lb. force at operating condition.

K.4.4.11.1 Vibration and dynamics.

Vibration requirements shall be verified by analysis and test.

VERIFICATION RATIONALE (4.4.11.1)

Thorough analysis and test are required to verify the desired characteristic of the vibration and dynamic response are met, and to identify and minimize potential vibration and dynamic response problems of the power drive subsystem which includes the external “plumbing” components (tube network), the plumbing “support structure” (clamps and brackets), and interconnecting rotating machinery.

VERIFICATION GUIDANCE (4.4.11.1)

Verification should be through a combination of analyses, static (such as Rap Test of components to confirm modal prediction) and dynamic testing. Analysis should show all critical speeds in relation to operational speeds throughout the range of possible shaft misalignments. The critical speeds of all shafting should be determined by demonstration. Demonstration of critical speeds on supercritical shafts should include measurement of stresses at the critical speed to insure they are within design limits. Data should also be provided to show the absence of dynamic coupling modes that are destructive or limit the use of the air vehicle for all permitted ground and flight modes. Data should also be shown that define all power drive subsystem spring constants, inertia and damping coefficients for use in torsional stability assessments.

The power drive subsystem dynamic analysis should consider engine control system interfaces to avoid torsional instabilities in the power drive subsystem.

Resonance frequencies and mode shapes should be determined for each gear. For the gear resonance test, the dynamic stress levels in each gear should be measured in locations sensitive to all significant vibratory modes. A speed scan from 0 to the speed of maximum overspeed should be performed with:

a. minimum load
b. approximately 50-percent (50%) load
c. maximum load.

This is usually accomplished in conjunction with gear stress survey of "Durability" verification in this appendix.

The externals should use Rap Testing and Shake Rig Testing based on plumbing location which demonstrates High Cycle Fatigue (HCF), and Vibration Dynamic Response capabilities are adequate for full life. These goals can be accomplished for using combination of Rap Testing and Shake Rig Testing. Option is based on plumbing location, and environment. All methods require an assembled engine or representative engine mockup to perform the component test.

VERIFICATION LESSONS LEARNED (4.4.11.1)

(TBD)

K.3.4.11.2 Misalignment.

A maintenance-free means shall be provided to accommodate continuously the maximum permissible misalignment of coupled drive shafts at combinations of torque and speed __(TBS)__.

REQUIREMENT RATIONALE (3.4.11.2)

High reliability of critical coupling mechanisms to accommodate misalignment is essential to avoid catastrophic failure. The intent of this requirement is to improve reliability by insuring the coupling will operate satisfactorily under the worst conditions that might reasonably be expected in service (for example, at maximum torque that could be delivered at worst permissible misalignment). Maintenance-free design is required to avoid the necessity of maintenance before every flight.

REQUIREMENT GUIDANCE (3.4.11.2)

TBS: Combinations of torque and speed should reflect representative operational scenarios.

Replacement of coupling mechanisms should not require realignment of the associated shafting.

Coupling mechanisms should be identified as being subject to the damage tolerant requirements of "Durability" and its subparagraphs in this appendix.

Couplings should be the dry type to avoid the necessity of doing maintenance checks before every flight.

REQUIREMENT LESSONS LEARNED (3.4.11.2)

Coupling designs that have failed to consider the effects of transient misalignment in high speed, high torque applications have resulted in premature failure.

Laminated disk type couplings have been known to be limited in misalignment capability and subject to fretting in high speed applications due to a lack of enough preload (bolt clamp-up force) to provide drive in friction to prevent fretting.

Coupling designs that have failed to consider misalignment induced loading has resulted in accelerated wear of internal engine and gearbox components.

Cracking in some diaphragm type couplings has been detected by a clicking sound upon shaft rotation.

K.4.4.11.2 Misalignment.

Misalignment requirements shall be verified by analysis and component testing.

VERIFICATION RATIONALE (4.4.11.2)

It is essential to perform testing to verify and demonstrate that the coupling meets the desired endurance and damage tolerance performance characteristics.

It is also essential to verify at a system level both the shafting system dynamic response and displacements are within the requirement operational parameters.

VERIFICATION GUIDANCE (4.4.11.2)

Damage and fault tolerance tests on coupling components should be conducted in accordance to the guidance of the verification subparagraphs under "Durability" in this appendix. The test conditions should be based on worst case air vehicle operating conditions as a minimum. The test should demonstrate continued operation from initial failure indication to complete loss of function for a duration of at least three times the normal inspection interval.

Testing should include anti-flail testing of coupling components where applicable. (See JSSG-2001, "Failures".)

See "Durability" in this appendix for coupling endurance testing.

VERIFICATION LESSONS LEARNED (4.4.11.2)

Damage tolerance testing has been recommended in one of the following ways:

a. Test after intentionally damaging the coupling.
b. Continue the endurance test after coupling has experienced a detectable crack.
c. Test after hanger bearing mount isolation system damage.
d. Test after hanger bearing contamination (water, sand, etc.).

K.3.4.11.2.1 Drive shaft supports.

For multiple-segment drive shaft systems such as a single main rotor with tail rotor drive system, tandem rotor aircraft with synchronization shafts or a tilt-rotor with an interconnect drive shaft system, the supporting bearings and their interface to the airframe shall be of a maintenance-free configuration.

REQUIREMENT RATIONALE (3.4.11.2.1)

The bearing and the bearing mount are critical components which are both required to support the segments of a drive shaft in a system.

REQUIREMENT GUIDANCE (3.4.11.2.1)

(TBD)

REQUIREMENT LESSONS LEARNED (3.4.11.2.1)

(TBD)

K.4.4.11.2.1 Drive shaft supports.

The shafting system support components (bearings and mounts) shall be verified by analysis, component, and system level testing.

VERIFICATION RATIONALE (4.4.11.2.1)

The ability of bearings and bearing mounts to support the segments of a drive shaft must be verified.

VERIFICATION GUIDANCE (4.4.11.2.1)

(TBD)

VERIFICATION LESSONS LEARNED (4.4.11.2.1)

(TBD)

K.3.4.11.3 Rotor braking, positioning, and holding.

If required, a means of slowing (braking) to a stop, securing (holding), and indexing the rotors shall be provided:

a. The rotors can be held from rotating in winds up to __(TBS 1)__ knots in any direction at engine power up to and including ground idle upon start up and while the air vehicle is not in use. Engine control interlock safeguards shall be provided to prevent inadvertent actuation of the system.

b. The braking system (consisting of aerodynamic rotor drag and subsequent mechanical braking) shall be able to stop the rotor __(TBS 2)__ times, without requiring the replacement of any part, from 100 percent (100%) speed in not less than __(TBS 3)__ but not more than __(TBS 4)__ seconds after engine shutdown. For emergency shutdown purposes, the braking system shall be capable of stopping the rotor when applied from 100 percent (100%) speed. The brake is permitted to be non-functional after the emergency stop.

REQUIREMENT RATIONALE (3.4.11.3)

The requirement for a rotor system control relates to:

a. Shipboard operations where air vehicle cycling time constraints are driven by mission needs or when quick dispersal and rapid concealment are needed in ground operations.

b. Minimizing hazard to ground or deck personnel when securing the vehicle.

c. Avoiding ground accidents from concentrated air vehicle activity in congested areas.

d. Emergency stopping when fast egress is required.

e. There may be a requirement to stop a rotor system in a specific position with respect to the airframe, engine exhaust, and the point or points of egress/ingress.

REQUIREMENT GUIDANCE (3.4.11.3)

Rotor system control includes the dynamic (slowing to stop), static (securing/holding/locking), and rotor/dynamic system component positioning for aircraft stowage.

Beyond transferring power from the engines to the rotor system, in some instances the drive system is required to effectively restrain the speed of the rotor system or prevent the rotor system from turning at all. Rotor speed reduction and rotation control may be accomplished via:

a. Rotor Braking System.

   The rotor braking system is normally hydraulically powered and either manually or electrically actuated and controlled. The hydraulic power actuates a brake caliper/rotor disc system that is mechanically coupled to the drive/rotor system that when actuated will restrain the rotor system to the desired level.

The Rotor Braking System procedures may include:

1. Rotor Holding.

   The rotors can be held from rotating in high winds in any direction at engine(s) power up to and including ground idle upon start up and/or while the air vehicle is not in use (parked with engines off).

2. Normal Operational Rotor Braking.

   The rotor brake system must be able to repeatedly slow the rotor system to a complete stop in a maximum specified amount of time without significant degradation that would impact mission capability and not exceed the operational design margins of the power drive system.

3. Emergency Operational Rotor Braking.

   The rotor brake system for a manned rotary wing aircraft must be able to stop the rotor system in the required amount of time after engine shutdown to allow emergency egress from the aircraft.

b. Rotor Lock Mechanism.

   The rotor lock mechanism is a passive mechanical lock which locks the rotor system from rotating and must provide a locking device to prevent the rotor(s) from rotating in high winds while the air vehicle is not in use. Refer to I.3.4.9.4.1, Ground wind environment, for more specific information.

c. Rotor Positioning (Indexing) System.

   The rotor positioning system is required to index the rotors to a position required for main rotor blade/tail pylon fold. The system may also be required to index (position) the rotor system to prevent degradation of the blades from engine exhaust heat. After the rotor system has been stopped by the brake system, the positioning system is used to index the rotor system upon demand with all engines off. In this method of operation, a separate motoring system is employed to move the rotor system. Usually, the system is a separate electrical-mechanical system or can be integrated into the rotor brake system to control movement of the rotor system.

   The rotor positioning (indexing) system may be integrated into the rotor brake system. It must provide motion and position of the rotors for correct blade fold and pylon fold in air vehicle storage purposes and correct engine(s) start up. Refer to I.3.4.9.4, Utility actuation systems, for more detailed information.

The rotor system control must contain a control interlock safeguard device to prevent inadvertent actuation of the system. Refer to I.3.4.9.4.2, Positive locking features, for more detailed information.

TBS 1: Insert wind speed and number of startup cycles. Usually 45 knots is specified.

TBS 2: Insert number of stops. The number of stops is dependent on TBS 4.

TBS 3: Lower time limit in seconds should be based on a load or structural analysis to protect power drive subsystem gears and other components from overloads due to sudden stops. The brake is applied at 100 percent (100%) speed for the emergency stop.

TBS 4 is usually dependent on shipboard operational time to cycle air vehicles for landing and stowage. The total stopping time consists of the combined effects of normal rotor speed decay due to aerodynamic drag and subsequent mechanical braking. The number of stops should be about 400 for a time of 40 seconds.

The interlocks used to prevent inadvertent application of the braking system during those conditions of engine operation when the brake should not be applied or held should be specified. Normally the interlock should prevent actuation of the system when the engine is running. However, the user may need to be able to apply the brake when the engine is running at or below ground idle. Also, the brake should not be capable of continued application if the control is forward of the ground idle position. Consideration should be given to prevent slippage of air vehicles under various ground conditions as a result of applying the rotor brake.

REQUIREMENT LESSONS LEARNED (3.4.11.3)

In the past, it was estimated that a reasonable maximum value for TBS 4 for shipboard operations was in the range of 40 to 50 seconds and a practical minimum value for TBS 3 was typically 30 seconds.

In the past, it was determined that the location of the brake with relation to the transmission may cause dynamically unstable conditions.

K.4.4.11.3 Rotor braking, positioning, and holding.

Rotor braking, positioning, and holding shall be verified by analysis and test.

The drive system rotor brake testing and qualification requirements are as follow:

1. Rotor Holding:

a. At engine start-up and in high wind conditions (demonstrate ability to hold rotor system from rotating up to __(TBS 1)__ knots wind in any direction and against engine(s)* at powers up to and including ground idle).

b. Parking (demonstrate ability to hold the rotor system while engines are off for __(TBS 3) period of time) if required.

*The number of engine(s) with which the rotor brake system will have to power against is dependant upon the control logic of the aircraft.

2. Rotor Braking:

The rotor brake system (consisting of aerodynamic rotor drag and subsequent mechanical braking) should be able to perform a spectrum of 400 operational non-emergency braking cycles plus the equivalent of one operational emergency rotor system stopping procedure while not exceeding any design margins within the drive system. The brake is permitted to be non-functional after the emergency stop.

For normal operational non-emergency braking cycles:

a. the spectrum of rotor speeds at which the brake is applied, _(TBS 4)

b. maximum time duration of each braking cycle, _(TBS 2)

c. interval between brake applications, _(TBS 5)

d. whether the brake is applied after engine shut down or dynamically against the torque of the engine(s), _(TBS 2)

For operational emergency rotor braking:

Initial speed of rotor system, and time duration to complete stop the rotor system, _(TBS 6) shall be specified in the air vehicle performance specification and/or by the airframe manufacturer and approved by the using service.

Under normal or emergency rotor brake operations, the system shall not cause fire.

Rotor Lock Mechanism: refer to I.4.4.9.4.1, Ground wind environment, for more detailed information.

Rotor Positioning System: refer to I.3.4.9.4, Utility actuation systems, for more detailed information.

In some instances, the rotor brake system in conjunction with the torque of an engine(s), may be required to re-position the rotor system for non-standard operational requirements. In this case, appropriate testing and analysis are required to prove operational suitability.

Analysis, testing, and qualification shall accompany demonstration to show design margins are not exceeded.

VERIFICATION RATIONALE (4.4.11.3)

Testing verifies that the rotor brake and locking mechanism can stop and hold the rotor as specified without damage to other components and also meet durability requirements. Bench testing is necessary under realistic conditions to identify any potential dynamic problems and to insure durability requirements. The suggested 400 stops is primarily based on the state-of-the-art. Testing also shows the amount of wear to be expected on the brake linings or pads that can be used to assess its impact on readiness.

VERIFICATION GUIDANCE (4.4.11.3)

TBS 1 is the wind speed (typically, 45 knots, but should be specified in the air vehicle specifications).

TBS 2 must be in accordance with the air vehicle specifications.

TBS 3 is usually dependent on shipboard operational time to cycle air vehicles for landing and stowage.

TBS 4 is spectrum of rotor speeds Nr that is chosen is dependant on the diameter of the rotor, as well as the rotor speed decay due to the aerodynamic drag.

TBS 5 is usually dependent of the heat capacity of the rotor disc and caliper pads and must be agreed upon between the using service, the OEM, and NAVAIR to be incorporated into the test plan.

TBS 6 is the initial rotor speed dependant upon the operational configuration of the aircraft rotor brake system and the time duration to stop the rotor system completely, and must be specified in the air vehicle specifications.

Analysis should include heat generation, provisions for isolation from flammable materials or fluids, energy absorption rate, and effects on the dynamic response of the transmission. Verification should be by component, bench, and system-level testing. The ability of the brake to stop the rotor within the specified stop time (at the specified engagement speed) and number of braking cycles from the specified speed, should be demonstrated in both component bench and system level testing. This should be followed by emergency stops which should also be demonstrated from 100 percent (100%) speed. The component bench test should be conducted in a test facility that duplicates the mass moment of inertia of the vehicle dynamic system. Detailed inspection of the rotor brake components should be made prior to and after conducting the tests.

The brake's ability to perform the specified repeated single engine startup cycles at the specified power without failure should be demonstrated in component endurance tests and a limited demonstration at the system level.

The system-level test should demonstrate the ability of the engine interlock safeguard system to prevent actuation during specified periods.

The test series of the normal stops should be considered successfully completed when:

a. The test component is operating satisfactorily at the end of the tests.
b. Recalibrations do not reveal excessive performance deterioration.
c. Tear down inspections do not reveal failure, impending failure, or undue wear which would compromise safety-of-flight.

VERIFICATION LESSONS LEARNED (4.4.11.3)

In the past, testing included wear measurement to confirm estimates of brake pad wear life. Also, the test plan specified the endurance cycle, such as cool down period of the brake.

K.3.4.11.4 Lubrication.

The system shall provide adequate and sufficiently filtered lubricant to all required components including bearings, gears, and splines for lubrication and cooling under all allowed attitudes and under all operational conditions during flight and ground operations. Gearbox breathers shall prevent the loss of lubricating oil and shall minimize the ingestion of debris and moisture into the gearbox.

REQUIREMENT RATIONALE (3.4.11.4)

This requirement is to specify the lubrication system upon which the power drive subsystem performance and reliability are based. The complexity and high load demands of the mechanical system are such that a properly sized and well functioning lubrication system is essential for high reliability. Also the need to provide lubrication during autorotation is essential to avoid any bearing seizures or gear failures that would interfere with the autorotation function. The primary purpose of lubrication is to provide cooling oil to remove heat generated due to friction at gear meshes and bearings and also to provide an oil film to reduce wear between sliding elements. This requirement is also needed to provide guidance to the elements that make up the lubrication system.

REQUIREMENT GUIDANCE (3.4.11.4)

The system used to lubricate the drive subsystem gearboxes and associated accessories should be independent from that used for other components and power plants to:

a. Avoid contamination from other systems.
b. Allow the use of lubricants optimized for gearbox operation.
c. Minimize exposure vulnerable areas. Precaution should be taken to prevent cross contamination of the lubricant, the gearbox, and associated accessories.

The maximum allowable static and dynamic oil loss should be specified to avoid unnecessary maintenance, thereby avoiding inadvertent gearbox damage during leak repairs. Dynamic leaks above the maximum allowable leak rate should result in a pilot caution. Essential functional elements of the lubrication system should include:

a. Gearbox Breathers. Breathers should be located to prevent loss of oil from the gearbox under all operating conditions and gearbox attitudes. Breathers should allow the passage of gearbox air and vapor during heat-up and cool down cycles and during changes in atmospheric pressure. Breathers should also prevent entrance of particulate contamination and water into the gearbox (for example during air vehicle waterwash) that can cause damage to internal components such as bearings and gears. Gearbox breathers should be replaceable without removal of any other gearbox components.
b. Lubricant Filtering. The lubricant filter should be able to remove particles whose size can cause distress to contacting surfaces. The design should incorporate features that preclude the contamination of the lubricant during operation and servicing (see lessons learned). The capacity should be sized to preclude frequent replacement under normal operating conditions. An integral bypass should be provided to bypass the filter element should it become clogged. The filter impending bypass indicator should have a thermal

lockout feature that prevents actuation of the indicator when the oil temperature is low. The bypass level should be set to allow direct visual observation of the indicator before actual bypass under all operating conditions. The filter should be replaceable without removal of any other gearbox component and without draining of all the lubricant. A method (screens are usually used) to protect each individual oil jet or group of oil jets from clogging should be incorporated into the lubrication design.

c. Filling provisions. The contractor should specify the arrangement and location of the filling provision for the gearbox lubrication system to prevent oil contamination and spillage (see lessons learned). Pertinent information as to the type, grade and quantity of lubricant should be indicated on the filler cap or adjacent to it on the gearbox housing.

d. Gearbox oil drain. A means should be provided to drain the oil. Gearbox oil drain should be accessible without removal of any other gearbox components.

e. Lubricant Selection. Lubricants should conform to DOD-PRF-85734 for normal operating conditions and MIL-PRF-7808 Grade 3 for cold weather conditions. Other oils should be used if substantiating data verifies its benefits and logistics impact to the field.

f. Cooling System. Suitable heat exchanger(s) should be provided to maintain the gearbox oil-in temperature below the maximum allowed under all possible operating combinations (gearbox power level, ambient conditions, lubricant flow rates and pressures, gearbox attitudes and air flow rates). An integral temperature and pressure bypass should be provided to bypass the heat exchanger when the oil temperature is too low or the pressure to high. Failure of the heat exchanger blowers should not cause failure of the power drive subsystem or any of its components.

g. Valves and pressure pumps. The pump(s) should provide the required flow rate and pressure without degradation of performance at all attitudes up to and including the air vehicle maximum operating altitude. Loss of one pump should not degrade operation of other pumps in a multi-pump system. No air traps should exist at the pump inlet. The pump should be a line replaceable unit (LRU). The system pressure regulating valve should have provisions for changing system pressure during assembly and overhaul and be properly secured to prevent arbitrary field adjustment. Pressure fluctuations should not damage lubrication system components.

h. Oil level indication. Suitable means should be provided for direct visual observation during servicing, without the use of tools, of the oil quantity of each gearbox lubrication system when installed in the air vehicle at all ground attitudes. The oil level indicator should be directly marked to indicate low oil levels and the oil quantity to be added to reach the specified operating oil level and overfill condition. The oil level indicator should be located to minimize errors due to attitude position of the gearbox. Should the indicator be a sight glass, the lens should be resistant to staining.

i. Oil Leakage. The lubrication system should not leak onto the air vehicle structure. Provisions should be made for collection and routing to overboard drains in those cases where a small amount of oil seepage is possible. Provision should be made to alert the pilot in the event of a rapid oil leak.

REQUIREMENT LESSONS LEARNED (3.4.11.4)

Filtration and Contamination. Successful design features which have been developed or have been recommended to prevent contamination of the gearbox were:

a. The oil filter was located on the pressure side of the pump to prevent contamination of the main gearbox should the pump fail.

b. The bypass was designed such that when it opens, it did not dump accumulated particles into the lubricant system.

c. The filter housing was oriented such that entrapped oil within the filter housing is removed when the filter is removed.

d. Filter elements were non-cleanable, disposable types.

e. The bypass indicator was resettable only when the filter was removed.

f. The minimum size of the filtered particles were usually on the same scale as the film thickness of contacting surface in gears and bearings and were on the order of 3 to 5 microns.

g. Oil jet protection screens having screen openings of a maximum of 1/2 the minimum jet orifice diameter and a total open area of 100 times larger than the total jet area being protected to assure proper jet functioning during cold starts (minimum orifice diameter of 0.040" for single jet and 0.030" for multiple jets recommended).

Filling Provision. The lubrication system filler arrangement was provided with a scupper and drain connection, and was readily accessible when installed in the airframe. The filling port cap was positioned higher than the scupper to prevent intrusion of contaminants with a clogged scupper drain. The filling port had a 16 mesh or finer screen to prevent particles from entering the gearbox during servicing. The strainer was removable and cleanable at the Organizational Level.

Gearboxes that share oil with accessories have had problems in which accessory-produced debris entered and contaminated the gearbox lubrication system.

In the past, external lines and fittings were minimized to reduce the vulnerability of the lubrication system. Also design features which helped were the use of gearboxes that incorporated a wet sump type of oil supply system in which all oil passage connecting points in the same gearbox were located within the gearbox and the oil cooler-heat exchanger was directly mounted to the gearbox.

In the past, splash-lubed (non-pressurized) gearboxes have lost critical amounts of oil during extended flights that resulted in undetectable failures. The continuous-monitoring temperature sensor and chip detector both depended on the gearbox oil (now missing) to be the thermal and debris transporter.

Gearbox breathers were commonly designed to limit gearbox internal gauge pressure to no more than 0.5 pounds per square inch. Desiccant breathers have been incorporated on newer platforms in an attempt to limit internal corrosion of gears and bearings.

Provisions were included to permit convenient removal of small quantities of oil for physical property testing. The location was selected to permit obtaining a true representative sample of the oil in the system.

K.4.4.11.4 Lubrication.

Lubrication requirements shall be verified by analysis and test.

VERIFICATION RATIONALE (4.4.11.4)

The capability of the power drive subsystem to operate within specified temperature limits and efficiencies at all loads using the specified lubrication system can only be verified by analysis and extensive testing. The intent here is to determine if the lubrication system and its cooling provisions are adequate for all operating environments and to know what margins exist, especially under conditions of maximum gross weight in hover on a hot day.

VERIFICATION GUIDANCE (4.4.11.4)

Verification should be by analysis and testing at the element, component, and system levels.

Analysis should include a functional description of the lubrication system indicating the limits of the lubrication system with respect to environments (high and low temperature) and air vehicle flight envelope limits (attitude and altitude) and associated schematics showing all components and indicating minimum flow rates to each oil jet. The design of the cooling system for all transmissions and gearboxes should be substantiated by applicable schematics, analysis and pertinent testing. The cooling system or heat balance analysis should include consideration of the highest ambient air condition specified herein, the minimum gearbox oil flow, the maximum allowable oil temperatures and the minimum cooling airflow as a basis for sizing the cooling system.

a. Filter component tests. To verify performance, the filter assembly should successfully complete a series of functional and integrity tests. These should include:
    1. filter element multi-pass filtration ratio test
    2. maximum particle passed test
    3. filter bypass performance test
    4. impending bypass indicator performance test
    5. cold start and temperature lockout test
    6. filter assembly clean pressure drop test
    7. filter assembly proof pressure test
    8. filter housing burst test
    9. filter element bubble point test
    10. filter element collapse pressure test

11. pressure build-up (dirt capacity).

b. Heat exchanger component test. The following tests should be conducted on a heat exchanger representative of production units to substantiate compliance with requirements:

1. oil pressure drop test
2. decongeal test
3. anti-congealing test
4. static pressure drop test (air side)
5. pressure cycling test (0 to max operating pressure)
6. thermostatic control valve performance test
7. environmental testing (including vibration)
8. thermal capacity.

c. Heat exchanger blower component. Test should include:

1. self-induced vibration test
2. performance tests
3. endurance test (at least 200 hours)
4. Ground-Air-Ground (GAG) cyclic testing (Low Cycle Fatigue (LCF)) should include start/stop cycles for LCF
5. overspeed test
6. Containment test: blade or hub burst

d. Pressure pump. Test should include:

1. performance verification
2. endurance (with and without contamination, 500 hours recommended)
   (a) 200 hours with no contamination
   (b) 150 hours with water contamination
   (c) 150 hours with water/metal contamination
3. 50-hour altitude endurance.

e. Oil management test. This test is to optimize the oil distribution, jet targeting, flow rate, capacity and heat rejection for each gearbox. Tests should be run at all applicable attitude conditions.

System-level tests may be run in conjunction with tests described in "VTOL-STOL power drive subsystem" verification in this appendix, and flight test. The tests should include:

1. measurement and quantity of usable oil
2. measurement of oil tank expansion space if applicable
3. oil tank pressure capability if applicable

4. oil bypass demonstration
5. gearbox vent system
6. calibration of oil tank quantity indication
7. oil cooling in all flight modes; for example, hover, climb, cruise
8. oil pressure fluctuation
9. verification of satisfactory oil distribution within the gearbox.

VERIFICATION LESSONS LEARNED (4.4.11.4)

(TBD)

K.3.4.11.5 Power train condition monitoring.

Condition monitoring shall provide appropriate personnel all necessary information for their action. It shall supply warning of impending failure that could result in mission abort, loss of the air vehicle, or prevent a safe landing. Elements of the power train condition monitor shall include ___(TBS)___ information. If required, some or all of the elements of the power train condition monitor shall be configured for incorporation with other subsystems into any planned integrated diagnostic system.

REQUIREMENT RATIONALE (3.4.11.5)

Special power drive subsystem Condition Monitoring fault detection, isolation, and parametric recording capabilities for maintenance or life tracking actions should be specified to insure operational readiness.

REQUIREMENT GUIDANCE (3.4.11.5)

TBS: Elements of condition monitoring may include:

a. Debris monitoring. Debris monitors capable of detecting oil borne particles for the purpose of identifying an impending failure should be used on all gearboxes and transmissions. The monitors should be capable of isolating faults to each gearbox or module. The monitor should be insensitive to normal wear debris. Monitors should be self-closing, if necessary, to allow removal without draining the gearbox lubricant. See Lessons Learned for important design features.

b. Lubrication system - oil pressure and temperature. The oil operating temperature and pressure for pressurized systems should be provided on a continuous real time basis along with indications of out-of-control limits to cockpit instrumentation. Temperature and oil level for non-pressurized (splash-lubricated) systems should be provided through a monitoring system.

c. Health monitoring. Sensor number and location should be selected to isolate the condition of critical rotating components including drive shafts, heat exchanger blowers and internal gearbox components. Sensor mounting positions should be provided as an integral part of the gearbox and drive shaft system design.

d. Usage monitoring. A system should be provided for accurate in-flight monitoring of the power drive subsystem operational usage (power and time) for life management of specified components.

Removable components should be made readily accessible without necessitating the removal of other components.

REQUIREMENT LESSONS LEARNED (3.4.11.5)

A removable, cleanable screen was usually installed downstream of the monitor to protect the lubrication pump. Experience has shown that for pressurized oil systems, it was important for early failure detection, to locate the monitors:

a. so that all the lubricant passed through it

b. prior to the filter or pump in the oil circuit.

For non-pressurized oil systems consideration was given to locating the monitor to optimize debris collection. A gearbox that had areas where debris particles could collect and not be exposed to the monitor has been known to experience an undetected failure. There is no established correlation between gearbox oil level and vibration that is suitable for oil level monitoring.

K.4.4.11.5 Power train condition monitoring.

Verification of power train condition monitoring shall be by analysis, demonstration, and test.

VERIFICATION RATIONALE (4.4.11.5)

The elements of the condition monitoring need to be analytically and functionally verified to ensure their usefulness as diagnostic and parametric recording and trending tools.

VERIFICATION GUIDANCE (4.4.11.5)

Analysis should include a review of designs, schematics and functional descriptions of the monitoring systems for compliance with requirements.

a. Debris monitor. Debris monitors representative of production units should be tested to substantiate that it can detect debris of the size shape and material defined by the contractor to be characteristic of debris that is considered abnormal and demonstrate insensitivity to normal wear. Also, capture efficiencies should be demonstrated in component-level tests, as necessary.

b. Health monitoring. Data should be recorded during development, verification and acceptance testing to form a characteristic normal baseline for applying diagnostic indicators to isolate mechanical component faults. Data should be recorded in a manner that can be used for incorporation into any planned integrated diagnostic system (see Lessons Learned). The number of sensors, tachometer frequency, recorder specifications, and record length should be selected so as to adequately isolate the characteristics of the dynamic components in each gearbox.

VERIFICATION LESSONS LEARNED (4.4.11.5)

Health monitoring was traditionally done through vibration monitoring. Experience in the development of integrated diagnostic systems has shown that acquired raw broadband data with a usable band width up to at least 20 kHz, (for example, a digitization rate of 80,000 samples per second was needed in order to take full advantage of the latest diagnostic algorithms). A high frequency, phase accurate synchronous tachometer signal (best if on high speed shaft) was recorded with the vibration data for post test processing. Related parameters such as temperature and torque have also been recorded for correlation with flight test data.

K.3.4.11.6 Durability.

All gears shall have infinite life in tooth bending at 100 percent (100%) of rated torque. Surface durability of gears, without scoring, and bearings shall be at least __(TBS 1)__ hours at __(TBS 2)__ power conditions. The life shall be specified at the __(TBS 3)__ level. Driveshaft coupling mechanisms shall have an endurance life, under conditions of maximum permissible misalignment and 110 percent (110%) of rated torque. All other power drive subsystem components shall have a minimum of __(TBS 4)__ hours life.

REQUIREMENT RATIONALE (3.4.11.6)

The special durability requirements of the power drive subsystem must be applied since they are the primary criteria for the structural design of the subsystem components. The requirement, based on experience, is expected to achieve acceptable endurance without imposing an unnecessary weight and volume burden.

REQUIREMENT GUIDANCE (3.4.11.6)

TBS 1 through TBS 3 should be completed with the information in table K-II. Analysis of durability should consider a detailed determination of loads and stresses from all sources including vibration, thermal, transmitted torque, and housing deflections.

a. Gear tooth bending fatigue. Life calculation should be based on American Gear Manufacturer Association (AGMA, www.agma.org) standards. No increase of endurance stress allowables should be taken for gear materials as a result of inducing beneficial residual compressive stresses such as results from shot peening.

b. Surface durability (spalling and pitting) should include all the conditions in table K-II.

TABLE K-II. Surface durability.

COMPONENT	TBS 1	TBS 2	TBS 3
Gears	4500 hours	L1 life level	Mean effective load based on the power spectrum or 70 percent (70%) rated power, whichever is greater
Gears	1500 hours	L1 life level	100 percent (100%) rated power
Bearings	4500 hours	B10 life	Mean effective load based on the power spectrum or 70 percent (70%) rated power, whichever is greater
Bearings	1500 hours	B10 life	100 percent (100%) rated power

The use of Lundberg-Palmgren bearing life models which use life adjustment factors derived from ANSI/ABMA 9:1990; ANSI/ABMA 11:1990; and Society of Tribologists and Lubrication Engineers (STLE) Life Factors for Rolling Bearings, 1992; or other substantiated data should be acceptable. Life of critical rolling element bearings should be derived from a detailed analysis of the internal load distributions using state-of-the-art computer programs.

Other components:

TBS 4: 4500 hours based on fatigue related failures, at any power level and duration allowed by the flight spectrum. Fatigue calculations should be based on minus 3-sigma working curves.

Deflections of the gearbox and transmission housings should not affect the durability of internal components under any combination of input loading and air vehicle operating condition.

REQUIREMENT LESSONS LEARNED (3.4.11.6)

Shot Peening. It was necessary with some vendors to employ a fully-automated, computer-controlled process for shot peening to be effective and not detrimental in improving gear tooth fracture resistance. SAE AMS2430 provides further guidance.

K.4.4.11.6 Durability.

Durability verification shall be by analysis and test.

VERIFICATION RATIONALE (4.4.11.6)

Thorough analysis and testing are necessary to verify durability requirements are met. The incremental tests described, resulting from many years of experience, are expected to provide a high level of assurance that the power drive subsystem will meet the durability goals or will reveal durability problems early enough in the development program for timely corrective action.

VERIFICATION GUIDANCE (4.4.11.6)

a. Analysis: Vibration and stress analyses of all components subjected to potential stress or vibration induced failure should be conducted prior to component testing. The analysis should include prediction of the range of values for steady, cyclic and vibratory stresses, and the design point and life predictions relative to the analysis. Verification by analysis should insure the loading reflects the influence of all environmental and operational factors on the life calculation methods of all fatigue sensitive components especially critical components such as bearings and gears. Bearing analysis methods should be evaluated for accurate predication of internal load distribution among the rolling elements. If bearing life analyses employs an endurance stress limit criterion, data should be presented that clearly establishes the value of the limit stress. All material and operational life factors should be substantiated by pertinent data. Finite element analysis of the main gearbox and transmission housings should be provided. The deflections of the housings under worst-case conditions of input loading and air vehicle flight condition should be determined. The main gearbox housings should be included as part of the transmission mounting system fatigue tests. Housings should be instrumented during bench tests to determine deflections and loads.

b. Gear testing: Prior to endurance testing, gearboxes should undergo gear pattern development tests, and a gear tooth load distribution survey and fatigue test as follows:

1. Gear pattern development tests. The contractor should build-up a gearbox, using the latest configuration parts and assembly procedures, for the purpose of developing the gear tooth contact patterns of all internal gears. The torque level at which the patterns are optimized should be defined and justified by the contractor. The patterns should be acceptable over the range of loading specified in the flight spectrum. There is no duration requirement for this test.

2. Gear load distribution survey. Following successful completion of the gear pattern development test, a gear load distribution survey should be conducted. A gearbox should be built up, using the latest configuration parts and assembly procedures, for the purpose of performing a gear load distribution survey. The primary load gear teeth should be strain-gauged in the gear teeth's roots, gear webs, and gear rims. The gearbox should be operated at input loads of up to at least 120 percent (120%) of Gearbox Power Rating and at speeds up to the maximum speed. Testing should also be conducted to minimum speeds including ground idle. Gear loads should be less than design allowables. The survey should be conducted at normal oil-in operating temperatures.

3. Fatigue. Infinite gear tooth bending fatigue life should be substantiated by bench testing each gearbox to typically 130 percent (130%) rated torque (to account for the 3 sigma factor) at 100 percent (100%) rated speed to accumulate sufficient cycles on the slowest rotating gear to substantiate infinite life. It is usually not economically feasible or timely to run a sufficient number of test samples and test hours to verify the surface durability design life of all bearings and gears. Therefore, verification is dependent on accurate load analysis and well established surface durability fatigue data for the materials selected as well as on bench and system-level tests as described in the "VTOL-STOL power drive subsystem" verification in this appendix.

c. Couplings: Test a minimum of six couplings to substantiate the endurance life.

VERIFICATION LESSONS LEARNED (4.4.11.6)

(TBD)

K.3.4.11.7 Engagement and disengagement of load absorbers.

Means shall be provided to permit engagement and disengagement of the engines from the load absorbers as required for all applicable modes of air vehicle operation. For rotary-wing air vehicles in autorotation mode, the engine(s) not supplying torque shall be immediately and automatically disengaged from the power drive subsystem. For multi-engine air vehicles conducting single engine operations, the engines not supplying torque shall be similarly disengaged to permit continued operation of the rotor system and accessory drive for 2 hours without damage to the clutch/overrunning mechanism.

REQUIREMENT RATIONALE (3.4.11.7)

This requirement for clutching devices is essential to provide for:

a. autorotation of the rotor blades during total power failure without the rotational drag of the failed engines
b. single engine failure in the case of multi-engine configuration
c. disengagement of the lift fan.

REQUIREMENT GUIDANCE (3.4.11.7)

The number of engagements without losing the ability to transmit the required power (torque and speed) should be consistent with all applicable reliability and operational requirements.

REQUIREMENT LESSONS LEARNED (3.4.11.7)

The location of the clutch(es) should allow for the continuation of necessary functions of the transmission system and safe operation of the air vehicle for any combination of clutch engagement and disengagement. Clutch engagements should not damage components of the clutch or other components of the power drive subsystem.

K.4.4.11.7 Engagement and disengagement of load absorbers.

Verification shall be by __(TBS)__.

VERIFICATION RATIONALE (4.4.11.7)

These tests are necessary to verify the operational capability, durability, and reliability of the clutching design. The clutch can be a problem area in terms of excessive wear, failure to engage, and failure to provide the overrunning function.

VERIFICATION GUIDANCE (4.4.11.7)

TBS: The following bench tests should be conducted:

a. Static torque test. During the static torque check, the torsional spring rate (angular deflection of the outer race relative to the inner race) of the clutch should be determined. Static torque should be gradually increased until the occurrence of slip such that further torque increase is not possible. The torque transmitted should be based on the limit of system dynamic loads as determined by test or equal to 200 percent (200%) maximum rated torque.

b. Cyclic fatigue (stroking) test. Stroking tests should be performed to define the clutch's fatigue characteristics.

c. Overrunning test. The overrunning clutch test should be conducted in two parts. The first should be a differential overrunning test at 100 percent (100%) differential speed (the clutch driving member stationary and the driven member at 100 percent (100%) speed). The second overrun test should be to the worst case engagement element pressure velocity (PV). Each test should be conducted for two hours.

d. Cold temperature engagement test. The clutch should be subjected to cold temperature engagement tests, using the lubricants selected under the "Environment" requirement in Part 1 of this specification guide.

e. Clutch durability test. A minimum of 2,400 clutch engagements should be conducted on two of each clutch configuration of the power drive subsystem. In each engagement, the clutch should be loaded to rated torque and speed after engagement. The clutch engagements should include a minimum of 1500 dynamic engagements, for example second engine starts, practice autorotation (for engine clutches), in percentages that estimates usage. A dynamic engagement is defined as a condition where the clutch engages a rotating shaft in a manner that simulates how it will be used in service. The time between engagements should represent the minimum time expected in usage. After completion of the 2400 engagements, the static torque test should be conducted to verify component condition.

VERIFICATION LESSONS LEARNED (4.4.11.7)

(TBD)

K.3.4.11.8 Loss-of-lubricant operation (loss of lubrication).

The gearboxes shall function for at least 30 minutes after complete loss of the lubricant from the primary lubrication system and shall be in a condition such that the gearbox is still capable of transmitting the required power and that no components shall be in a state of imminent failure. The operational conditions shall be such that the loss of lubricant occurs at the most severe power condition and that the air vehicle can transition to cruise and land vertically at the end of the 30-minute period. Also, the power drive subsystem shall be capable of safe operation in the overrunning mode for at least 30 minutes with complete loss of gearbox lubricant. The running mechanism shall be permitted to be non-repairable after 30 minutes of loss-of-lubricant operation.

REQUIREMENT RATIONALE (3.4.11.8)

The requirement is necessary to provide the capability to egress the hostile area in the event the lubricant or oil pressure is lost. Oil lines are particularly vulnerable to damage because of the extensive lubrication system connecting various components (pumps, heat exchangers, filters). The 30 minutes of operation is considered within the state-of-the-art without imposing an undue weight and volume burden on the system.

REQUIREMENT GUIDANCE (3.4.11.8)

Any resulting attitude limitations during loss of lubricant operation should be defined if an alternative or additional, or back-up or secondary lubrication system be used to meet this requirement.

REQUIREMENT LESSONS LEARNED (3.4.11.8)

(TBD)

K.4.4.11.8 Loss-of-lubricant operation (loss of lubrication).

Verification shall be by bench testing a gearbox and/or alternative/auxiliary lubrication system and transmission in its production configuration.

VERIFICATION RATIONALE (4.4.11.8)

Testing is needed to verify this requirement.

VERIFICATION GUIDANCE (4.4.11.8)

Two thirty minute tests should be conducted. A teardown inspection should be conducted following each thirty minute test. Testing should be conducted after completion of the system level verification test described in the "VTOL-STOL power drive subsystem" in this appendix. Test article dimensions and clearances should be recorded prior to test and should be representative of a production configuration. Transmission and gearbox lubrication systems should be starved at the system's supply side (downstream from the pump) and continue to scavenge. Operation should be demonstrated for a 30-minute period, typically, as follows:

a. Two minutes at rated power to simulate hover.

b. Twenty six minutes at a power condition to simulate cruise.

c. Two minutes at a power condition simulating vertical landing.

Creditable run time should start at the point at which the cockpit low oil pressure warning would be displayed. For non-pressurized gearboxes, creditable run time should start when the oil being drained from the gearboxes ceases to flow in a steady stream. The transmission should be configured in an air vehicle attitude simulating the cruise power condition. For a VTOL air vehicle, the test spectrum and attitudes should be commensurate with expected field use. Inspection of components should not indicate a condition of impending failure. However, the components need not be in a condition suitable for further service.

A thirty minute loss-of-lubrication overrunning test consistent with the loss-of-lubricant test spectrum above should be conducted. The residual lubricant trapped in the clutch need not be separately drained for this test.

VERIFICATION LESSONS LEARNED (4.4.11.8)

An oil starvation test is not equal to a loss of lubricant test. Oil starvation testing requires starving a specific component(s) while the rest of the primary lubrication system continues to operate without any loss of lubricant in the system. An oil starvation test can potentially be impacted by splashing lubricant or oil mist inside the gearbox housing which can reach the starved component, and is therefore not equal to a loss-of-lubrication test.

K.3.4.11.9 Rotor meshing.

For intermeshing-rotor systems, phased externally, means shall be provided in the power drive subsystem to prevent operation with rotors which are not properly phased for safe operation. Means shall be included for cockpit indication that the rotors are locked in phase.

REQUIREMENT RATIONALE (3.4.11.9)

The purpose of this requirement is to prevent the blades of one rotor from contacting the blades of the other rotor, thereby preventing catastrophic failure. Such contact can occur on systems having intermeshing or overlapping blades unless the rotors are locked in phase.

REQUIREMENT GUIDANCE (3.4.11.9)

Rotor phasing devices should be provided with positive mechanical and/or electrical interlocks to prevent engine starting unless they are locked in phase. The proper definition of applicable maintenance actions is required to insure the aircraft configuration will be safe following drive system maintenance.

REQUIREMENT LESSONS LEARNED (3.4.11.9)

(TBD)

K.4.4.11.9 Rotor meshing.

Verification shall be by analysis and demonstration.

VERIFICATION RATIONALE (4.4.11.9)

Analysis and demonstration are required to verify functionality.

VERIFICATION GUIDANCE (4.4.11.9)

Analysis and demonstration should be accomplished during system-level verification in "VTOL-STOL power drive subsystem" in this appendix.

VERIFICATION LESSONS LEARNED (4.4.11.9)

(TBD)

K.3.4.11.10 Accessory drives.

Cover plates shall be provided for use when accessories are not installed. Failure or seizure of any individual accessory shall not cause damage to any power drive subsystem components. For rotary-wing air vehicles, accessories shall be driven whenever the rotor system is rotating, including during autorotation, and when the rotor system is not rotating if required to support ground operations.

REQUIREMENT RATIONALE (3.4.11.10)

The main purpose of this paragraph is to provide essential design requirements for the accessory pads and drives. It is essential that certain accessories continue to operate during autorotation; these include main generators, lubrication oil pumps that supply the main gearbox, oil cooler fans, tachometer generators that provide a rotor rotations per minute (rpm) indication to the pilot, and hydraulic pump drive for the rotor controls.

REQUIREMENT GUIDANCE (3.4.11.10)

Accessory drive splines should be protected from wear with non-metallic inserts or should be positively lubricated with oil when functioning.

REQUIREMENT LESSONS LEARNED (3.4.11.10)

Refer to MS3325, MS3326, MS3327, MS3328, MS3329, and MS3336 for accessory drive pad standards. Refer to MS9948, MS9949, and MS9950 for cover plate standards.

K.4.4.11.10 Accessory drives.

Verification of accessory drives shall be by inspection and testing.

VERIFICATION RATIONALE (4.4.11.10)

Testing and inspection are needed to verify the functionality during normal and autorotation operation. Verification should be incorporated in system-level testing to minimize impact on development schedule.

VERIFICATION GUIDANCE (4.4.11.10)

Testing and inspection should be accomplished during system-level verification of "VTOL-STOL power drive subsystem" verification in this appendix.

VERIFICATION LESSONS LEARNED (4.4.11.10)

(TBD)

K.5 PACKAGING

K.5.1 Packaging.

For acquisition purposes, the packaging requirements shall be as specified in the contract or order (see 6.2). When packaging of materiel is to be performed by DoD or in-house contractor personnel, these personnel need to contact the responsible packaging activity to ascertain packaging requirements. Packaging requirements are maintained by the Inventory Control Point's packaging activities within the Military Service or Defense Agency, or within the military service's system commands. Packaging data retrieval is available from the managing Military Department's or Defense Agency's automated packaging files, CD-ROM products, or by contacting the responsible packaging activity.

K.6 NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

K.6.1 Intended use.

The VTOL/STOL power drive subsystem descriptions in this appendix are intended for use in air vehicle systems developed to perform combat and combat-support missions in environments unique to military weapon systems.

K.6.2 Acquisition requirements.

Acquisition documents should specify the following:

a. Title, number, and date of the specification.

K.6.3 Acronyms.

The following list contains the acronyms/abbreviations contained within this appendix.

AGMA	American Gear Manufacturer Association
GAG	Ground-Air-Ground
LCF	Low Cycle Fatigue
LRU	Line Replaceable Unit
OEI	One Engine Inoperative
PFAT	Preliminary Flight Acceptance Test
PV	Pressure Velocity
rpm	Rotations Per Minute
STLE	Society of Tribologists and Lubrication Engineers
STOL	Short Takeoff and Landing

VTOL	Vertical Takeoff and Landing

K.6.4 Subject term (key word) listing.

Accessory drive

Bearings

Dephased

Gearbox

Gears

Load absorber

Lubricant

Phased

Power train

Rotors

Vibration

K.6.5 Responsible engineering office.

The office responsible for the development and technical maintenance of this appendix is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL. Requests for additional information or assistance on this appendix can be obtained from AFLCMC/ENRS, BLDG 28 RM 118, 2145 MONAHAN WAY, WPAFB OH 45433-7017 USA; DSN 674-5476; COMMERCIAL (937) 904-5476; ENGINEERING.STANDARDS@US.AF.MIL.

K.6.6 Amendment notations.

The margins of this specification are marked with vertical lines to indicate modifications generated by this amendment. This was done as a convenience only and the Government assumes no liability whatsoever for any inaccuracies in these notations. Bidders and contractors are cautioned to evaluate the requirements of this document based on the entire content irrespective of the marginal notations.

APPENDIX L

AIR VEHICLE PROPELLER SUBSYSTEM

REQUIREMENTS AND GUIDANCE

L.1 SCOPE

L.1.1 Scope.

This appendix provides the requirements, verifications, tailoring guidance, and background information for the Propeller Subsystem provided for in Part 1 of this specification. The appendix has been developed and coordinated by technical personnel from the Air Force, Navy, and Army and has been approved as an official guide for use by Government personnel for assistance in tailoring the air vehicle subsystems specification for acquisition and model specifications. This appendix is a mandatory part of the specification. The information contained herein is intended for compliance.

L.1.2 Structure.

The appendix structure replicates the structure of the Air Vehicle Subsystems Specification except it places each corresponding section 3 requirement and section 4 verification together.

L.1.3 Appendix.

This appendix provides tailoring guidance and background information for individual paragraphs of the Air Vehicle Subsystems Specification. Guidance gives recommendations on how to tailor the specification paragraph. Where __(TBS)__ appears, the guidance paragraph provides recommended values or text that the Using Service may use to insert in the __(TBS)__. When contractors are expected to complete the _(TBS)__, the Guidance paragraph will so state. The Using Service makes the final decision on whom completes the __(TBS)__ in the specification. Finally, Lessons Learned are provided to give insight to past events that could impact the tailoring of the specification.

L.1.4 Deviations.

Projected designs for given applications which will result in improvement of the system performance, reduced life cycle cost, or reduced developmental cost through deviations from this guidance, or where requirements of the specification results in compromise in operational capability, should be brought to the attention of the Using Service.

L.1.5 Environmental impact.

Air Vehicle Subsystems will be designed such that their operation, maintenance, and repair may be accomplished without violating the most stringent environmental regulations applicable to locations where subsystems are used or supported. Compliance with environmental regulations will not prevent subsystems from achieving and sustaining mission performance capability. Materials, processes, and environmental control equipment necessary to meet these environmental requirements must currently be available in the Using Service's maintenance and supply system. The design will not use environmentally unsuitable materials such as ozone depleting fluorocarbons, chlorofluorocarbons, and halons, or highly volatile organic compounds in solvents and coatings during development, production, operation, maintenance, or repair. The Environmental Protection Agency maintains an online list of toxic chemicals and hazardous substances on its Ozone Layer Depletion Website at http://www.epa.gov/ozone/snap/ that should be consulted. The Significant New Alternatives Policy (SNAP) Program available thereon identifies substitutes for ozone depleting chemicals.

The contractor will conduct an environmental analysis of air vehicle subsystems.

L.1.6 Responsible engineering office.

The responsible engineering office (REO) for this appendix is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL.

L.2 APPLICABLE DOCUMENTS

L.2.1 General.

The documents listed in this section are specified in sections 3 and 4 of this handbook. This section does not include documents cited in other sections of this guide specification or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3 and 4 of this handbook, whether or not they are listed.

L.2.2 Government documents

L.2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this appendix to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

DEPARTMENT OF DEFENSE SPECIFICATIONS

JSSG-2007	Engines Joint Service Specification Guide

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-704 Aircraft Electric Power Characteristics

(Copies of these documents are available online at http://quicksearch.dla.mil or from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia PA 19111-5094 USA.)

L.2.3 Order of precedence.

Unless otherwise noted herein or in the contract, in the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

L.2.4 Streamlining.

The Air Vehicle Subsystems Specification has been streamlined. The documents listed in this appendix which are required for acquisition have the same status as those referenced directly in section 2 (first tier). All other documents referenced through tiering may be used for guidance and information only.

L.3 REQUIREMENTS

L.4 VERIFICATIONS

L.3.1 Definition

L.4.1 Definition

L.3.2 Characteristics

L.4.2 Characteristics

L.3.3 Design and construction

L.4.3 Design and construction

L.3.4 Subsystem characteristics

L.4.4 Subsystem characteristics

L.3.4.1 Landing subsystem

L.4.4.1 Landing subsystem

L.3.4.2 Hydraulic subsystem

L.4.4.2 Hydraulic subsystem

L.3.4.3 Auxiliary power subsystem

L.4.4.3 Auxiliary power subsystem

L.3.4.4 Environmental control subsystem

L.4.4.4 Environmental control subsystem

L.3.4.5 Fuel subsystem

L.4.4.5 Fuel subsystem

L.3.4.6 Aerial refueling subsystem

L.4.4.6 Aerial refueling subsystem

L.3.4.7 Fire and explosion hazard protection subsystem

L.4.4.7 Fire and explosion hazard protection subsystem

L.3.4.8 Electrical power subsystem

L.4.4.8 Electrical power subsystem

L.3.4.9 Mechanical subsystems

L.4.4.9 Mechanical subsystems

L.3.4.10 Cargo, aerial delivery, and special operations

L.4.4.10 Cargo, aerial delivery, and special operations

L.3.4.11 VTOL-STOL power drive subsystem

L.4.4.11 VTOL-STOL power drive subsystem

L.3.4.12 Propeller subsystem.

The propeller subsystem shall be capable of operating without excessive vibration while accepting power from a shaft power engine and providing thrust to the air vehicle as demanded by the controlling input in all modes of flight and ground operation for all allowed environments and within its operating envelope and operating limits. It shall maintain control of power and thrust in a manner to assure continuous operational compatibility between the propeller and engine.

REQUIREMENT RATIONALE (3.4.12)

The function of the propeller subsystem is to convert the power delivered by a shaft power engine to a propulsive thrust for the air vehicle as required in all modes of flight or ground operation while assuring compatibility with engine operation and minimization of mechanical and aerodynamically generated vibrations. The propeller must be able to deliver the appropriate thrust as determined by pilot input to its control, and the engine operating status (such as torque, rotational speed, and proximity of engine limits) and air vehicle operating status (such as the position in the air vehicle flight envelope or taxi and landing regime).

REQUIREMENT GUIDANCE (3.4.12)

The propeller should provide for a ground idle mode sufficient for control of taxiing on the ground and a flight idle mode for control of thrust and drag during idle descent.

For propeller control systems with a mechanical interface, the torque required to operate the control input lever or any additional levers necessary to control the propeller through their range of travel should be no greater than 25 in.-lbs. throughout all flight loads and conditions. Movement of the control input lever(s) throughout the operating range should be free of abrupt changes in actuating torque. The torque variation with travel should be no greater than 10 in.-lbs.

All propeller steady-state and transient operating limits (maximum, minimum) and polar moment of inertial and steady-state governing speed should be specified. The specified limits should be predicated on the most critical tolerances and operating limits of the propeller and engine. The propeller system should operate satisfactorily in all thrust modes up to these limits.

The propeller should be free from flutter in both forward and reverse thrust modes under conditions up to 120 percent (120%) of maximum rated engine speed and at powers up to the standard day maximum take-off power rating of the engine.

Any limitation of the propeller system caused by loss of hydraulic power should be specified.

Any limitation of the propeller system caused by loss of electrical power should be specified.

When power is required from the air vehicle electrical system, the following should apply:

a. The electrical power requirements of the propeller system such as voltage, current, phase, and frequency should be specified.

b. Propeller system electrical equipment should operate satisfactorily under the applicable long term and transient voltage variations set forth in MIL-STD-704.

The design of propeller blades should take into consideration the fact that blades must not deflect to such a degree as to contact any parts of the airframe or engine during all phases of propeller operation.

The blade cuff should be described. The attaching means should be such that injury will not result to the blade from chafing and maximum corrosion protection will be afforded.

The dry weight of the complete propeller subsystem should be specified. The weights of propeller components which are not mounted on the propeller should be listed and included in the dry weight of the propeller. The location where the propeller center of gravity (c.g.) occurs should be specified.

The estimated weight of residual fluids remaining in the propeller after operation and drainage, while the propeller is in its normal attitude should be specified. The location where the propeller c.g. occurs with the specified residual fluid conditions should be specified.

The total mass of fluids in an operating propeller should be specified. The location where the c.g. occurs with the specified operating fluids conditions should be specified.

A propeller should incorporate an ice control system if the propeller operating envelope requires it. (See Lessons Learned for design information.)

REQUIREMENT LESSONS LEARNED (3.4.12)

a. External mechanical power. When external mechanical drives for mounting and driving propeller components have been utilized, they have been specified in the model specification.

b. Structural design considerations. Table L-I presents load factors which have been specified for propulsion system components in the past.

TABLE L-I. Propulsion system load factors.

LOAD TYPES	LIMIT	ULTIMATE
Externally-applied loads	1.0	1.5
Thermal loads	1.0	1.5
Thrust loads	1.0	1.0
Internal pressures	1.5	2.0
Air vehicle flow field loads	1.0	1.5
Crash loads	N/A	1.0

NOTES:

For all castings, a safety factor of 1.33 should be applied to the limit and ultimate load factors specified above, unless the castings have been fully characterized.

Factors of safety should be applied to design usage induced loads to establish limit and ultimate conditions.

c. Blade index marking. A mark has been needed in the past to provide an indication of reference station to determine blade pitch in order to index the blades to the control and to each other. This mark has historically been specified as a stripe of yellow enamel, $^{1}/_{8}$-in. by 2 in., which conformed to TT-E-527, color No. 33538 of Federal Standard No. 595, applied on the thrust face of each blade. The stripe is along the chord of the referenced station used for blade indexing. The stripe is centered on the referenced chord within $\pm^{1}/_{16}$ in. longitudinally and within $\pm^{1}/_{2}$ in. laterally.

L.4.4.12 Propeller subsystem.

The propeller subsystem requirements shall be verified incrementally by analysis and a series of component and propeller tests to insure propeller and engine compatibility, controllability, structural integrity, endurance, performance, aerodynamic and mechanical limits, and capability to withstand transient excursions and emergency conditions.

VERIFICATION RATIONALE (4.4.12)

The design and operating characteristics should be known before completion of full-scale development to ensure performance and functional requirements of the weapons system are met.

VERIFICATION GUIDANCE (4.4.12)

Analysis should consist of detailed descriptions with associated schematics and drawings of the entire propeller subsystem and all related modules and components to include but not limited to, blades, barrel, control system, pitch change system, and anti-icing system. The analysis should also identify the propeller subsystem's arrangement, functional relationships, weight, engine interfaces, design margins, and growth potential, and associated structural, vibration, and cooling analyses. In addition, the analysis should address maintenance concepts, producibility, safety, survivability, and corrosion resistance.

Propeller subsystem testing consists of the following four major types of tests:

a. Component testing wherein many cycles of operation, high loads, or wide excursions are required which are not achievable in a propeller system test

b. Whirl tests wherein a calibrated, instrumented, variable-speed rig is used to drive the propeller throughout and beyond its range of normal operation

c. Propeller and engine test stand tests wherein the propeller is operated on a test stand with its intended operational engine

d. Air vehicle tests wherein the propeller is tested on the ground and in flight with its intended operational air vehicle

e. Component tests

    1. Conditions. Test apparatuses necessary for conducting the tests, method and procedures of tests, and data obtained during the tests should be determined by the contractor and approved by the procuring activity.

    2. Structural. The blades and barrel should be subjected to fatigue tests to assure their durability under all service applied loads. The components subject to test, the methods and procedure of test, and data to be obtained during the test should be specified.

    3. Durability. Prior to installation of the propeller on the prototype or first production air vehicle, the components of the propeller designed to perform certain functions should be subjected to applicable tests. This is recommended in order to establish the capability of the components to perform their respective functions for at least a

recommended period of 1,500 hours between overhaul, removal, or service interruption. The tests should be of a "cycle" type for the specified time duration or number of cycles and should be conducted on those control or emergency system components which are not limited to the following. Where possible, a Reliability Growth Testing methodology should be employed to determine the actual number of test hours and components to be tested to achieve the recommended hours between overhaul, removal, or service interruption.

(a.) Control unit. (such as a complete, unitary-housed control assembly which provides general control and pitch change power) Test duration should be for a minimum of 500 hours.

(b.) Pitch change mechanism. Test duration should be for a minimum of 500 hours.

(c.) Low pitch stop. Exposure should be of the maximum magnitude which the component will encounter in service. Test duration should be for a minimum of 100 cycles.

(d.) Mechanical pitch lock. Exposure should be at various rates of actuation. Test duration should be for a minimum of 1,500 cycles.

(e.) Feathering and unfeathering. Exposure should be under various conditions of speed and power. Test duration should be for a minimum of 500 cycles of which no less than 100 cycles should be accomplished at maximum conditions of propeller operation.

(f.) Negative torque signal. Exposure should be under those conditions normally expected to be encountered in service. The test should be for a minimum of 1,000 cycles.

(g.) Ice control system. The propeller electrical ice control system components, including brushes and rings, should be subjected to a 500-hour durability test at the temperature-altitude conditions specified in the model specification.

4. Teardown inspection. After completion of the tests, the propeller components which underwent test should be completely disassembled for examination of all parts and measured as necessary to disclose excessively worn, distorted, or weakened parts. These measurements should be compared to measurements taken before assembly and the contractor’s drawing dimensions and tolerances. Records should be made of failures, wear, and other unusual conditions.

f. Whirl Stand Tests.

Adequate whirl flutter modeling and analysis should be performed by the propeller/blade manufacturer to demonstrate stable operation of the propeller under all operating conditions within the given flight operating envelope of the air vehicle on which the propeller system is to be used. Modeling and analysis should be performed prior to any whirl rig testing. The flight envelope must be defined along with mission profiles which define each phase of each mission profile; i.e., climb, cruise, descent, braking maneuvers, etc.

Whirl stand tests should be performed at a time in the program which will permit analysis of all test data prior to first flight. The whirl stand tests of the propeller should be conducted on a test apparatus capable of developing horsepower and variations of rotations per minute (rpm) without forward velocity, in excess of that specified in the propeller specification.

The same test propeller should be used for all the whirl stand tests and should consist of specification aerodynamic configuration blades assembled in the hub and properly restrained to assure a fixed setting for test under the following testing. When whirl rig testing does not allow for use of full-size blades, blade simulator stub arms may be used provided they accurately reproduce centrifugal loads, bending moments, and propeller polar moment of inertia, and adequate whirl flutter analysis has been performed.

1. Pre-test disassembly inspection. The propeller submitted for test should be completely disassembled to allow a detailed inspection of all vital working parts. Exception to the disassembly inspection are those components which are permanently joined together. Individual parts or components should be examined for evidence of suitable quality of materials based on physical inspections and process control data, and may be supplemented by physical and chemical tests to determine the extent of conformance to contractor's specifications and drawings. The condition of the individual parts or components should be approved by the procuring activity. After instrumentation, the propeller should be reassembled for test.

2. Vibratory stress survey. A vibration stress survey should be conducted on the whirl stand to determine the stress characteristics of the hub and blade and the flutter characteristics of the blade. The data obtained in this survey should be used in determining the test operational limitations for subsequent testing of the propeller on the whirl rig. Blade angle settings for the test should be selected so that, if flutter is present, a flutter boundary can be determined for the propeller. This vibratory stress survey could be conducted simultaneously with the calibration test.

3. Calibration test. The propeller calibration procedure should establish the sea level static performance characteristics of the complete propeller. The propeller should be calibrated at various rotational speeds up to 120 percent (120%) of the maximum rated speed of the propeller, in increments of not more than 5° settings of the blade angle over the range specified for the test program. Data should be recorded at each blade angle at appropriate increments of rpm. The increments of rpm at which data are recorded should be reduced to obtain more detailed information in the suspected high stress conditions. The blade angle absorbing minimum power should be determined and recorded. Blade deflection data should be recorded during calibration runs. Curves should be drawn showing corrected power and thrust at various speeds for each blade angle from data obtained during the test. The estimated blocking factor attributed to the test rig should be noted on the curves.

4. Endurance run. A 20-hour endurance run should be conducted on the propeller including spinner, cuffs, and ice control equipment. During the run the blade angle should be set at that angle at which the propeller absorbs maximum continuous rated actual static sea level horsepower at maximum continuous rated rpm. The propeller should be run at an rpm at which the propeller absorbs 150 percent (150%) of the maximum propeller rated horsepower.

5. Overspeed run. A one-hour overspeed run should be conducted on the propeller including spinner, cuffs and ice control equipment. During the run, the blade angle should be set at that angle at which the propeller absorbs at least maximum continuous rated actual static sea level horsepower at 120 percent (120%) of the maximum rated propeller rpm. The propeller test should be run at 120 percent (120%) of the maximum rated speed.

6. Teardown inspection. After completion of the above whirl stand tests the propeller and components should be completely disassembled for examination of all parts and measured as necessary to disclose excessively worn, distorted, or weakened parts. These measurements should be compared to measurements taken before assembly and the contractor's drawing dimensions and tolerances. Photographic records should be made of failures, wear, and other unusual conditions.

7. Overspeed feather test. The propeller should be reassembled with counterweights and control assemblies necessary for conduct of the overspeed feather test. The propeller should be subjected to an overspeed feather test consisting of 25 cycles of operation of the control mechanism as follows:

   (a.) Feathering action should be initiated from the low pitch stop blade angle at 141 percent (141%) of maximum rated rpm.

   (b.) The rpm should be reduced at a linear rate from 141 percent (141%) at the low pitch stop blade angle to 120 percent (120%) at a 45° blade angle.

   (c.) After 45°, rpm can be reduced to prevent exceeding the test facility torque and power limitations.

   The propeller should demonstrate that feathering can be accomplished at the conditions descibed, above, to overcome the encountered maximum centrifugal twisting moment in normal and emergency operation.

g. Propeller and engine test stand tests.

Two propeller and engine test stand tests should be conducted. A 50-hour test should be conducted at a time which will permit analysis of all test data prior to first flight. A 150-hour test should be conducted at a program timing which will permit analysis of all data prior to commencement of initial production.

1. 50-hour test. The test should be conducted on a test stand equipped with the engine model specified for use with the propeller. The stand should include provisions to mount the engine and accurately control engine temperatures, pressures, speed, and fuel rates so that the desired power conditions may be maintained during propeller testing. The same test propeller should be used for the entire 50-hour test.

   (a.) Calibrations, checks, and adjustments. Engine and propeller performances should independently meet the requirements specified in their respective model specifications prior to the 50-hour engine test.

   (b.) Installation static functional check. The propeller and engine test installation should be checked in the static condition to determine the functional characteristics of the control linkages, voltages, continuity of control circuitry and typical preflight checks. The relationship between all lever positions and signal levels and the propeller blade angle should be established for the complete range of lever and signal excursions for increasing and decreasing power conditions. Any adjustments required should be made using only external means to obtain the limits required.

(c.) Vibratory stress survey. A vibration stress survey of the propeller covering all appropriate conditions of engine operation should be conducted on the test stand to determine the stress characteristics of the propeller when operated in the stand environment.

(d.) Instrumentation. The instrumentation and techniques used for the required vibratory stress survey of the 50-hour engine test should be the same as that specified for the whirl stand vibratory stress survey.

(e.) Control response test. The control response test should be conducted concurrently with the vibratory stress survey and should include the response of the engine-propeller to power and speed changes throughout the range of operation of the engine under normal ground and simulated flight conditions of the air vehicle.

(f.) Steady-state check. The steady-state check procedure should establish that the static sea level performance characteristics of the complete engine-propeller combination satisfactorily meets the required values of the contractors' model specifications. External adjustments should be made to obtain the required operational performance. Further propeller adjustments should not be permitted without appropriate approval. After all adjustments have been made, a calibration procedure should be conducted to obtain steady-state data for a series of power lever settings. The appropriate power settings are as follow:

(1.) Full reverse

(2.) Ground idle

(3.) Flight idle

(4.) 60 percent (60%) maximum continuous power

(5.) 80 percent (80%) maximum continuous power

(6.) Maximum continuous power

(7.) Intermediate power

(8.) Maximum power (if applicable).

The steady-state operation at each of the various power lever settings specified, above, should be recorded by automatic equipment.

(g.) Transient check. After completion of the steady-state check, the engine-propeller control system should undergo a transient check to determine the stability of the control system, rate of pitch change, and response of the engine-propeller combination. The procedure during the transient check should be conducted in the order given unless otherwise approved by the procuring activity. For all power lever and input mechanism movements, if applicable, the lever should be advanced or retarded in 1 second or less.

Transient checks should be conducted in accordance with the schedule shown in table L-II, and automatic equipment recordings should be made at each transient throughout the specified power lever movement.

TABLE L-II. Transient schedule.

NORMAL TRANSIENTS	I.A.S. (KNOTS)[1]	ALTITUDE[1]
Flight idle to 60% Max continuous to flight idle Flight idle to 80% Max continuous to flight idle Flight idle to 100% Max continuous to flight idle Flight idle to Maximum to flight idle	0, 150, 250, 350, and normal operating speed	Sea level to Max in 10,000-ft increments
Flight idle to Maximum to ground idle Flight idle to Maximum to max reverse	0 and Max landing speed	Sea level
Flight idle to Maximum reverse Ground idle to flight idle	0	Sea level
Maximum to 60% Max continuous to Maximum Maximum to 80% Max continuous to Maximum	0, 150, 250, 350 V_{NO}	Sea level to Max in 10,000-ft. increments
Maximum to ground idle to Maximum Maximum to Max reverse to Maximum	0 and Max landing speed	Sea level
SPECIAL TRANSIENTS Flight idle to 60% Max continuous to flight idle Flight idle to 80% Max continuous to flight idle Ground idle to flight idle to Maximum to ground idle[2] Ground idle to flight idle to Maximum to Max reverse[2] Flight idle to Max reverse to Maximum		

[1] Applicable only when transients are conducted as part of flight tests.

[2] A maximum of 5 seconds should be expended in going from ground idle through flight idle to intermediate; holding full take-off power for 3 seconds before moving to next power setting.

NOTES: Power lever movement is 1 second or less for all transients. Sufficient time should be allowed at each new power setting for stabilization of all normal transients. A pause of 3 seconds is permitted at the middle power setting for the special transients before moving to the final power setting.

If the engine installation incorporates bleed, all the transients should be repeated with maximum bleed.

Power transients should be checked with "dry" and "wet" if the engine has a wet rating.

Intermediate power should be substituted for maximum power if the engine has no maximum rating.

(h.) Miscellaneous checks. Miscellaneous system operation checks, as applicable, should be conducted on the propeller. The propeller should be subjected to operating loads simulating as nearly as practicable those encountered during emergency operations. Sufficient instrumentation should be provided to indicate the performance of each applicable component and to indicate that the functional relationships of components acting together are maintained as required by the applicable test schedule. Functional checks should be performed to indicate that no calibrated component has changed its calibrations beyond allowable service limits and that the function of uncalibrated components is unimpaired. When applicable, the miscellaneous systems operation checks should be as follow:

(1.) normal feather shutdown

(2.) emergency feather shutdown with simultaneous manual fuel shutoff

(3.) manual feather and unfeather after shutdown

(4.) emergency negative torque signal by means of a momentary fuel interruption

(5.) effects of changes in electrical voltage and power supply within the limits specified in MIL-STD-704

(6.) effects of ac power failures

(7.) overspeed mechanical pitch lock

(8.) mechanical low pitch stop.

A continuous recording should be made at each of the miscellaneous checks, above.

(i.) Cyclic tests. Following the control response tests, the propeller should be subjected to the cyclic test consisting of 50 successive one-hour cycles of operation. A continuous recording should be made of the transitory and steady-state conditions prior to and after the cyclic test. Visual inspections should be accomplished as a precautionary measure for detection of parts failure and other irregular functioning of the propeller. These inspections should be accomplished after the first, third, sixth, and every tenth hour interval thereafter unless test conditions warrant more frequent intervals. Each cycle should consist of the following runs shown in table L-III.

TABLE L-III. Cyclic tests.

Time at Setting	Type of Running or Power Lever Position
5	Ground idle
N/A	Taxi cycles
N/A	Ground idle to Maximum reverse
N/A	Maximum reverse to flight idle
N/A	Flight idle to ground idle
5	Maximum
5	Intermediate
10	Maximum continuous power
10	90% Maximum continuous
10	75% Maximum continuous
4	Flight idle
1	Maximum reverse
5	Repeat of taxi cycles

NOTE: Repeat approximately 10 times with alternate slow and rapid power lever motion.

The number of creditable hours of testing should be disallowed if any of the following discrepancies are detected after start of the cyclic test:

(1.) Linkages which pertain to the propeller require adjustment.

(2.) Propeller speed setting exceeds the established schedule by ±0.5 percent (±0.5%).

(3.) Failure of any component adversely affecting propeller control performance

(4.) Failure of any component adversely affecting propeller integrity

(5.) Detection of any failure of any component directly or indirectly affecting control performance during teardown inspection

(6.) Detection of excessive wear of any part or component during teardown inspection

(7.) Necessity to add operating fluid, if applicable.

A suitable retest penalty might be imposed in the event of a discrepancy of a propeller component.

(j.) Teardown inspection. After completion of the 50-hour engine test, the propeller and components should be completely disassembled for examination of all parts and measured as necessary to disclose excessively worn, distorted, or weakened parts. These measurements should be compared to measurements taken before assembly and the contractor's drawing dimensions and tolerances. Photographic records should be made of failures, wear, and other unusual conditions.

2. 150-hour test. The 150-hour test should be conducted on the same or similar test stand used for the 50-hour test. A production representative propeller should be used for these tests and the same propeller should be used for the entire test. The test should consist of 150 cycles of the same endurance cycle used in the 50-hour endurance test. In addition, the ice control system should be operated continuously during the cyclic test in accordance with the contractor's model specification. Applicable ice control data should be recorded in conjunction with other data. Prior to operation during the cyclic test, the ice control system(s) should be initially checked to establish proper functioning.

(a.) Teardown inspection. After completion of the 150-hour engine test, the propeller and components should be completely disassembled for examination of all parts and measured as necessary to disclose excessively worn, distorted, or weakened parts. These measurements should be compared to measurements taken before assembly and the contractor's drawing dimensions and tolerances. Photographic records should be made of failures, wear, and other unusual conditions.

h. Air vehicle tests.

1. Preliminary air vehicle test. The preliminary air vehicle test should be completed and all data analyzed before the initiation of the air vehicle flight test program. The preliminary air vehicle test of the propeller should be conducted on an air vehicle test bed or a suitable air vehicle having a nacelle configuration similar to the proposed application. If the propeller is a replacement propeller design for an existing air vehicle, that air vehicle type with modifications required for incorporation of the propeller should be used. The same test propeller should be used for all the preliminary air vehicle tests and should be in accordance with the contractor's model specification.

(a.) Installation static functional check. The propeller and engine test installation should be checked in the static condition to determine the functional characteristics of the control linkages, voltages, continuity of control circuitry and typical preflight checks. The relationship between all lever positions and signal levels and the propeller blade angle should be established for the complete range of lever and signal excursions for increasing and decreasing power conditions. Any adjustments required should be made using only external means to obtain the limits required.

(b.) Steady-state check. The procedure for the steady-state check should be such as to establish that the static sea level performance characteristics of the complete engine-propeller combination satisfactorily meets the required values of the model specifications. External adjustments should be made to obtain the required operational performance. Further propeller adjustments should not be permitted without appropriate approval. After all adjustments have been made, a calibration should be conducted to obtain steady-state data for a series of power lever settings. The appropriate power settings are as follow:

(1.) Full reverse

(2.) Ground idle

(3.) Flight idle

(4.) 60 percent (60%) maximum continuous power

(5.) 80 percent (80%) maximum continuous power

(6.) Maximum continuous power

(7.) Intermediate power

(8.) Maximum power (if applicable)

(9.) The steady-state operation at each of the various power lever settings specified above should be recorded by automatic equipment.

(c.) Transient check. After completion of the steady-state check, the engine-propeller control system should undergo a transient check to determine the stability of the control system, rate of pitch change, and response of the engine-propeller combination. For all power lever and input mechanism movements, if applicable, the lever should be advanced or retarded in 1 second or less. Transient checks should be conducted in accordance with the schedule shown in table L-II, and automatic equipment recordings should be made at each transient throughout the specified power lever movement.

(d.) Ground vibratory stress survey. A ground vibratory stress survey of the propeller should be conducted on all nacelles of the air vehicle to determine the stress characteristics of the propeller when operated in the air vehicle environment.

(e.) Flight vibratory stress survey. A flight vibratory stress survey of the propeller should be conducted on all nacelles of the air vehicle to determine the stress characteristics of the propeller when operated in the air vehicle environment.

(f.) Miscellaneous checks. Individual miscellaneous system operation checks, as applicable, should be conducted on the propeller. The propeller should be subjected to operating loads simulating as nearly as practicable those encountered during emergency operation. Sufficient instrumentation should be provided to indicate the performance of each applicable component and to indicate that the functional relationships of components acting together are maintained as required by the applicable test schedule. Functional checks should be performed to indicate that no calibrated component has changed its calibrations beyond allowable service limits and that the function of uncalibrated components is unimpaired. When applicable, the miscellaneous systems operation checks should be as follow:

(1.) Normal feather shutdown

(2.) Emergency feather shutdown with simultaneous manual fuel shutoff

(3.) Manual feather and unfeather after shutdown

(4.) Emergency negative torque signal by means of a momentary fuel interruption

(5.) Effects of changes in electrical voltage and power supply within the limits specified in MIL-STD-704

(6.) Effects of ac power failures

(7.) Overspeed mechanical pitch lock

(8.) Mechanical low pitch stop.

A continuous recording should be made at each of the miscellaneous checks described, above, throughout the contractor's procedures.

2. Prototype air vehicle test. The prototype air vehicle test of the propeller should be conducted on the prototype or first production air vehicle which would provide suitable means for testing the propeller. In the case of a multiengine air vehicle application, the test should be conducted on all nacelles. The propeller(s) used for all the air vehicle tests should be in accordance with the model specification except for modification required for instrumentation. For multi-engine air vehicles, all nacelles should incorporate identical models of the propeller.

(a.) Ground vibratory stress survey. A ground vibration stress survey of the propeller should be conducted on all nacelles of the air vehicle to determine the stress characteristics of the propeller when operated in the air vehicle environment.

(b.) Flight vibratory stress survey. A flight vibratory stress survey of the propeller should be conducted on all nacelles of the air vehicle to determine the stress characteristics of the propeller when operated in the air vehicle environment.

(c.) Control response test. A control response test should be conducted. The test should include the response of the engine propeller to power and speed changes throughout the range of operation of the engine under all normal ground and flight conditions of the air vehicle.

(d.) Temperature survey. A temperature survey should be conducted on the propeller during ground and flight operation to demonstrate propeller cooling within specified temperature limits.

(e.) Fluid tank test. If an airframe mounted fluid tank is furnished as a part of the propeller system, the tank should withstand without failure the vibration and slosh tests as specified by approved test procedures.

VERIFICATION LESSONS LEARNED (4.4.12)

a. Whirl test facilities. The Whirl Tests specified in the guidance above assume the availability of a suitable Whirl Test facility, typically available at most propeller OEMs. Wright-Patterson Air Force Base (WPAFB) in Ohio maintained a Whirl Test facility used by the Navy to develop and qualify the E2/C2 and OV10 propellers in the late 1970’s. The facility consisted of a number of pedestals on top of which were mounted dc motors of various power capabilities. These motors were powered and controlled by motor-generator sets in an adjacent building. The Wright-Patterson facility provided the ability to drive propellers at rotational speeds and torques beyond the capabilities of the engine planned for the developmental propeller while measuring thrust, shaft torque, and propeller deflections. These capabilities are necessary to map fully the propeller aerodynamic characteristics, flutter boundaries, vibration characteristics, and blade deflections. In addition, the overspeed and overtorque capabilities provide the means to conduct structural proof testing. All the data obtained during these tests is essential to propeller development.

b. Test plans. In the past, test plans have specified the following:

1. General test conditions.

During all testing, the fluid pressure adjustments, if any, should be made at the beginning of the test to the values specified in the test plan. No further adjustments that may affect the loading, functioning, or operation of the components or the propeller should be permitted during the test.

The fluid system should be drained and filled with new fluid at the start of each specific test. When externally supplied hydraulic power is a requirement, only new makeup fluid should be introduced into the system subsequent to initial servicing. No fluid should be drained from or added to the system during the test unless authorized. The system should further be maintained in accordance with the requirement of hydraulic system contractor.

2. Test data.

(a.) The following data should be recorded during the whirl stand tests, where applicable, in multiple increments of 50 or 100 rpm, as may be required, throughout the total rpm range of the test run:

(1.) Time of day

(2.) Total test time

(3.) Broad band strain gauge readings

(4.) Propeller speed, rpm

(5.) Blade angle, degrees

(6.) Corrected horsepower

(7.) Corrected thrust, lbs.

(8.) Torque, ft-lbs.

(9.) Barometer, in.

(10.) Ambient temperature, ^{o}F*

(11.) Established formula for determining corrected horsepower, thrust and torque

(12.) Data for reading oscillograph recordings of stress traces

*Note: Ambient temperature should be recorded at intervals not greater than 60 minutes.

(b.) The following data should be recorded during the propeller and engine test stand tests, where applicable, at intervals not greater than 60 minutes:

(1.) Time of day

(2.) Time of starts and stops, and total time accumulated

(3.) Total test time

(4.) Engine speed, rpm

(5.) Engine actual shaft horsepower*

(6.) Torque, ft-lbs

(7.) Engine case or gearbox vibration at points shown on installation drawing, mils

(8.) Fuel flow, lbs/hr*

(9.) Main or manifold pressure, psi or in. mercury

(10.) Primary pump pressure, psi

(11.) Secondary pump pressure, psi

(12.) Transient recovery time*

(13.) Oil inlet pressure, psi

(14.) Oil inlet temperature, ^{o}F

(15.) Engine compressor inlet and discharge pressure, psi

(16.) Engine compressor inlet and discharge temperature, ^{o}F

(17.) Engine compressor bleed opening point*

(18.) Engine or gearbox oil outlet temperature, ^{o}F

(19.) Engine turbine inlet temperature, ^{o}F*

(20.) Condition or power lever positions, degrees

(21.) Synchrophaser operation

(22.) Negative torque signal operation

(23.) Ambient temperature, ^{o}F

(24.) Propeller pitch pressure, psi

(25.) Propeller speed, rpm*

(26.) Propeller operating fluid temperature, ^{o}F

(27.) Blade angle, degrees*

*Note: For steady-state and transient calibrations, items marked with an asterisk, as applicable, need be recorded and such other data as may be pertinent to the installation.

(c.) Instrumentation. The instrumentation and techniques used for recording the vibratory stress survey of the whirl stand and air vehicle tests should be subject to review and approval. The instrumentation and techniques include:

(1.) The distribution and number of each type of strain gauges used

(2.) The range of operating conditions over which vibratory stress data will be recorded

(3.) The type of recording equipment used and the intervals at which recordings will be made

(4.) The propeller components to be subjected to the vibratory stress survey.

Additional or revised instrumentation similar in nature is permitted. The instrumentation should be sufficient to record stress traces, propeller rpm, and blade angle. As a general guideline, strain gauges should be installed on one blade of the propeller for measurement of blade shank and airfoil longitudinal and transverse stresses. A limited number of strain gauges should be installed on adjacent or opposite or both adjacent and opposite propeller blades, as required. The instrumentation data format should be specified for strain gauge installation on the propeller blade and their respective connection to the data acquisition system used for making the vibratory stress survey.

L.3.4.12.1 Control signals.

The control signal input or output from the airframe and propeller shall be __(TBS)__.

REQUIREMENT RATIONALE (3.4.12.1)

The characteristics of the control signals must be described. This will provide for compatibility and interchange of information between the propeller, engine, and air vehicle flight controls.

REQUIREMENT GUIDANCE (3.4.12.1)

TBS: The propeller control system should be compatible with and receive and process airframe signals for propeller control input. Propeller control interpretation of input signals should be defined.

A single input (pitch actuating) mechanism should be provided for the propeller to modulate blade pitch throughout the operating range. The total travel and position of this mechanism should be compatible with the air vehicle system. In the governing and beta regimes the relationship between the motion of the propeller input mechanism should be essentially linear.

If reversing features are provided as part of the propeller system, a reverse thrust condition should be reached by movement of an appropriate mechanism. The total travel and position should be compatible with the air vehicle system.

The propeller should provide for an input of an engine Negative Torque Signal (NTS). This signal should be used to command increase pitch action on the propeller which will minimize windmilling drag and prevent the engine from exceeding negative torque limits. The sensitivity and adjustment range of the NTS system should be specified.

The propeller should provide for the input of a feather command. This command should result in an increase pitch action at the fastest rate available from the pitch actuating system. Pitch change should traverse fully to the full feather position without further pilot commands.

REQUIREMENT LESSONS LEARNED (3.4.12.1)

Propeller governor speed setting. In the past, propeller controls have often provided for the input of a propeller speed set command. Variation of this input signal has provided a corresponding variation in the propeller governor speed setting. When incorporated, the characteristics of the required signal and the corresponding governor response have been specified.

L.4.4.12.1 Control signals.

The control signals requirements shall be verified by test.

VERIFICATION RATIONALE (4.4.12.1)

The control signals must be verified to ensure that no incompatibility exists

VERIFICATION GUIDANCE (4.4.12.1)

The satisfactory operation of the control signals should be verified by the installation static functional checks, conducted during the engine and propeller test stand and air vehicle tests specified in "Propeller subsystem" verification in this appendix.

VERIFICATION LESSONS LEARNED (4.4.12.1)

(TBD)

L.3.4.12.2 Propulsion interface.

The interface of the propeller with the airframe shall allow the propeller to perform as __(TBS)__.

REQUIREMENT RATIONALE (3.4.12.2)

The interfaces between the airframe and the propeller should be established and controlled to ensure compatibility. The propeller, airframe, and engine contractors must control the interface to ensure the propeller will work properly when installed in the air vehicle.

REQUIREMENT GUIDANCE (3.4.12.2)

TBS: The maximum allowable loads for all parts that interface with the airframe should be specified.

The maximum effective mass moment of inertia about the resultant rotational axis of the propeller rotating system and the direction of rotation when looking forward from the propwash should be specified.

If propellers are used in a multi-engine air vehicle they should be suitable for installation in any engine position in the air vehicle with minimum parts replacement.

The components which define each propeller module, and the length of time to remove and replace each module, should be specified. These modules should include at a minimum, the propeller control, individual blades, and the spinner. All modules should be capable of removal and replacement on the wing without the removal of other engine or propeller modules. All modules should be replaceable at the organizational or intermediate maintenance level.

The allowable range of characteristics of the propeller at the engine interface should be specified. No resonant frequency should be transmitted to or from the engine through the propeller.

The propeller mounting type should be specified and should be of a type which conforms to and is compatible with the engine or gear box design. The mounting should retain the propeller including retained fluids and externals at all flight, takeoff and landing, and ground conditions and withstand elastic limit loads without permanent deformation and ultimate tensile strength loads without complete fracture. The propeller loads transmitted to the engine propeller shaft (i.e., bending moment spectrum), should be specified and not negatively impact the service life of the propeller shaft or the propeller gear box. The allowable range of characteristics of the propeller at the engine interface should be specified. No resonant frequency should be transmitted to or from the propeller through the engine. The propeller should receive and transmit signals as required by the airframe and ground support systems. The signals, signal characteristics, and physical interface should be specified.

The propeller control system interface should ensure compatibility between the airframe power demand output signal or load, and the control system. The control lever(s) should not move with the engine operating unless external torque is applied. The maximum allowable loads at the control lever connections should be specified for the static (1g) axial, shear and overhung moment, and for the maximum maneuver loads defined.

There should be no leakage of fluids from any part of the propeller except at the drains provided for this purpose. The flow rate into all drains should be specified.

Propeller subsystems that interface with the airframe and ground support system; and control system human interface for any required propeller control system adjustments, maintenance data input or retrieval, and system fault data should be specified.

Components mounted on engines or gearboxes should be located to provide the necessary installation clearances.

REQUIREMENT LESSONS LEARNED (3.4.12.2)

(TBD)

L.4.4.12.2 Propulsion interface.

The Propulsion interface requirement shall be verified by inspection, analysis, and test.

VERIFICATION RATIONALE (4.4.12.2)

The interfaces must be verified to ensure they are functionally and physically correct.

VERIFICATION GUIDANCE (4.4.12.2)

Analysis should consist of a detailed description of the propeller interface with associated schematics and drawings of the propeller, engine, and airframe interface, all related modules and components, their arrangements functional relationships, interface loadings, weight, and position. In addition, maintenance concepts should be addressed, especially as related to module replacement “on-the-wing” and interfaces with ground support systems. Analysis providing rotor mass moment of inertia should be provided.

Removal and replacement “on-the-wing” and the modular maintenance concept should be verified by a demonstration test based upon procedures specified in the maintenance manuals.

Resonant frequency characteristics should be verified by analysis of data acquired during the propeller and engine test stand and air vehicle tests in “Propeller subsystem” verification in this appendix.

Control system interface should be verified by the installation static functional checks during the air vehicle tests of “Propeller subsystem” verification in this appendix.

Verification of no external leakage should be by inspection of all test articles before, during, and after test.

VERIFICATION LESSONS LEARNED (4.4.12.2)

(TBD)

L.3.4.12.3 Ground handling.

The propeller shall incorporate provisions for ground handling as __(TBS)__.

REQUIREMENT RATIONALE (3.4.12.3)

The propeller must be compatible with the logistic system equipment for ease of transportation.

REQUIREMENT GUIDANCE (3.4.12.3)

TBS: Ground handling mounts should be provided which support the propeller, including all propeller-mounted equipment and externals, components, and operating fluids, under at least the following inertia load conditions, without deformation to the mounts or damage to the propeller: 4g's axial, 2g's lateral, and 3 g's vertical acting in combination at the propeller c.g.

REQUIREMENT LESSONS LEARNED (3.4.12.3)

(TBD)

L.4.4.12.3 Ground handling.

The ground handling requirement shall be verified by analysis and test.

VERIFICATION RATIONALE (4.4.12.3)

Ground handling provisions need to be verified to ensure the propeller will not be damaged during handling and shipment.

VERIFICATION GUIDANCE (4.4.12.3)

Adequacy of the ground handling mounts should be verified as part of the structural design analysis. In addition, a static test should be conducted which applies a static load to each ground handling mount position equivalent to the load which would occur as the result of applying the specification inertial load conditions.

VERIFICATION LESSONS LEARNED (4.4.12.3)

(TBD)

L.3.4.12.4 Performance characteristics.

The performance shall be __(TBS)__.

REQUIREMENT RATIONALE (3.4.12.4)

All propellers must meet or exceed minimum performance to ensure the capability of the weapon system to accomplish established missions. Performance computer programs provide a means of estimating performance without actual testing of hardware.

REQUIREMENT GUIDANCE (3.4.12.4)

These performance characteristics should be determined using the specified electrical supply, grade and quantity of lubricants and fluids, if applicable, together with the engine, engine control, and air vehicle system which should be specified.

The propeller steady-state performance requirements should be defined by a steady-state performance computer program which should be controlled by a date and identifying number.

Tables should be used to specify rated performance. These tables specify performance points at sea level static conditions for the atmospheric temperatures which are appropriate to the usage of the air vehicle.

Tables should also be used to specify performance at selected altitude, True Airspeed (TAS), and inlet temperature conditions. The computer program should take precedence in the event of a conflict between tables and the performance computer program.

During all permissible power transients and times of accomplishment of such transients established for the engine, the propeller response should be compatible with the transient engine performance requirements stated in the engine model specification. Transient response of the propeller system should be defined by a transient performance computer program which should be identified by a date and identifying number.

The propeller feathering, unfeathering, and forward and reverse thrust operating limits should be specified for the specification operating environment.

REQUIREMENT LESSONS LEARNED (3.4.12.4)

(TBD)

L.4.4.12.4 Performance characteristics.

The performance characteristics shall be verified by test.

VERIFICATION RATIONALE (4.4.12.4)

The propeller performance characteristics must be verified by test to ensure steady state and transient performance is adequate to meet projected air vehicle mission requirements.

VERIFICATION GUIDANCE (4.4.12.4)

The propeller aerodynamic performance characteristics should be verified by data obtained during the whirl tests in "Propeller subsystem" verification in this appendix.

Transient performance characteristics should be verified during the transient checks of the air vehicle tests in "Propeller subsystem" verification in this appendix.

Feathering, unfeathering, forward and reverse thrust limits should be verified by data obtained during the whirl tests in "Propeller subsystem" verification in this appendix.

In the selection of specific test points for performance verification, consideration should be given to the fact that any performance data produced as an output of the steady state and transient computer programs but not specifically verified by test should be considered to be estimated performance.

VERIFICATION LESSONS LEARNED (4.4.12.4)

(TBD)

L.3.4.12.5 Control of propeller.

The control system shall control propeller operation to attain the steady state and transient propeller performances as __(TBS)__.

REQUIREMENT RATIONALE (3.4.12.5)

Control of the propeller is accomplished by means of a propeller control system which is required to assure compatibility with the engine and air vehicle requirements under steady state, transient and emergency conditions. The control system architecture and related functional propeller capability requires a description that shows compliance with operational, environmental, and mission requirements.

REQUIREMENT GUIDANCE (3.4.12.5)

TBS: The propeller control system should include all necessary provisions required for proper and complete automatic, manual, or emergency control of the propeller. These provisions should be listed and defined. These provisions depend upon the requirements for a given application and should include one or more of the following:

a. All elements of self-contained type propeller control systems required for speed governing in normal or reverse pitch, for control in the beta regime, and for emergency features should be contained within the propeller and should function independently of the synchronizer. The only elements that might be mounted remotely are the synchronizers of the governor trimming type, the elements that must be incorporated in the pilot's or flight engineer's power control unit, sources of emergency signals such as NTS and items of secondary importance, such as tachometers and generators. In other type systems, emergency features not self-contained within the propeller should be defined and listed.

b. The primary features of self-contained propeller control systems should function independently of the engine oil system or the air vehicle electrical system insofar as flight safety features are concerned. Other functions such as back-up protection or those that do not involve flight safety of the air vehicle such as speed synchronization, phase synchronizing, or feathering near zero rpm may utilize electrical power from the air vehicle electrical system. In other types of control systems, functions dependent upon the engine oil system or the air vehicle electrical system, should be defined and listed.

c. The propeller control system should incorporate the following emergency features:

    1. A mechanical low pitch stop

    2. A feathering system operable under all flight conditions including windmilling dives. An emergency means of initiating feathering should be incorporated which is independent of the normal means for such operations. Upon receiving a signal from the airframe for feathering the propeller pitch should advance completely to the feather position within an appropriate period of time. The time required for the propeller to achieve full feather position should be consistent with flight safety requirements as determined by asymmetric thrust on multi-engine air vehicles and loss of flight energy due to drag on single engine air vehicles. Rotation of the propeller should not be required to complete the feathering cycle.

    3. A control linkage which when connected with the engine NTS output mechanism should provide protection against catastrophic drag.

    4. An adequate overspeed protection system that engages in the event of overspeeding or loss of hydraulic pressure or similar failure. The system should act, when engaged, to prevent motion of the blades toward low pitch in the normal governing range but should permit motion of the blades toward high pitch. System settings should be specified.

d. Speed and phase synchronization of propellers for multi-engine air vehicles should be provided as a secondary speed control and should be described. The control should act to maintain the rotational speed of the slave propeller(s) to that of the master propeller within ±2 rpm in the propeller normal governing range. Phase synchronization should maintain the blade phase angle relationship of all propellers to one another within ±15° under all normal steady-state flight conditions in smooth air.

e. Reverse operation to a fixed negative blade angle compatible with the engine. Overspeed during propeller reversal should be compatible with engine overspeed limits. Maximum time to reverse from the low pitch stop should be specified.

f. The propeller response should be sufficiently rapid that it will not permit overspeeds in excess of those specified in the engine specification. Transient limitations may be a function of the engine overspeed mechanism on installations where applicable. The system exclusive of the synchronizer should prevent speed oscillations in excess of ±0.5 percent (±0.5%) under stabilized flight conditions.

Normal and reverse governing should be specified. Selective constant speed governing at any selected speed within the range necessary for optimum performance of the applicable engine should normally be incorporated into the propeller design. Where the propeller is controlled by a governor which is not an integral part of the propeller assembly, the governor should be constructed to conform to the mounting specified by JSSG-2007, Engines Joint Services Specification Guide. The governor should regulate the propeller speed between the limits specified.

Adequate provisions should be provided for situations in which it is desired to change pitch while the propeller rotational speed is at zero.

REQUIREMENT LESSONS LEARNED (3.4.12.5)

Control system adjustment. In the past, external adjustment to the control have been limited to adjustments which can be made correctly with the propeller assembled. These adjustments have been clearly marked and accessible with the propeller installed. All other adjustments have been protected to avoid tampering. These external adjustments were listed and defined.

When adjustments of limiting values of the controlled propeller variables were required, positive features were provided so that it would not be possible to preset the adjustments to the extent that would result in catastrophic consequences to the air vehicle.

L.4.4.12.5 Control of propeller.

The control of the propeller requirements shall be verified by analysis and test.

VERIFICATION RATIONALE (4.4.12.5)

Verification of the ability of the propeller control system to control the propeller is required to ensure air vehicle mission capability throughout all flight and ground handling regimes including emergencies.

VERIFICATION GUIDANCE (4.4.12.5)

Analysis should consist of detailed descriptions with associated schematics and drawings of the entire propeller control system and its component parts, their arrangement, functional relationships, and engine and engine control interfaces.

Demonstration of satisfactory control of the propeller should be accomplished through the control response test, the steady state check, the transient check and miscellaneous checks conducted as part of the engine and propeller test stand and air vehicle tests specified in "Propeller subsystem" verification in this appendix.

VERIFICATION LESSONS LEARNED (4.4.12.5)

(TBD)

L.3.4.12.6 Vibration and balance.

The propeller shall be free of vibration and dynamic response that could cause the equipment to operate below specified requirements or cause excessive crew discomfort. It shall be free of destructive vibrations at all steady-state and transient operating conditions.

REQUIREMENT RATIONALE (3.4.12.6)

Since the propeller is the largest and highest energy piece of rotating equipment on the air vehicle, its ability to produce discomforting as well as destructive vibration is substantial.

REQUIREMENT GUIDANCE (3.4.12.6)

The propeller should be adequately balanced to achieve satisfactory operation and suitable crew comfort and should contain provisions for maintenance rebalancing. The contractor should specify vibration limits and associated locations.

Propeller critical speeds existing below the operating range should be at least 20 percent (20%) below the minimum steady state operating speed. Critical speeds existing above the maximum operating speed should be at least 20 percent (20%) above the maximum allowable transient shaft rotational speed.

Means of limiting these vibrations should be aggressively considered in the design and construction of the propeller. Maintenance methods should also provide for methods of assuring the maintenance of the propeller vibration within design limits. Vibration limits and their associated locations should be specified to provide for installation of instrumentation as required to detect when the propeller is producing vibrations beyond the design operating limits.

REQUIREMENT LESSONS LEARNED (3.4.12.6)

a. Blades. Prior to or after painting, as the design allows, all blades should be balanced against a master balance which has been approved, the blade should balance horizontally and vertically at any two blade angles 90° apart. The rotation of the blade caused by horizontal out-of balance should be stopped or reversed by an opposite moment determined as the weight of the blade times an eccentricity of .002 in. except that a moment of .010 lb-in. minimum should be used. The rotation of the blade caused by vertical out of balance should be stopped or reversed by an opposite moment determined as the weight of the blade times an eccentricity of .004 in. except that a moment of .020 lb-in. minimum should be used. It is permissible to use equipment of equivalent accuracy in which the balance is determined with the blade centerline located in either a horizontal or vertical position. Where balancing equipment other than a knife edge is used, the unbalance moment specified above may be applied as scale reading deviations from the specified master components.

1. Ground adjustable. For correction of unbalance in ground-adjustable blades a concentric hole should be bored in the shank end of the blade in such a manner that it will not be detrimental to the strength of the blade. The balancing material placed within the hole should be adequately secured.

2. Wood. Final balance of wood blades should be attained by the removal of material not to exceed the minimum allowable tolerances specified in the model specification. Other means should be subject to approval.

b. Hub. The rotation of the hub caused by out-of-balance should be stopped or reversed by an opposite moment determined as the weight of the hub times an eccentricity of 0.0005 in. applied in such a manner that no force other than the mass of the applied balancing or reversing weight is the indicating feature. When equipment other than knife edges is used the same tolerance should be applied in an equivalent manner.

1. Ground adjustable. The hubs should be balanced without the clamp rings being in place. In order to attain final balance of the finished hub about the axis of the shaft, metal may be removed.

2. Controllable pitch. In the case of hubs which have been provided with means of correcting the unbalance of the completely assembled propeller, the balancing of the hub assembly should be accomplished with this balancing means adjusted to its neutral or mean position so as to retain its maximum effectiveness for correcting any unbalance of the completely assembled propeller. Other means should be used to correct any unbalance of the hub assembly.

3. Fixed pitch. Final balance of the finished hub about the axis of the shaft should be attained without the addition of weights. Metal may be removed to meet the final balance requirements.

c. Spinner. The means used to support the spinner for balancing should provide the same degree of accuracy of centering and aligning the spinner as will be obtained when the spinner is installed on the propeller. Spinner balance should be attained by either or both of the following means:

1. Static. The assembled spinner with all parts attached should be balanced on knife edges so that the rotation of the spinner caused by out-of-balance should be stopped or reversed by an opposite moment. The opposite moment should be determined as the weight of the spinner times an eccentricity of 0.0005 in., applied in such manner that no force other than the mass of the applied balancing or reversing weight is the indicating factor. Other equipment of equivalent accuracy may be used in which case the unbalance may be applied as a scale reading.

2. Dynamic. The assembled spinner with all parts attached should be balanced at (TBS) rpm on a machine having an accuracy of correction for balance in terms of

displacement of 0.000025 in., to secure an unbalance of not more than 2.0 ounce-in. in each of two planes.

d. Propeller.

1. Provisions. Provisions should be made for attaching balance weights in each of two balancing planes located as far apart axially as practicable, fore and aft of the plane of the blades. Points of attachment must be readily accessible with the propeller mounted on the air vehicle.

2. Propeller balance. Propeller balance should be attained by any of the following means:

(a) Static. The rotation of the propeller caused by out-of-balance should be stopped or reversed by an opposite moment. The opposite moment should be determined as the weight of the propeller times an eccentricity of 0.0005 in. applied in such manner that no force other than the mass of the applied balancing or reversing weight is the indicating factor. The balance requirement should be met with any blade in a vertical and horizontal position. It is permissible to use equipment giving equivalent accuracy which balances the propeller in a horizontal plane, in which case the unbalance may be applied as a scale reading.

(1) Ground adjustable. Horizontal balance should be accomplished without additional provisions.

(2) One piece wood. One-piece wood propellers should be balanced with a hub bolted securely onto the propeller. Balance may be secured by the application of liquid finish to the lighter blades for horizontal balance, or by securing a brass plate to the wood portion of the hub for vertical balance.

(b) Dynamic. The assembled propeller with all parts attached should be balanced at 100 percent rpm once installed on-wing to a vibration level of __(TBS)__ inches per second (ips).

L.4.4.12.6 Vibration and balance.

The vibration characteristics of the propeller shall be verified by test and analysis. The provisions for balancing and rebalancing shall be verified by inspection. Adequacy of balance shall be verified by test.

VERIFICATION RATIONALE (4.4.12.6)

Only actual operational tests with appropriate instrumentation can verify that the propeller is not producing excessive vibration. Balancing is critical to operating the propeller at a minimum vibration level. Since propeller balance can change due to service wear and damage, the provisions for balancing and rebalancing must be verified by actual testing of the resultant balance.

VERIFICATION GUIDANCE (4.4.12.6)

Verification should be through a combination of analysis and testing. Analysis should show all critical vibratory modes, their frequencies and stresses as a function of blade angle and rpm. This vibration analysis should form the basis for instrumentation and data reduction during testing. The vibratory characteristics of the propeller should be verified from the data obtained during the vibratory stress surveys conducted during the whirl stand tests, the engine and propeller test stand tests and the air vehicle tests in the "Propeller subsystem" verification in this appendix. Data representing all bending and twisting modes as well as unbalance should be identified and compared to design calculated values and to specified limits.

Verification of balancing methods should be based on analysis of vibration data obtained during propeller and engine stand tests and flight tests. Verification of balancing and re-balancing provisions should be obtained by inspection of assembly and maintenance procedures.

VERIFICATION LESSONS LEARNED (4.4.12.6)

(TBD)

L.5 PACKAGING

L.5.1 Packaging.

For acquisition purposes, the packaging requirements shall be as specified in the contract or order (see 6.2). When packaging of materiel is to be performed by DoD or in-house contractor personnel, these personnel need to contact the responsible packaging activity to ascertain packaging requirements. Packaging requirements are maintained by the Inventory Control Point's packaging activities within the Military Service or Defense Agency, or within the military service's system commands. Packaging data retrieval is available from the managing Military Department's or Defense Agency's automated packaging files, CD-ROM products, or by contacting the responsible packaging activity.

L.6 NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

L.6.1 Intended use.

The propeller subsystem descriptions in this appendix are intended for use in air vehicle systems developed to perform combat and combat-support missions in environments unique to military weapon systems.

L.6.2 Acquisition requirements.

Acquisition documents should specify the following:

a. Title, number, and date of the specification.

L.6.3 Component information

L.6.3.1 Propeller anti-icing system.

a. Ice control system. The propeller should incorporate an ice control system for the blades, cuffs, and spinner. Either electrical, fluid, gas, compound, or mechanical ice control systems may be used when approved by the procuring activity. As an alternattive to these ice control systems the physical shape and or surface finish of the blades, cuffs, and/or spinner may prevent or reduce ice accumulation without negatively impacting system performance or causing damage to the propeller, engine, or aircraft. In this case, upon approval by the procuring activity, an ice control system will not be required. Specify in the model specification the ice control system(s) or alternate means of preventing or reducing ice accumulation.

   1. Type of ice control. The type of ice control may be continuous, cyclic, or a combination of both as specified in the model specification. Unless continuous ice control is provided, operation of the ice control system should be accomplished either automatically or

manually as specified in the model specification. Continuous operation of the ice control system in flight should not damage the propeller system. Requirements for indication of the operation of the ice control system should be identified.

2. Electrical ice control system.

(a.) Electrical contact surface. All aluminum-oxide films, lacquers, or similar nonconducting coatings should be removed from the actual contact area of all surfaces required to act as a path for electrical power and from the local areas under screws, nuts, or the like used for assembly or mounting purposes to provide an electrical connection in accordance with the requirements of MIL-W-5088.

(b.) Electrical ice control circuits. All electrical circuits pertaining to ice control systems should be so physically and electrically isolated that no interference with the propeller operation or control will result. The leads used to conduct electrical power to the heating elements should withstand the aerodynamic centrifugal and vibratory loading to which they will be subjected during propeller operation.

(c.) Bonding materials. Cements, adhesives, or brazing used to bond blade, spinner, or cuff electrical heating elements should be specified in the model specification. Bonding processes which cause a reduction in physical properties of the item to which the element is bonded should be specified in the model specification.

(d.) Cover surfaces. Surfaces exposed to the air blast should consist only of materials designed to resist abrasion and corrosion. External surfaces of installed heating elements should be aerodynamically smooth. Externally mounted rubber or plastic surfaced elements should be inherently of sufficient flexibility and elasticity to allow installation in service areas without special dies, and stretching equipment.

(e.) Blade heating area. The heating elements should heat the inboard section of the exposed blade length to the propeller radius approved by the procuring activity. The width of the blade heated on both the thrust and camber faces should extend from the leading edge back to a distance at no point less than 17 percent (17%) of the blade chord.

(f.) Cuff heating area. The heating elements should heat the leading edge of the cuff for its entire length and at least 20 percent (20%) of both cuff face areas emanating from the leading edge.

(g.) Blade heating elements. Heating elements for propeller blades not equipped with cuffs should be continuous throughout their length. The heated area should approach as near as practicable the juncture between the blade and spinner or hub. Heating elements for propeller blades equipped with cuffs may be of two pieces with the cuff element and blade element separate, but compatible and designed for a single electrical supply circuit. The non-heated length between cuff and blade elements should not exceed 2 in. The external heating element installation should result in no distortion of the propeller airfoil contour.

(h.) Spinner heating area. The heating elements should heat the entire area of the rotating spinner surface.

(i.) Power requirements. The power requirements of the ice control system depend on the mission, performance and design of the specific air vehicle application and should be specified in the model specification. Heating element wattage should be calculated after reducing the voltage by an amount equal to the voltage drop in the complete circuit to each heating element. The type of phase loading, overload, and open-circuit sensing devices should be described.

(j.) Cycle heating controls. A cyclic control unit should be provided as a component part of the system. The schedule of the cyclic control should be specified in the model specification.

3. Fluid ice control system.

(a.) Fluid flow pattern. The system should accomplish a flow pattern of the fluid on the propeller blades, cuffs, and spinner, as necessary, to provide satisfactory ice control under all anticipated icing meteorological conditions.

(b.) Fluid. The fluid, flow rate, and pressure should be specified.

(c.) Connecting lines and fittings. Straight thread fittings should be in accordance with MIL-F-5509.

4. Compound ice control system.

(a.) Compounds. The compound used should produce a surface which will prevent ice adhesion when applied to the spinner, cuff, or blade surface as applicable. No damage to the protected surface should occur from the solution resulting when the compound comes into contact with water. The kind of compound used should be specified.

(b.) Protected blade area. The blade area to be protected by the compound should not be less than 75 percent (75%) of the blade length on inboard section and transversely from the leading edge to include approximately 25 percent (25%) of the chord.

(c.) Protected cuff area. The cuff area to be protected by the compound should be at least 20 percent (20%) of the cuff area on both cuff faces along the entire leading edge.

(d.) Protected spinner area. The entire spinner surface should be protected by the compound.

5. Gas ice control system. Gas ice controller systems should produce sufficient heat to melt the layer of ice adhering to the surface of the blade, cuff, and spinner, as applicable, which should permit ice removal by action of centrifugal force or produce sufficient heat to prevent ice formation on the blade, cuff, and spinner, as applicable, and should not affect the functional operation of the propeller or produce any undesirable structural or aerodynamic effects.

(a.) Ice control pattern. The system should accomplish a pattern of heat on the propeller blades, cuffs, and spinners, as necessary, to provide satisfactory ice control underall anticipated icing meteorological conditions.

(b.) Heat requirements. A complete definition of the heat source and heat requirements of the system should be specified.

(c.) Controls. Protective devices supplied as part of the propeller system should be specified.

L.6.3.2 Pitch-changing system.

The pitch-changing system should function satisfactorily throughout all regimes of flight and ground operation and should be described in model specification.

a. Hydraulic operation. When the pitch-changing system is hydraulically actuated, in whole or in part and the source of hydraulic power or fluid is self-contained, the system should be independent of the engine lubricating system and the air vehicle hydraulic system. If the engine lubricating oil is used, the propeller manufacturer should utilize the oil passages provided by the applicable engine or external lines if passages are not provided.

b. Electric operation. When the pitch-changing system is electrically operated, in whole or in part, the voltage and frequency of the current for which the pitch-changing system is designed should be compatible with the air vehicle electrical system. In cases where the propeller manufacturer provides the source of power that is independent of the air vehicle electrical system, the electrical source should be contained within the propeller.

c. Mechanical operation. When the pitch-changing system is entirely mechanically operated, the pitch change operating force should be available at all propeller speeds. Provisions for unfeathering of the propeller should be provided.

L.6.3.3 Lubrication system.

If the propeller incorporates a lubrication system the following should be considered.

If the propeller lubrication system is shared with the engine lubrication system, provisions should be made to prevent contamination of the engine oil system from debris that originates from the propeller lubrication system.

The propeller should meet the requirements of the specification when using the specified lubricating oil. The maximum and minimum operating oil pressure limits, maximum transient and maximum allowable steady-state oil temperature limits should be specified. The maximum and minimum oil pressures during starting and initial operation should be specified.

The maximum allowable oil consumption rate should be specified.

Unvented oil reservoirs should meet pressure vessel requirements. If the lubrication system and hydraulic systems share a common reservoir, the lubrication system should be protected from total depletion in the event of a hydraulic failure.

The oil reservoir should contain features to determine the oil level in the reservoir for all operating attitudes. An oil quantity signal should be provided to the airframe. The reservoir should have a drain system and should have features for overfill protection. Oil servicing should be possible with the propeller in a range of positions from 15° nose-up to 20° nose-down.

Drain ports should be provided at appropriate low points in the oil system for draining the oil and taking oil samples with the propeller in a range of positions from 15° nose-up to 20° nose-down.

Oil filter type(s), micron size, capacity, and filtration ratio should be specified. Primary filter assemblies should incorporate a pressure relief bypass, an impending bypass, and a bypass indicator. The bypass indicators should provide both local and remote indications and incorporate provisions to preclude activation during low-temperature starts. The indications should be visible until manually reset.

L.6.3.4 Hydraulic system.

a. Self-contained hydraulic system. The capacity of any self-contained hydraulic system should be specified.

b. External hydraulic power. When externally-supplied hydraulic power is required for the propeller system, the pressure, flow, and quantity requirements should be specified.

c. Fluids. The operating fluid should be specified. The fluid should be selected from defense specifications, and no change in fluid should be required for operation throughout the complete ground and air temperature range.

d. Fluid contamination. Hydraulic filter capacity should be such as to allow operation between the filter inspection periods specified by the propeller manufacturer.

   1. Self-contained hydraulic systems. The propeller manufacturer should specify the filtration requirements of fluid being installed in the systems.

   2. Non-self-contained hydraulic systems. The propeller should operate on the fluid being supplied.

L.6.3.5 Propeller rotating assembly.

a. Blades. Prime attention in the selection of materials and methods of construction of the blades should be given to such factors as abrasion, moisture, corrosion, and other deteriorating operational factors that tend to have adverse effects on structural integrity and safety.

   1. Blade pitch. The variation in pitch between blades when the propeller is assembled should not affect propeller performance. Means should be provided to assure the limitation in variation is maintained during assembly or to provide for adjustment to within this limitation.

   2. Blade track. Corresponding points adjacent to the tips of the blades of the propeller should be in the same plane perpendicular to the axis of rotation within the tolerance specified.

   3. Blade vent hole. When vent holes are required they should be specified.

   4. Standard blade shank ends. Ground adjustable blade shank ends should be specified.

5. Finishing wood blades. The external surface of wood blades should be specified in the model specification. After finishing, the tip of each blade should be painted for an inboard distance of 4 in.

b. Spinner. A spinner which provides an airflow compatible with airframe and engine requirements should be specified. Spinner designs should provide access for inspection and servicing of the propeller pitchchange mechanisms, propeller brushblock and slipring assembly, oil filler opening, lubrication fittings and such other items as may be applicable to the installation. It should accurately maintain its form in the installed position when rotating under operating conditions as well as when subjected to normal handling during maintenance or overhaul.

1. Symmetry. Dimensional symmetry should be maintained throughout the entire axial length of the spinner.
2. Balance provisions. Provisions for correcting static or dynamic unbalance condition should be identified.
3. Spinner blade seals. The seals should be replaceable parts and mounted without restriction to movement between the blade and hub and capable of withstanding rotational forces without loss or impairment.
4. Quick detachment. Quick detachment features should be incorporated in the spinner. External fasteners or other attaching means should be designed and installed to prevent their separation from the spinner in the unlocked condition.
5. Installation. The spinner should be such that when installed it should in no way impair the strength of the propeller and should not interfere with the functioning of the propeller or propeller controls. Mounting provisions for accurately centering the spinner on the hub should be capable of withstanding frequent installation or removal of the spinner without damage.

c. Hub. The hub should withstand all loads imposed during all operating regimes of the propeller.

Cone and cone seats. Cone seats of hubs with splined bores should be free from plating and able to provide an evenly-distributed bearing area contact and interchangeability of mating cones.

L.6.4 Definitions.

Engine operating status. The torque, rotational speed, and proximity of engine limiters

Air vehicle status. The position in the air vehicle flight envelope or taxi and landing regime

L.6.5 Acronyms.

The following list contains the acronyms/abbreviations contained within this appendix.

IAS	Indicated Airspeed
NTS	Negative Torque Signal
TAS	True Airspeed

L.6.6 Subject term (key word) listing.

Anti-icing

Balance

Blade

Calibration

Deicing

Hub

Hydraulic

Pitch

Propulsion

Spinner

Vibration

Whirl stand

L.6.7 Responsible engineering office.

The office responsible for the development and technical maintenance of this appendix is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL. Requests for additional information on this appendix can be obtained from AFLCMC/ENRS, BLDG 28 RM 118, 2145 MONAHAN WAY, WPAFB OH 45433-7017 USA; DSN 674-5476; COMMERCIAL (937) 904-5476; ENGINEERING.STANDARDS@US.AF.MIL.

L.6.8 Amendment notations.

The margins of this specification are marked with vertical lines to indicate modifications generated by this amendment. This was done as a convenience only and the Government assumes no liability whatsoever for any inaccuracies in these notations. Bidders and contractors are cautioned to evaluate the requirements of this document based on the entire content irrespective of the marginal notations.

APPENDIX M

AIR VEHICLE PNEUMATIC SUBSYSTEM

REQUIREMENTS AND GUIDANCE

M.1 SCOPE

M.1.1 Scope.

This appendix provides the requirements, verifications, tailoring guidance, and background information for the Pneumatic Subsystem provided for in Part 1 of this specification. The appendix has been developed and coordinated by technical personnel from the Air Force, Navy, and Army and has been approved as an official guide for use by Government personnel for assistance in tailoring the air vehicle subsystems specification for acquisition and model specifications. This appendix is a mandatory part of the specification. The information contained herein is intended for compliance.

M.1.2 Structure.

The appendix structure replicates the structure of the Air Vehicle Subsystems Specification except it places each corresponding section 3 requirement and section 4 verification together.

M.1.3 Appendix.

This appendix provides tailoring guidance and background information for individual paragraphs of the Air Vehicle Subsystems Specification. Guidance gives recommendations on how to tailor the specification paragraph. Where __(TBS)__ appears, the guidance paragraph provides recommended values or text that the using service may use to insert in the __(TBS)__. When contractors are expected to complete the __(TBS)__, the Guidance paragraph will so state. The Using Service makes the final decision on whom completes the __(TBS)__ in the specification. Finally, Lessons Learned are provided to give insight to past events that could impact the tailoring of the specification.

M.1.4 Deviations.

Projected designs for given applications which will result in improvement of the system performance, reduced life cycle cost, or reduced developmental cost through deviations from this guidance, or where requirements of the specification results in compromise in operational capability, should be brought to the attention of the Using Service.

M.1.5 Environmental impact.

Air Vehicle Subsystems will be designed such that their operation, maintenance, and repair may be accomplished without violating the most stringent environmental regulations applicable to locations where subsystems are used or supported. Compliance with environmental regulations will not prevent subsystems from achieving and sustaining mission performance capability. Materials, processes, and environmental control equipment necessary to meet these environmental requirements must currently be available in the Using Service's maintenance and supply system. The design will not use environmentally unsuitable materials such as ozone depleting fluorocarbons, chlorofluorocarbons, and halons, or highly volatile organic compounds in solvents and coatings during development, production, operation, maintenance, or repair. The Environmental Protection Agency maintains an online list of toxic chemicals and hazardous substances on its Ozone Layer Depletion Website at http://www.epa.gov/ozone/snap/ that should be consulted. The Significant New Alternatives Policy (SNAP) Program available thereon identifies substitutes for ozone depleting chemicals.

The contractor will conduct an environmental analysis of air vehicle subsystems.

M.1.6 Responsible engineering office.

The responsible engineering office (REO) for this appendix is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL.

M.2 APPLICABLE DOCUMENTS

M.2.1 General.

The documents listed in this section are specified in sections 3 and 4 of this handbook. This section does not include documents cited in other sections of this guide specification or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3 and 4 of this handbook, whether or not they are listed.

M.2.2 Government documents

M.2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this appendix to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

DEPARTMENT OF DEFENSE SPECIFICATIONS

JSSG-2010	Crew Systems Joint Service Specification Guide
MIL-DTL-5513	Swivel Joint, Hydraulic
MIL-DTL-7891	Filler Valve, Aircraft Oxygen

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-961	Defense and Program-Unique Specifications Format and Content
MIL-STD-5522	Test Requirements and Methods for Aircraft Hydraulic and Emergency Pneumatic Systems

(Copies of these documents are available online at http://quicksearch.dla.mil or from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia PA 19111-5094 USA.)

M.2.2.2 Other Government documents, drawings, and publications.

The following other Government documents, drawings, and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

USAF TECHNICAL REPORTS

AFWAL-TR-84-4104	Preliminary Review of Statistical Treatment of S-Glass/ Epoxy Stress Rupture Data (Accession Number ADA149810)

(Copies of this document are available at www.dtic.mil to qualified users; Defense Technical Information Center, 8725 John J. Kingman Rd., Suite 0944, Ft. Belvoir VA 22060-6218 USA.)

M.2.3 Non-Government publications.

The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

SAE INTERNATIONAL

SAE ARP584	Coiled Tubing - Corrosion Resistant Steel, Hydraulic Applications, Aerospace
SAE ARP994	Recommended Practice for the Design of Tubing Installations for Aerospace Fluid Power Systems
SAE AMS-P-5510	O-Ring, Preformed, Straight Thread Tube Fitting Boss, Type I Hydraulic (-65 to 160 °F)
SAE AS8879	Screw Threads - UNJ Profile, Inch Controlled Radius Root with Increased Minor Diameter
SAE AMS-P-83461	Packing, Preformed, Petroleum Hydraulic Fluid Resistant, Improved Performance at 275 Degrees F (135 Degrees C)

(Copies of these documents are available from www.sae.org; SAE International, 400 Commonwealth Drive, Warrendale PA 15096-0001 USA; and from www.ihs.com to qualified users.)

"Stress-Rupture of S-Glass/Epoxy Multi-Filament Strands," T.T. Chiao and R.L. Moore, Journal of Composite Materials, Vol. 5, 1971.

(This report is available from the Air Force Research Laboratory Materials & Manufacturing Directorate at http://www.wpafb.af.mil/afrl/rx/; AFRL/RX, WRIGHT-PATTERSON AFB OH 45433-7734 USA).

M.2.4 Order of precedence.

Unless otherwise noted herein or in the contract, in the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

M.2.5 Streamlining.

The Air Vehicle Subsystems Specification has been streamlined. The documents listed in this appendix which are required for acquisition have the same status as those referenced directly in section 2 (first tier). All other documents referenced through tiering may be used for guidance and information only.

M.3 REQUIREMENTS

M.4 VERIFICATIONS

M.3.1 Definition

M.4.1 Definition

M.3.2 Characteristics

M.4.2 Characteristics

M.3.3 Design and construction

M.4.3 Design and construction

M.3.4 Subsystem characteristics

M.4.4 Subsystem characteristics

M.3.4.1 Landing subsystem

M.4.4.1 Landing subsystem

M.3.4.2 Hydraulic subsystem

M.4.4.2 Hydraulic subsystem

M.3.4.3 Auxiliary power subsystem

M.4.4.3 Auxiliary power subsystem

M.3.4.4 Environmental control subsystem

M.4.4.4 Environmental control subsystem

M.3.4.5 Fuel subsystem

M.4.4.5 Fuel subsystem

M.3.4.6 Aerial refueling subsystem

M.4.4.6 Aerial refueling subsystem

M.3.4.7 Fire and explosion hazard protection subsystem

M.4.4.7 Fire and explosion hazard protection subsystem

M.3.4.8 Electrical power subsystem

M.4.4.8 Electrical power subsystem

M.3.4.9 Mechanical subsystems

M.4.4.9 Mechanical subsystems

M.3.4.10 Cargo, aerial delivery, and special operations

M.4.4.10 Cargo, aerial delivery, and special operations

M.3.4.11 VTOL-STOL power drive subsystem

M.4.4.11 VTOL-STOL power drive subsystem

M.3.4.12 Propeller subsystem

M.4.4.12 Propeller subsystem

M.3.4.13 Pneumatic subsystem.

The pneumatic power subsystem shall generate and store, condition, and distribute pneumatic power to the control and actuating devices dependent on pneumatic power for normal, alternate, or emergency operation. The pneumatic power subsystem may include components in using systems dependent upon pneumatic power. The pneumatic power subsystem(s) shall be sized and configured to supply pneumatic power, as required, to the selected using functions in all modes of ground and flight operations.

REQUIREMENT RATIONALE (3.4.13)

Pneumatic subsystems are used where air vehicle intermittent and emergency power is required; including, landing gear and wing flap extension, and wheel brake application.

REQUIREMENT GUIDANCE (3.4.13)

The following should be considered for pneumatic subsystems:

Pneumatic power subsystem back pressure should be limited to preclude performance degradation and subsystem malfunction(s). This is a concern in multiple subsystem pneumatic circuits. To control damping back pressures in pneumatic subsystem actuators using a 4-way valve control, the valve pressure poppets should open prior to return opening. Return gas should be vented overboard. Damping back pressure is not available during the actuator stroke, if the return is opened too early.

Tubing size and gas velocity should be selected to be consistent with design limits and to control actuator rates. Actuation systems should operate at limited speeds and with sufficient deceleration characteristics to prevent structural damage. Although actuator speed is often controlled by restriction or flow regulation and snubbing, line size can be a factor. The subsystem should operate within design limits which permit suitable control of actuator rates. For example, stopping or snubbing a cylinder piston at full stroke can be a design problem.

The snubbing pressure of a pneumatic cylinder depends on the driving pressure and the time available for back-pressure bleed off. Trouble arises if the back pressure can bleed away before the damping function is complete. Use of the differential area for the effective output force ensures proper damping and maintains a controlled pressure in the damping section. Cylinders installed in such a system can be subjected to expansion forces if high leakage rates occur across the piston seal.

REQUIREMENT LESSONS LEARNED (3.4.13)

Pneumatic compressor systems were used in some World War II USAF aircraft after the development of an automatic gun charger and the development of an electric-motor-driven air compressor unit. One of the early military applications was the gun charger for the B-25 medium bomber. The B-29 and B-50 bombers used electric-motor-driven 1500-psi pneumatics to operate bomb bay doors. On a bomb run, the doors could be opened in a fraction of the time compared to electric system operation. Some advantages of pneumatic power are:

a. Energy is easily stored because of gas compressibility;

b. Operation is essentially independent of temperature;

c. Distribution lines are relatively small;

d. Fire hazard is negligible; and

e. Fast actuation.

Some concerns are:

a. Not practical for continuous operation; for example, air vehicle flight controls

b. Leakage

c. Moisture removal

d. Lubrication

e. Compressor output at altitude

f. Dieseling

g. Insufficient actuator column stiffness to resist flutter.

M.4.4.13 Pneumatic subsystem.

The capability of the pneumatic subsystem to provide for generation and storing, conditioning, and distributing pneumatic power to the control and actuating devices dependent on pneumatic power for normal, alternate, or emergency operation shall be verified incrementally by __(TBS)__.

VERIFICATION RATIONALE (4.4.13)

Verification is required to ensure performance, interface, and functional requirements are met.

VERIFICATION GUIDANCE (4.4.13)

TBS: Verification should encompass planning, procedure preparation, and reporting; and should be accomplished by inspection, analysis, demonstration, or test, or a combination of these methods.

Operating performance should be shown by appropriate laboratory component and subsystem tests, and applicable ground, taxi, and flight tests (using MIL-STD-5522 for guidance). Component tests should be performed using applicable defense or contractor-prepared specifications. Pass criteria is based on successfully meeting all test objectives. Exceptions can be allowed where verification can be substantiated by valid comparisons to subsystems previously qualified on other programs.

VERIFICATION LESSONS LEARNED (4.4.13)

(TBD)

M.3.4.13.1 Gas.

The subsystem gas medium shall be __(TBS)__.

REQUIREMENT RATIONALE (3.4.13.1)

The selection of the gas medium can be a critical item from the viewpoint of availability, cost, servicing, and performance.

REQUIREMENT GUIDANCE (3.4.13.1)

TBS should be filled in with the type of gas medium to be utilized within the subsystem. Air is cheap and universally available.

Dry nitrogen may be preferred for stored-gas bottles because it is inert and generally available.

Helium may be preferred for stored gas in missiles because of its compressibility factor which results in more energy at low temperatures (-65°F) than air or nitrogen.

REQUIREMENT LESSONS LEARNED (3.4.13.1)

Stored helium gas was selected for the Maverick missile. Analysis showed that helium was superior to air or nitrogen because of the better compressibility factor which resulted in greater energy at colder temperatures for a given stored gas volume. This fact was also demonstrated in 1980 on a development missile which used stored gas to deploy control surfaces. The control surfaces would not deploy at altitude with stored nitrogen gas, but did deploy when the nitrogen was replaced with helium.

M.4.4.13.1 Gas.

Subsystem gas medium selection shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.13.1)

Verification will ensure the gas medium within the system is the required gas.

VERIFICATION GUIDANCE (4.4.13.1)

TBS: The gas medium selected should be verified by test, analysis, or inspection, or a combination of these.

VERIFICATION LESSONS LEARNED (4.4.13.1)

(TBD)

M.3.4.13.2 Pressure.

Operating pressure shall be __(TBS 1)__ psi at __(TBS 2)__°F. Pressure transients during subsystem operation shall not exceed __(TBS 3)__ percent of operating pressure.

REQUIREMENT RATIONALE (3.4.13.2)

Control of pneumatic subsystem pressures at a specified temperature is needed to prevent subsystem malfunctions and failures. Pressure selection affects availability, standardization, and testing parameters.

REQUIREMENT GUIDANCE (3.4.13.2)

TBS 1 should be filled in with the main subsystem operating pressure.

If a pressure reducer is used, the subsystem should be able to operate at the primary pressure or have a pressure relief device to accommodate a pressure reducer malfunction.

TBS 2 should be filled in with the operational temperature.

TBS 3 should be filled in with a specific percentage of operating pressure, or taken from a table which lists pressure values (reference legacy Military Specification MIL-P-5518).

Pressure transients exceeding 10 milliseconds should not exceed the proof pressure of the subsystem.

REQUIREMENT LESSONS LEARNED (3.4.13.2)

(TBD)

M.4.4.13.2 Pressure.

Subsystem pressure requirements shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.13.2)

Verification will ensure that the pressure within the system is the required pressure.

VERIFICATION GUIDANCE (4.4.13.2)

TBS should be filled in with either analysis or test, or both.

Subsystem pressure characteristics are generally verified by analysis of design reports and drawings, laboratory tests of components, and system tests.

Laboratory and flight tests should verify adequate pressure to meet operational and life requirements when blowdown bottle systems are used.

VERIFICATION LESSONS LEARNED (4.4.13.2)

(TBD)

M.3.4.13.3 Status indication.

A means shall be provided to indicate pneumatic power subsystem status.

REQUIREMENT RATIONALE (3.4.13.3)

Flight-station or maintenance personnel need to know the status and operating condition of the pneumatic power subsystem(s) prior to flight, and to be made aware of the status of the pneumatic power subsystem during flight. Status indication can provide alternate choices or corrective actions to the aircrew or maintenance personnel.

REQUIREMENT GUIDANCE (3.4.13.3)

This requirement should be in consonance with JSSG-2010, Crew Systems Joint Service Specification Guide.

REQUIREMENT LESSONS LEARNED (3.4.13.3)

(TBD)

M.4.4.13.3 Status indication.

The means of indicating pneumatic subsystem status shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.13.3)

Verification is to ensure that pneumatic status indications are adequate to meet operational needs.

VERIFICATION GUIDANCE (4.4.13.3)

TBS should be filled in with analysis, inspection, and test.

VERIFICATION LESSONS LEARNED (4.4.13.3)

(TBD)

M.3.4.13.4 Moisture content.

The pneumatic power subsystem shall operate with moisture content not to exceed __(TBS)__.

REQUIREMENT RATIONALE (3.4.13.4)

Moisture content which exceeds the maximum allowed value leads to degraded subsystem performance. Limiting the moisture content in the gas to a low value limits corrosion-induced failures and ice formation.

REQUIREMENT GUIDANCE (3.4.13.4)

TBS should be filled in with the grains of moisture per pound of dry air (specific humidity) that the subsystem design will allow.

Drains should be placed at low points in the subsystem to drain accumulated water periodically.

Components should not be installed in low point(s) in the subsystem without adequate drainage provisions.

If applicable, there should be means to remove entrained moisture from the pneumatic power subsystem gas during flight, ground, and servicing operations.

Filter elements, where used, should be easily replaced.

REQUIREMENT LESSONS LEARNED (3.4.13.4)

Past practice has been to limit air discharged from dehydrators used in airborne-compressor-charged systems to no more than 0.12 grains of moisture per pound of dry air (specific humidity). A solenoid valve installed at a low point in a bomb bay door system froze due to accumulated moisture and made the valve inoperable.

Experience has shown that maintenance personnel must be continuously aware of the importance of keeping contamination out of pneumatic power subsystems. The maintenance Technical Orders (T.O.s) should provide adequate instructions to prevent subsystem contamination when the systems are opened for maintenance and inspections.

M.4.4.13.4 Moisture content.

The operation of the pneumatic power subsystem with the allowed moisture content shall be verified by __(TBS)__.

VERIFICATION RATIONALE (4.4.13.4)

Moisture content which exceeds the maximum allowed value leads to degraded subsystem performance and failure.

VERIFICATION GUIDANCE (4.4.13.4)

TBS should be filled in with test, or test and analysis.

VERIFICATION LESSONS LEARNED (4.4.13.4)

(TBD)

M.5 PACKAGING

M.5.1 Packaging.

For acquisition purposes, the packaging requirements shall be as specified in the contract or order (see 6.2). When packaging of materiel is to be performed by DoD or in-house contractor personnel, these personnel need to contact the responsible packaging activity to ascertain packaging requirements. Packaging requirements are maintained by the Inventory Control Point's packaging activities within the Military Service or Defense Agency, or within the military service's system commands. Packaging data retrieval is available from the managing Military Department's or Defense Agency's automated packaging files, CD-ROM products, or by contacting the responsible packaging activity.

M.6 NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

M.6.1 Intended use.

The pneumatic subsystem descriptions in this appendix are intended for use in air vehicle systems developed to perform combat and combat-support missions in environments unique to military weapon systems.

M.6.2 Acquisition requirements.

Acquisition documents should specify the following:

a. Title, number, and date of the specification.

M.6.3 Component information

M.6.3.1 Clearance.

Clearance should be maintained between moving subsystem components and structure or other components to ensure no possible combinations of temperature effects, airloads, wear, or structural deflections can cause binding, rubbing, or jamming. There should also be adequate clearance for component installation, removal, and maintenance. The intent is to prevent binding, chafing, or jamming of components in static or operating modes. In addition, there are minimum clearances necessary to accommodate removal and installation of components. Component installation should have separation clearances which are maintained under all air vehicle operating modes. There should be clearance for hand tools required to remove and install components. There should be sufficient space to remove and install components. This may require additional access panels and doors. Refer to SAE ARP994 for detailed guidance.

M.6.3.2 Actuators.

Actuator design and performance requirements should be defined in the contractor's specification(s). Provision should be made for control of rates of operation for resisting, assisting, and no load conditions. Actuators are usually nonstandard components with unique requirements. The actuator performance, design, and verification requirements should be established in accordance with MIL-STD-961.

The problem areas with linear actuators have been:

a. Fatigue, especially with aluminum parts
b. Rod end fitting backout
c. Structural deformation of attach point; also, bearing distortion
d. Rod end attachment cracking at thread relief
e. Rod seal leakage
f. Bore wear in aluminum barrels
g. Leakage through "faulty" chrome plating
h. Column buckling of piston rods.

General considerations in actuator design module:

a. Use of steel barrels
b. Use of generous radii (to avoid stress risers)
c. Use of rolled threads when practical
d. Provision of positive attachment and anti-rotation locking of the rod end. Ordinary jam lockouts have not been sufficient.

M.6.3.3 Multiple control valves.

In subsystems which incorporate two or more directional control valves, provision should be made to prevent the medium from being transferred inadvertently, at any possible valve setting, from the cylinder ports of one valve into the cylinder ports of another valve. The control of the air flow is required so that subsystem operation will not be affected by interflow between valves.

M.6.3.4 Fittings.

Straight-threaded fittings should be used. Unless specifically approved by the procuring activity, no thread lubricants should be used on straight-threaded fittings. All nonstandard fittings should require approval by the procuring activity. Standardization of fitting threads is essential. Threads which conform to SAE AS8879 are preferred for high-stress applications but are more costly to produce. Fitting threads in accordance with legacy Military Specification MIL-S-7742 have proven satisfactory for many years. Defense-standard fittings should be used to reduce the inventory of nonstandard fittings.

Only straight threads should be used for reconnectable fittings. The use of permanent-type fitting connectors employing no screw threads requires procuring activity approval. In the late 1940s, the 37° cone "flared" fitting was the only tube fitting standard and required mechanical flaring of the connecting tube. In the 1950s, the flareless fitting was made available as an alternate standard because of its increased resistance to vibration. In the 1960s, the introduction of higher strength tubing made the standard flared and flareless fitting inadequate, because the harder tubing is difficult to flare, and also too hard for the flareless sleeve to penetrate the tube surface. New fittings were introduced for attachment to the harder tubing. This has created changes such as special tools and mechanical equipment to assemble the fittings to the tubing. The procuring activity should either specify tube fittings or consider a trade study.

Pipe-thread fittings tend to leak after repeated assembly and disassembly and were discontinued for use in air vehicles. Permanently installed pipe-thread fittings were permitted as plugs, but today there are other accepted methods for air vehicle component plugs. Use of pipe-threaded plugs for external sealing of drilled passages can set up internal stresses in component houses resulting in cracks.

Flared fitting sleeves of aluminum bronze are subject to stress corrosion cracking and are prohibited for use.

Aluminum flared fittings should not be used with steel tubing in sizes smaller than -8 because of the low relative yield strength of aluminum.

Aluminum fittings and aluminum tubing are not permitted in designated fire zones.

The use of free-machining steels such as American Iron and Steel Institute (AISI) Code 1137 and Code 1141 have caused problems because of marginal yield strength when subjected to repeated fitting assembly.

M.6.3.5 Seals.

Packing and gasket materials should be compatible with the fluid medium and capable of performing under the specified environment. Packing and gasket materials should have good compatibility with the fluid medium so that their sealing performance and life are not compromised in the specified environment. Aerospace Material Specification SAE AMS-P-5510 and MIL-P-83461 may be used as guides for materials compatible with the fluid medium. Legacy Military Specification MIL-P-8564 may be used for guidance for pneumatic component design. The Air Force Research Laboratory Materials & Manufacturing Directorate (AFRL/RX, 2977 P STREET, SUITE 1, WRIGHT-PATTERSON AFB OH 45433-7734 USA; http://www.wpafb.af.mil/afrl/rx/) is one source for data on fluid-elastomer seal compatibility. Allowable leakage is a function of subsystem needs and ground servicing criteria.

M.6.3.6 Tubing.

Tubing and tube connectors should have a subsystem durability life equal to or greater than the life of the air vehicle. Because of the cost and downtime required for tubing replacement, tubing and tubing connectors should have a subsystem life equivalent to the life of the air vehicle. When new tubing material or tube fittings are proposed, endurance-limit tests should be conducted. It is also recommended that SAE ARP994 be used for guidance.

Early tubing failures have occurred in areas of extreme vibration. Engine nacelle and pylon areas can induce resonance which can fail tube supports and tubing. For example, in the engine area of one type air vehicle, tubing failures occurred within 90 flight hours. The very early failures were caused by a combination of resonant frequency, marginal strength loop clamps, and tubing cross section which had excessive ovality (out-of-roundness at the tube bend). Corrective action was to change from carbon-steel clamps to stainless-steel clamps, add additional loop clamps, use some block clamps, and revise quality assurance procedures.

All pneumatic lines should be identified (reference legacy Military Standard MIL-STD-1247). For maintenance purposes, the pneumatic lines should be identified (1) as pneumatic lines and (2) for function; for example, landing gear down, flaps down, and so on. Identification is required as often as necessary, to track the line function, particularly on lines entering and emerging from closed compartments. Other unique requirements can be added.

Repair and replacement methods for tubing and fittings should be established. This information should be included in appropriate technical manuals and technical orders (T.M.s and T.O.s). A recommended procedure is required for repair and replacement of damaged sections of pneumatic lines by maintenance personnel at organizational levels. It has been a standard practice, when a factory-made replacement is not available, to make full tubing replacement with 304 $^1/_8$ Hard tubing which is easier to form than the high-strength AM350 or 21-6-9 tubing material. Partial tube replacement has been with 304 $^1/_8$ Hard tubing and Permaswage® fittings. Titanium tubing repair may require special procedures.

M.6.3.7 Relative motion.

Means should be provided to accommodate relative motion. Relative motion between two points is usually accommodated by:

a. Hose assemblies: Standard tetrafluoroethylene (TFE) hose assemblies are preferred to rubber hose assemblies, especially when age limitations and high temperatures are a factor. Proper routing of hoses is critical. Allow for flexibility without binding or crimping. Do not use hose(s) under constant pneumatic pressure because of gas permeability with time. Use SAE ARP994 as a guide. Rubber hose assemblies have leaked or failed because of heat aging. Teflon hose should be used in higher temperature applications. If rubber hose is used, it should not exceed the recommended temperature environment, and should be inspected on a periodic basis. Hose assemblies, like rigid tubing, should be installed for chafing resistance by making allowance for minimum clearance during normal operation and structural deflection and vibration.

   Chafe-resistant sleeves are available but should not be used as a substitute for good installation practices.

b. Coiled tubing: Use SAE ARP584 as a guide. Coiled tubing has been used successfully in commercial and military air vehicle installations. Coiled tubing has been used most successfully in tube diameters of 3/8 inch or less.

c. Swivel joints: Use MIL-DTL-5513 as a guide. Swivel joint leakage has been a problem. Nonplanar actuation (side loading on the swivel joint) is a contributing factor. The C-141 swivel joints were susceptible to dirt entering the seal cavity. Laboratory tests were conducted on the swivel joints with dust excluders and the leakage problem was significantly reduced.

M.6.3.8 Air compressors.

When an airborne compressor package(s) is used, general and specific requirements should be defined in a Critical Item Development specification. The operating characteristics and associated equipment for a compressor package must be defined in detail. Legacy Military Specification MIL-C-6591 can be used for guidance for either an electric-motor-driven package, or for a compressor (engine-driven or hydraulic-motor-driven). A compressor package may include:

a Driven air compressor

b. Relief valve

c. Moisture separator

d. Chemical dehydrator

e. Check valve

f. Priority (or back-pressure valve)

g. Means for periodic draining of the moisture separator

h. Pressure switch and relay

i. Cooling means to prevent exceeding maximum operating temperature.

Experience has led to the following criteria:

a. The moisture separator should provide conditioned air to the reservoir which is relatively moisture-free to prevent blocking of expansion lines by freezing. At rated discharge pressure, air entering the inlet at sea level pressure, and a dewpoint temperature of +85°F, the dewpoint of the discharge air should not exceed a specified maximum value based on sea level pressure.

b. Automatically, at intervals specified in the air compressor package specification and at shutdown, the condensate in the moisture separator should be purged to atmosphere. During the purging process, there should be no backflow of air from down stream of the moisture separator. The moisture separator should be provided with a heater that operates concurrently with the air vehicle operation to prevent any remaining condensate from freezing, and should be thermostatically controlled.

c. One or more blow-out disks should be incorporated as necessary to provide against possible explosions within the compressor package.

d. Pressure switch contacts should be snap action and should be moisture sealed.

e. The compressor package should be lubricated from its own oil supply.

   At altitude, there may be insufficient inlet air for compressor operation. Supercharging of the compressor inlet may be necessary for adequate performance. Another problem at altitude, or even at sea level, is adequate ram-air cooling flow. At one time, the F-84 package was located in the air vehicle wing root where ram-air cooling flow was insufficient.

M.6.3.9 Air bottles.

When air bottles are used, the general and specific requirements, quality assurance provisions, and preparation for delivery requirements should be defined in a Critical Item Development specification. Air bottles are safety-critical items. Legacy Military Specifications MIL-P-5518 and MIL-R-8573 can be used as guidance. Unique characteristics can be added when appropriate. Gas bottles should be located in an area where bottle failure will not result in personnel exposure to fragmentation and will minimize structural damage.

Materials impact:

a. A helium bottle ruptured in a stored short-range attack missile (SRAM). Failure was attributed to stress corrosion which may have been caused by cleaning agent(s) residue. Room-temperature pressure was 7,700 psi; burst pressure, 24,000 psi; material was 18 Ni 200 maraging steel.

b. F-102 and F-106 filament-wound plastic pressure bottle explosions occurred at 2,100 psi during filling on the ground. Maximum allowable pressure was 3,100 psi. The bottle(s) increased considerably in circumference when pressurized. Loss of strength occurred after repeated proof pressure tests (circa 1959).

c. A 5,000-psi nitrogen storage bottle, of fiberglass S-Glass-epoxy composite structure, ruptured and caused major air vehicle damage. The bottle had been pressurized for more than eight years. Failure was attributed to the phenomenon known as "stress rupture." Stress rupture of S-glass has been extensively investigated by Dr. T.T. Chiao and associates of the Lawrence Livermore National Laboratory. Empirical data shows an inverse relationship between the safe life of S-glass/epoxy composite structures and the ratio of loading stress to ultimate stress of the composite structure. A discussion of the stress rupture phenomenon in composites is presented in "Stress-Rupture of S-Glass/Epoxy Multi-Filament Strands" published in the Journal of Composite Materials. Technical Report AFWAL-TR-84-4104 contains tabular life data as a function of the fiber stress, quantile level, and confidence interval.

Consider the following points in air bottle design and installation:

a. Use moisture bleed valves in accordance with MIL-DTL-7891. Fittings designed to the since-cancelled Air Force-Navy Aeronautical Standard AN814 resulted in "O"-ring blowout during bleeding.

b. Proper bottle positioning and air vehicle access for water purging are required.

c. Avoid allowing water to spray on electronic equipment.

d. Installations requiring moisture pick-up tubes should have a flex tube long enough to reach the lowest point of bottle. Use a plastic end to avoid bottle interior coating damage.

e. Do not drop sharp objects on fiberglass bottles.

f. Problems have occurred with the internal coating inside air bottles flaking off and then obstructing the control valve. Studies showed the problem was caused by rapid ground charging of the air bottles. The bottles were being charged on the ground with an external source in approximately one second. The temperature inside the bottle would be over 400°F which would cause the internal coating to flake off. The solution was to charge the bottles more slowly (approximately 1 minute for 0 to 3000 psi).

M.6.3.10 Electric motors.

Electric-motor-driven equipment should be capable of continuous operation. Other requirements for electric-motor-driven equipment such as test duty cycle(s), operational temperature range, rated voltage, altitude, explosion proofing and, automatic control versus manual control should be defined. Legacy Military Specifications MIL-M-7969 and MIL-M-8609 can be used as guides for preparation of electric motor design requirements. Electric motor-driven equipment has been subject to early failures when the electric motors were rated for intermittent duty. For reliability and long life, it is necessary to have electric motors with continuous-duty capability.

M.6.3.11 Snubbing.

The pneumatically-powered B-29 bomb bay doors departed the air vehicle during a ground demonstration because adequate snubbing was not provided to slow the piston actuator after full stroke. This was corrected by restricting the air on the back side of the actuators to provide a snubbing air cushion.

Canopy cylinder failures have been caused by air loads stalling the motion of the actuator during the closing cycle allowing the snubbing pressure to be lost. The original canopy cylinder design did not have differential area design. Canopies have also been jettisoned because of loss of damping air on the retract side of piston during the canopy opening cycle.

M.6.3.12 Chemical dryers.

Chemical dryers should be large enough to meet specifications for moisture removal. They should not require too frequent cartridge removal under the most adverse conditions. Use of the pneumatic power subsystem, such as for normal or emergency functions, is a determining factor. Drier housing and cartridge housing materials should resist corrosion (e.g., plastic shell cartridge). Dissimilar metals should be avoided because of electrolytic action. Use built-in filters to prevent desiccant powder migration. The unit should be rigidly mounted to facilitate servicing. Although molecular-sieve is frequently used in air vehicle over silica-gel as a desiccant because of its greater moisture holding ability, it can attack aluminum in the presence of water. Therefore, maximum corrosion protection is required. Visual moisture indicators would simplify cartridge removal time and save on cartridges.

Chemical dryer problems:

a. Cracked housing. Fix: material change.
b. Corrosion throughout unit. Fix: plastic cartridge. Also, consider sealing cartridge in housing at inlet end instead of outlet end. This will allow cartridge housing to be pressurized with dry air to avoid corrosion.
c. Desiccant particle migration. Fix: better cartridge filter. Porous bronze filter allowed desiccant migration.
d. Rigidity of mounting inadequate for servicing. Fix: Rigid mount capable of withstanding wrenching torques.

M.6.3.13 Filters.

At least 25-micron absolute filters should be provided in all systems. These filters should be used to filter all the gas supply in the subsystem. Reservoir filters should be of the replaceable element type in refillable or rechargeable systems. The total gas supply should be filtered through a 25-micron absolute filter before use in the subsystem. In some subsystem(s) finer filtration, less than 25-micron absolute may be required.

M.6.4 Acronyms.

The following list contains the acronyms/abbreviations contained within this appendix.

SRAM Short-Range Attack Missile

M.6.5 Subject term (key word) listing.

Fittings

Gas

Moisture

Pressure

Seals

Snubbing

Tubing

M.6.6 Responsible engineering office.

The office responsible for the development and technical maintenance of this appendix is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; AFLCMC.EZF.MAILBOX@US.AF.MIL. Requests for additional information on this appendix can be obtained from AFLCMC/ENRS, BLDG 28 RM 118, 2145 MONAHAN WAY, WPAFB OH 45433-7017 USA; DSN 674-5476; COMMERCIAL (937) 904-5476; ENGINEERING.STANDARDS@US.AF.MIL.

M.6.7 Amendment notations.

The margins of this specification are marked with vertical lines to indicate modifications generated by this amendment. This was done as a convenience only and the Government assumes no liability whatsoever for any inaccuracies in these notations. Bidders and contractors are cautioned to evaluate the requirements of this document based on the entire content irrespective of the marginal notations.

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