NON MEASUREMENT SENSITIVE

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DEPARTMENT OF DEFENSE

JOINT SERVICE SPECIFICATION GUIDE

AIR VEHICLE

This specification guide is for guidance only.

Do not cite this document as a requirement.

AMSC N/A FSC 1510

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FOREWORD

JSSG Release Notice

This specification guide supports the Acquisition Reform initiative and is predicated on a Performance Based Business Environment approach to product development. As such, it is intended to be used in the preparation of performance specifications. It is one of a set of specification guides. This is the second release of this guide. In that sense, this document will continue to be improved as the development effort is accomplished.

1. During the 1970's, the Department of Defense (DoD) and the Defense Science Board (DSB) investigated the cost of DoD acquisition development programs. DoD results were reported in a 1975 memorandum from the Deputy Secretary of Defense, which cited the blanket application and unbounded subtiering of development specifications and standards as a major cost driver. The DSB investigation concluded that, rather than specifying functional needs, the documents dictated design solutions. It also noted that blanket application of layer upon layer of design specifications actually represented a bottom-up versus a top-down process, which not only failed to develop systems responsive to user operational needs but also inhibited technical growth. As a result of these findings, DoD directed that policies be established to require tailored application of development specifications on all new system acquisitions. The June 1994 Memorandum from the Secretary of Defense regarding “Specifications & Standards—A New Way of Doing Business” further emphasized these policies.

2. In response to acquisition reform, a set of eight Joint Service Specification Guides (JSSGs) has been developed to support performance-based aviation acquisition. These JSSGs are generic documents intended to provide a best starting point for tailoring a specification for development program applications. Furthermore, they are intended for common use among the services. This not only facilitates joint programs but also provides industry a single, consistent approach to defining requirements.

3. A Joint Service Specification Guide itself never goes on contract. It is, as its title reads, a guide. It is the tailored derivative of the specification guide, with its program-peculiar system identification number, that becomes part of the system definition and, in the case of specifications intended for contractual application, part of the acquisition package.

4. This Joint Service Specification Guide is intended to assist Government and contractor personnel in developing an air vehicle specification tailored to an acquisition development program. To tailor the document to the specific application, the applicable requirements must be selected and the blanks within those requirements filled in appropriately for the air vehicle being developed. For each of the requirements selected, the associated verifications are examined and tailored as needed.

a. The fundamental objectives of this document are to provide consistent organization and content guidance for describing air vehicle requirements as translated from validated needs. Air vehicle requirements must be

(1) meaningful in terms of meeting user operational needs;

(2) performance-based and avoid specifying the design;

(3) measurable during design, development, and verification; and

(4) achievable in terms of performance, cost, and schedule.

b. The systems engineering approach is emphasized to ensure the air vehicle is the complete, integrated, and balanced solution to customer needs, and accounts for all inputs and outputs. The up-front integration of requirements defined in the context of the air vehicle life cycle helps ensure a complete air vehicle definition and enables a disciplined top-down flow of requirements to lower-tier specifications.

c. The unique features of this document that help to satisfy operational requirements include

(1) Specifying in section 3 the conditions, scenarios, and mission descriptions against which the air vehicle performance requirements are defined, for both peacetime and wartime operations.

(2) Expressing performance requirements for the air vehicle in technically based, quantitative, user-oriented terms.

(3) Defining external air vehicle interfaces.

(4) Providing representative incremental verifications in section 4 at program milestones to help confirm progressive compliance with section 3 requirements.

d. The complete set of JSSGs establishes a common framework to be used by Government-industry program teams in the aviation sector for developing program-unique requirements documents for air systems, air vehicles, and major subsystems. Each JSSG contains a compilation of candidate references, generically stated requirements, verifications, and associated rationale, guidance, and lessons learned for program team consideration. The JSSGs identify typical requirements for a variety of aviation roles and missions. By design, the JSSG sample requirements are written as generic templates, with blanks that need to be completed in order to make the requirements meaningful. Program teams need to review the rationale, guidance, and lessons learned found in the JSSG to (1) determine which requirements are relevant to their program; and (2) fill in the blanks with appropriate, program-specific requirements.

e. This specification guide is a generic document containing requirement statements for the full range of aviation sector applications. It requires tailoring to form the program-unique specification. Tailoring involves selecting the essential requirements and deleting non-applicable requirements. In addition, where blanks exist in the selected requirements, these blanks must be filled in appropriately to form a complete set of program-unique specification requirements to meet program objectives. The guide also provides the rationale, guidance, and lessons learned relative to each requirement statement. The section 4 verifications must be tailored to reflect an understanding of (1) the system solution; (2) the identified program-specific milestones and the associated level of maturity expected to be achieved at those milestones; (3) the approach to be used in the design and verification of the required products and processes; and (4) criteria to be used in establishing satisfaction of the requirements. The rationale, guidance, and lessons learned document what has been successful in past programs and practices. They should not be interpreted to limit new practices, processes, methodologies, or tools.

5. This specification guide is still in development. Emphasis thus far has been to assure that the requirements and verifications, and their guidance, are adequate for application to tactical fighter and attack types of air vehicles. Although some requirements for other types of air vehicles are included, the document does not yet represent the entire set of requirements which should be considered for non fighter/attack air vehicles.

6. Request the previous version of JSSG-2001 from ASC/ENOI, 2530 Loop Rd. West, Wright-Patterson AFB, OH 45433-7101 or e-mail Engineering.Standards@wpafb.af.mil.

7. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Department of the Navy; Commander; AIR 4.1C, Suite 2140, Bldg. 2185; Naval Air Systems Command Headquarters; 22347 Cedar Point Rd, Unit 6; Patuxent River, Maryland 20670-1161.

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(Distribution D; detached from document. To request a copy, contact ASC/ENOI, 2530 Loop Rd. West, Wright-Patterson AFB, OH 45433-7101. Address e-mail requests to Engineering.Standards@wpafb.af.mil.)

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1. SCOPE

1.1 Scope

This Joint Service Specification Guide (JSSG) establishes general requirements and verification parameters, integration, performance, and functions for the preparation of an air vehicle program-unique specification. The program specification developed from this JSSG will be used for contractual commitments between the Government and the prime contractor for the procurement of an air vehicle.

1.2 Air vehicle specification

When this JSSG is tailored for a particular air vehicle, the resulting section 1 Scope should include an introduction such as the following:

“This specification establishes the performance and verification requirements for the ___(1)___ air vehicle to perform the ___(2)___ mission(s). Other significant features of the air vehicle include___(3)___.”

GUIDANCE (1.2)

This summary description is intended to provide an overview definition of the air vehicle that the Government intends to procure.

Blank 1. Complete with the name or designation of the air vehicle to be procured.

Blank 2. Complete with the planned mission(s) of the air vehicle.

Blank 3. Complete based on the capability of the air vehicle, number of crew, and additional definitive capabilities (e.g., the type and number of engines, and cargo or passenger capacity). Examples include the following:

a. Mission examples may include carrier based, night attack, reconnaissance, fighter, or combinations thereof.

b. Operate the air vehicle at nap-of-the-earth (NOE) altitudes and employ weapons for self-defense in night and adverse weather conditions for the purpose of returning the air vehicle to home station in the event either crew member becomes disabled.

c. Conduct noncombat missions, such as maintenance test flights, ferry flights, demonstration and orientation flights.

d. Number of passengers to be transported.

e. Number of crew is as specified by the user consistent with operational requirements.

1.2.1 Air vehicle definition

For the purposes of this Joint Service Specification Guide, an air vehicle includes the installed equipment (hardware and software) for airframe, propulsion, air vehicle applications software, air vehicle system software, communications/identification, navigation/guidance, central computer, fire control, data display and controls, survivability, reconnaissance, automatic flight control, central integrated checkout, antisubmarine warfare, armament, weapons delivery, auxiliary equipment, and all other installed equipment.

1.3 Understanding this Joint Service Specification Guide

This specification guide is neither designed nor intended to be placed in its entirety on contract. A Joint Service Specification Guide is a tool that can be used to develop program-specific specifications. It is intended to capture the knowledge base and lessons learned for the various requirements associated with developing air vehicles. The guide contains a compilation of potential technical requirements for a class of like items that must be tailored to generate a complete and consistent set of requirements to meet program objectives.

This JSSG is a template for developing a 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, blanks within the selected requirements must be filled in to define the performance details for the program-unique specification.

As a guide, this document provides the rationale, guidance, and lessons learned relative to each requirement statement. Each section 3 paragraph provides a requirement rationale section explaining why and when the requirement should be considered, a requirement guidance section to assist in tailoring the requirement (including how to complete applicable blanks), and available lessons learned related to the requirement. Each section 3 requirement is followed by its complementary section 4 paragraph addressing verification of that particular air vehicle requirement, including verification discussion and guidance, tailorable final verification criteria statements, and verification lessons learned.

1.4 Use of this JSSG

The specification guidance herein is to be used to completely and accurately tailor the requirements for a particular air vehicle development specification. Subparagraphs should be added as required.

All specifications for development and production of air vehicles may be tailored from the requirements and format of this specification guidance. This JSSG, and applicable documents to be listed in section 2, cannot be put on contract untailored. The Government or contractor must tailor the specification guide into a specific, program-unique, air vehicle specification. Supplemental information provided in this document is authorized for release as indicated on the JSSG cover.

1.4.1 Adding lower-tier requirements

When a known, moderate- to high-risk characteristic exists (e.g., a requirement in a third-tier JSSG), the specific requirement should be extracted from the third-tier source, tailored as necessary, and added to the air vehicle specification. To avoid overspecification, the third-tier document will not be referenced unless needed for the purpose of parenthetically noting the source document by number and paragraph. Risk criteria will be established by the program manager.

2. APPLICABLE DOCUMENTS

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

GUIDANCE (2.)

When this specification guide is tailored for a particular program application, it should include only those references cited in the requirements and verifications section of the resulting document and only to the extent for which they have been cited. For example, if a cited document is intended to be contractual (see section 2.3 for tiering implications) it would be cited in this section in the appropriate category (i.e., Government documents, other publications, etc.). If the reference in the resulting specification indicates that a cited document is intended for use as guidance only, the reference in this section would also state that caveat.

Documents listed in section 2 should not include documents cited in sections 1, 2, 5, and 6.

2.1 Government documents

2.1.1 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 listed in the latest issue of the Department of Defense Index of Specifications and Standards (DoDISS) and supplement thereto.

SPECIFICATIONS	
Department/Agency	
Document Number	Document Title
STANDARDS	
Department/Agency	
Document Number	Document Title
HANDBOOKS	
Department/Agency	
Document Number	Document Title

(Unless otherwise indicated, copies of specifications, standards, and handbooks are available from the Defense Automated Printing Office, Standardization Document Order Desk, 700 Robbins Avenue, Bldg. 4D, Philadelphia, PA 19111-5094.)

GUIDANCE (2.1.1)

In the tailored program specification, list in section 2 only those specifications, standards, and handbooks called out in section 3 and 4 of the final specification. Users of specifications have found it useful to identify, for each document referenced, the number of the paragraph(s) containing the reference. Appendix B is a matrix of documents referenced in this JSSG, identifying the number(s) of the paragraph(s) in which they occur.

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 are those cited in the solicitation.

Document Category	
Document Number	Document Title

(Copies of specifications, standards, handbooks, drawings, publications, and Government documents required by contractors in connection with specific acquisition functions should be obtained from the contracting activity or as directed by the contracting activity.)

GUIDANCE (2.1.2)

Other Government documents, drawings, and publications called out in the final specification are listed in this section.

2.2 Non-Government publications

The following document(s) form a part of this document to the extent specified herein. Unless otherwise specified, the issues of the documents which are DoD adopted are those listed in the issue of the DoDISS cited in the solicitation. Unless otherwise specified, the issues of documents not listed in the DoDISS are the issues of the documents cited in the solicitation (see 6.5 Acquisition requirements).

Non-Government Standards (NGS) Organization Name	
Document Number	Document Title

Application for copies should be addressed to (insert the name and address of the source under the list of documents for each NGS body).

GUIDANCE (2.2)

Other publications called out in the final specification are listed here. Non-Government standards and other publications are normally available from the organizations which prepare or which distribute the documents. These documents also may be available in or through libraries or other informational services.

2.3 Document tiering

When the air vehicle specification is directly referenced in the contract, it is a first-tier specification and is applicable. Documents referenced in the Air Vehicle specification are applicable as follows:

a. Second Tier - All documents directly referenced in the first-tier specification are only applicable to the extent specified.

b. Lower Tier - All documents directly referenced in second- or lower-tier documents are for guidance only unless otherwise directed by the contract.

GUIDANCE (2.3)

Control of document tiering has become a primary way of controlling contractual applicability of referenced documents. Care must be taken to ensure that each referenced document is appropriately applicable in first-tier references (including those references cited in the contract, which themselves would become first-tier references and thus, their second tier would become contractually applicable as well).

Note that this guidance is primarily aimed at controlling applicable documents when an air vehicle specification, derived from this JSSG, is cited in the contract. During production phase, there are additional considerations as well. For example, specifications and standards listed on engineering drawings are to be considered first-tier references (see Dr. Perry's memorandum on "Specifications and Standards - a New Way of Doing Business" dated 29 June 1994). In a Performance Based Business Environment context, this option is primarily applicable to the Build-to-Print (BTP) and Modified Build-to-Print (MBTP) business practices when the drawings are directly cited in the contract. See the Performance Based Product Definition Guide for additional information about BTP and MBTP practices.

Exceptions to tiering applicability are generally defined by DoD policy. For example, in the Perry Memo previously cited, the direction on tiering of specifications and standards includes, "Approval of exceptions may only be made by the Head of the Departmental or Agency Standards Improvement Office and the Director, Naval Nuclear Propulsion for specifications and drawings used in nuclear propulsion plants in accordance with Pub. L. 98-525 (42 U.S.C. ß7158 Note)."

2.4 Order of precedence

In the event of a conflict between the text of the program specification and the references cited herein, the text of the specification takes precedence. Nothing in the specification, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

GUIDANCE (2.4)

This paragraph is used as written in the tailored, program-unique specification to establish the precedence of the completed specification when applied to the program.

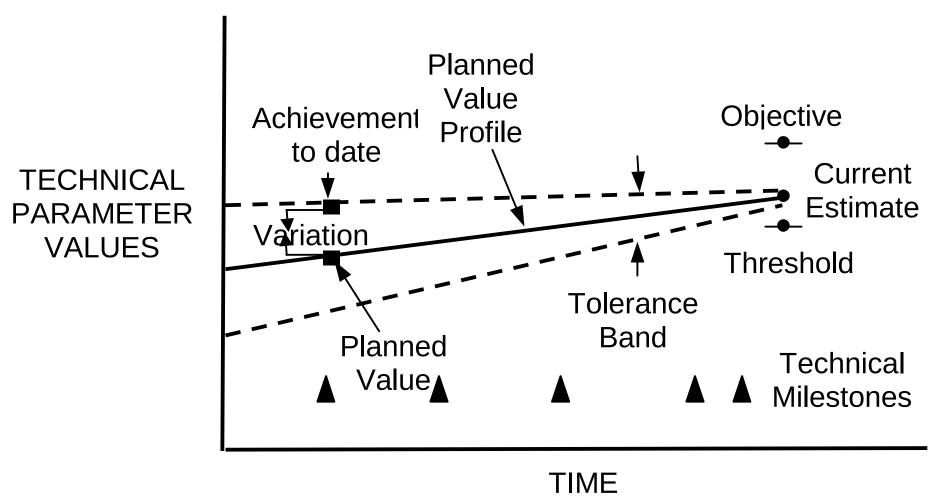
3. REQUIREMENTS / 4. VERIFICATIONS

The following portion of this guide combines section 3 requirements with section 4 verifications. Each requirement is written as a generic template, with blanks that need to be completed in order to make the requirements meaningful. Program teams should review the rationale, guidance, and lessons learned to determine which requirements are relevant to their program, and tailor those requirements with appropriate, program-specific details.

Each section 3 requirement is supported by a section 4 sample verification addressing air vehicle verification information, including sample milestone guidance, tailorable final verification criteria statements, and verification lessons learned for that particular requirement. To enable a user to select only those requirements (and associated verifications) needed for a particular program specification, this JSSG is arranged with each section 4 verification immediately following its section 3 requirement.

Section 4 consists of sample verifications which have been established for each of the requirements specified in section 3. To enable a user to select only those requirements (and associated verifications) needed for a particular program specification, this JSSG is arranged with each section 4 verification immediately following its section 3 requirement.

The sample verifications contained in this JSSG are intended to result in a progressive in-process review of design maturity consistent with key milestones of the system development and demonstration program schedule. Each verification includes method(s) employed similarly in past programs, which ensure product performance complies with specified levels at the conclusion of the development effort. Each sample also includes incremental verifications intended to establish that the product design is maturing according to the plan profile established by the program as shown in the following figure and that the required performance will be achieved at full maturity. As the product design matures, the fidelity of the incremental verifications improves and the uncertainty in the completed product's performance decreases.



Example incremental verification profile.

Incremental verification methods and timing must not be imposed in the performance specification; rather, they are defined through other tools in the developer's toolbox. These tools include the statement of work, the integrated master plan (IMP) or equivalent program management planning tool, the test evaluation master plan (TEMP) or verification plan, the program master plan (PMP), system engineering master plan (SEMP) and associated contract/program management processes. Acceptance criteria and supporting data should be documented in these tools, allowing effective evaluation of system performance maturity throughout the development program.

Verification of compliance to requirements for complex systems constitutes a significant element of the development cost. As such, the procuring agency should solicit innovative, cost effective verification methods from potential developers during source selection.

For each 3.XXX requirement, a 4.XXX incremental verification should be developed. This verification will consist of an incremental verification table, such as that shown below, and a discussion paragraph. The incremental verification table will consist of requirement elements from the requirements paragraph, associated measurands for each requirement elements, and the recommended incremental verification method(s) for each requirement element at each program milestone.

4.XXX Incremental verification table (example format).

Requirement Elements	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Element A						
Element B						
Element C						
Element D						

Development of the section 4.XXX incremental verification table

Requirement Element: If the section 3.X.X.X statement contains multiple requirement elements, they may be either grouped, when feasible, or identified as a distinct requirement element in the associated 4.X.X.X incremental verification table. Criteria for grouping are based on elements sharing common verification measurands and techniques across all milestones of the program. There must be a one-to-one correlation between the requirement elements in section 3 and section 4.

Measurands: Each section 4.X.X.X incremental verification table will identify the specific performance measurands recommended for use with each requirement element. A measurand is a parameter that can be measured in order to verify a required system/end item feature or characteristic.

Verification Methods: Specific verification methods should be identified for each milestone for the requirement elements. A blank cell is acceptable if no incremental verification is anticipated for a specific milestone.

The following tables describe the milestones and verification methods used in the JSSG incremental verification tables. See 6.4.18 Verification definitions for more detailed definitions of typical milestones and verification methods.

TABLE 4-I. Milestones.

Milestone	Description
SRR/SFR	System Requirements Review/ System Functional Review
PDR	Preliminary Design Review
CDR	Critical Design Review
FFR	First Flight Review
SVR	System Verification Review

TABLE 4-II. Verification methods for the air vehicle specification.

Method	Description
I	Inspection
A	Analysis*
S	Simulation
D	Demonstration
T	Test *

* Note: When the verification effort consists of reviewing/analyzing test data from lower-level tests, the verification method to be used at the higher level should be “Analysis” (i.e., analysis of lower-level test data). For instance, if an Air Vehicle requirement is to be verified by a tier three avionics test, the air vehicle verification would call out an "A" and the tier three avionics verification would call out a "T."

<u>Discussion Section</u>

The discussion section should provide supporting background or justification for the reasoning behind the overall verification process. This section should also provide

a. Clarification of the requirement elements to support verification methods chosen, types of data required, relationships to other requirements, and special test conditions.

b. Clarification of the verification method chosen for each milestone, with identification of alternatives, if applicable, and definition of expectations regarding what verification means for that phase of the program

c. A sample final verification criteria statement which establishes the specific verification tasks and methods which could be employed in verifying that product performance complies with specified levels at the conclusion of the development effort

d. Lessons learned that apply to this particular verification

The discussion section should only address the effort required to verify the specific section 3 requirement. Related verifications that are not required for specific compliance with the requirement, but rather address broader or related issues, should be avoided.

3.1 Operations

3.1.1 Point performance

Design performance shall be as follows: __(1)__.

REQUIREMENT RATIONALE (3.1.1)

The purpose of specifying air vehicle design performance is to bridge the gap between the operational need and the designers' need to have a quantifiable, measurable set of point performance parameters that will shape and size the resulting air vehicle.

REQUIREMENT GUIDANCE (3.1.1)

Complete the requirements to define the performance the air vehicle should be designed to fulfill as part of a military weapons system.

The guaranteed performance statements are an expression of a need to solve a known military requirement or to counter a known or anticipated military threat during a defined time period.

Requirements are supported by document(s) supplied by the user. If an air system specification exists, it should serve as the baseline for all specified air vehicle performance.

However, in the absence of an air system specification, the one document that will be the baseline for all specified performance is the approved program Operational Requirements Document (ORD). The specific conditions under which the requirement must be met need to be stated so verification of the requirement can be accomplished. Conditions must be selected such that an air vehicle that meets the specification performance requirements will meet the intent of the air system specification/ORD.

> Blank 1. Complete by specifying the point performance with operational requirements provided as guarantees. Examples of requirements that could be inserted in blank 1 include dash, climb, acceleration, specific excess power P(s), level flight acceleration time, approach speed, takeoff and landing distance, critical field length, etc. Other unique requirements, including shipboard performance criteria such as minimum altitude loss following wave-off, bolter distance, and minimum altitude loss following a catapult launch, should be included here.

Definitions and conditions that pertain to the performance requirements are contained in Appendix D to this document (which applies to fixed wing air vehicle being specified); Appendix E (which applies to rotary wing air vehicles); and Appendix C (which includes the flying qualities for specific air vehicle applications such as shipboard and VSTOL use).

The air vehicle mass properties should support vehicle operation for all defined mission requirements, basing/deployment concepts and interfaces, and necessary maintenance configurations. Gross weight should consist of appropriate elements and/or sub-elements of the air vehicle weight empty, the operating items, the usable fuel and payload for the mission or loading, items to be expended during flight, and any other configuration-specific items. In addition, there may be a maximum weight or not-to-exceed value. Any growth provisions must also be considered. In addition, explicit limitations or constraints on any air vehicle mass properties (weights, centers of gravity, or inertias) that result from the mission requirements, interfaces with other systems, or the operational environment must be identified for each air vehicle configuration(s) and load condition(s) to which the limit applies. Weight definitions for many typical configurations of interest are included in section 6 of this document. Other mass properties terminology and definitions are addressed in the Society of Allied Weights Engineers

Recommended Practices No. 7 and 8. These definitions should be tailored as appropriate and included in section 6 of a specific procurement specification to ensure mutual understanding.

These or any other weight configurations may be incorporated as requirements in this section for added emphasis as deemed appropriate.

Specific unit weights may need to be identified here as well. These should also be tailored as appropriate. See below for examples.

Unit Weights. Mass properties used for air vehicle design, analysis, and test should be based on the following unit weights.

	POUNDS
Crew (each)	
Military crew (without body armor or parachute)	200.0
Nonmilitary crew (normal clothing only)	180.0
Passenger (each): (without parachute)	180.0
Marine combat troop	240.0
Litter patients (Includes 30 lbs. for litter, splints and blankets)	230.0
Rescuee (rescued from water) with gear, water soaked, and less parachute	220.0
Fuel (per gallon)	
AV Gas	6.0
MIL-PRF-5624 (Grade JP-4)	6.5
MIL-PRF-5624 (Grade JP-5).	6.8
MIL-T-83133 (Grade JP-8)	6.8
Oil (per gallon) MIL-PRF-23699	8.4
Water injection fuel (per gallon): 50/50 mixture	7.5
Anti-icing fluid MIL-A-8243 (per gallon)	6.6
Hydraulic fluid MIL-PRF-83282 (per gallon)	7.0
Fresh water (per gallon)	8.33

REQUIREMENT LESSONS LEARNED (3.1.1)

The size, complexity, and cost of the air vehicle are a direct function of the performance requirements. The primary cause of increases in these items is the imposition of requirements beyond the ORD and beyond the realistic military realm of operation of the air vehicle. At the same time, however, it is imperative that the requirements ensure at least the minimum capability needed in the operational world.

4.1.1 Point performance verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Required air vehicle point performance	(1)	A	A,S	A,S	A,S	A,D, S,T

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.1.1)

Preflight verification for the point performance should be performed with a combination of analysis of design, analysis and inspection of modeling/simulation results, and analysis of wind tunnel testing results. Wind tunnel testing should be used to determine the air vehicle's lift and drag characteristics and engine installation losses to be applied to the uninstalled engine performance models. These air vehicle and engine characteristics and models should be used to predict the air vehicle's point performance capability.

Final verification for the point performance capability should be performed with a combination of analysis of design, analysis and inspection of modeling/simulation results, analysis of wind tunnel testing results, flight demonstration, and flight testing using standard flight test techniques. In-flight net propulsive forces and moments should be calculated from in-flight engine measurements, wind tunnel engine thrust calibrations, inlet pressure recovery determined from flight test measurements, and predicted inlet and nozzle power dependent forces and moments from wind tunnel model test data. Air vehicle drag should be determined from net propulsive forces and moments, and from air vehicle flight test acceleration/ deceleration, and rate of climb/descent. The resulting flight test drag polars should be in accordance with a thrust drag accounting system. All configurations such as clean, doors open, external stores, and ferry should be tested. Final verification for 3.1.1 Point performance should be calculated using flight test drag polars, production air vehicle weight and fuel quantities, and engine uninstalled performance corrected for flight test inlet pressure recovery, bleed and horsepower extraction, and inlet/ nozzle power setting effects. The inlet/nozzle power setting effects used should be identical to those used to derive the flight test drag polars.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of program conceptual design ensures that the specified flight envelope requirements and related mission requirements are addressed. Analysis indicates requirements have properly been allocated to all air vehicle system and subsystem requirements.

PDR: Analysis of the preliminary air vehicle design and lower-tier specifications ensures allocation of appropriate lower-tier requirements. Analysis of the preliminary design and flight simulation/modeling indicates the air vehicle's ability to achieve successful system point performance. This analysis, simulation, modeling should be performed on an iterative basis as the contractor modifies his design.

CDR: Analysis of air vehicle design, updated analysis of lower-level test/demonstration data, simulation and modeling results, and analysis and inspection of wind tunnel test results confirms the air vehicle can meet all point performance requirements.

FFR: This incremental verification milestone should be tailored based on the specified point performance requirement that may impact first flight. Typically, verifications would include analysis and simulations.

SVR: Analysis of lower-level test and demonstration data, flight simulation and modeling, wind tunnel tests, and ground/flight demonstrations and tests confirms the air vehicle can meet point performance requirements.

Sample Final Verification Criteria

The air vehicle point performance requirements shall be satisfied when the achieved__(1)__ analyses, __(2)__ demonstrations, __(3)__ simulations, and __(4)__ tests confirm point performance.

Blank 1. Identify the type and scope of analysis required to provide confidence that the requirement elements have been met.

Blank 2. Identify the type and scope of demonstrations required to provide confidence that the requirement elements have been met.

Blank 3. Identify the type and scope of simulations required to provide confidence that the requirement elements have been met.

Blank 4. Identify the type and scope of tests required to confirm that the requirement elements have been met.

VERIFICATION LESSONS LEARNED (4.1.1)

To Be Prepared

3.1.1.1 Flight envelope

The air vehicle speed, altitude, range, and G capability shall meet the following criteria: __(1)__.

REQUIREMENT RATIONALE (3.1.1.1)

A flight envelope succinctly discloses the key performance characteristics that the air vehicle is expected to achieve.

REQUIREMENT GUIDANCE (3.1.1.1)

Blank 1. Complete by including a figure showing the required flight envelope characteristics.

REQUIREMENT LESSONS LEARNED (3.1.1.1)

A flight envelope is the preferred approach for defining the required end points of air vehicle performance.

4.1.1.1 Flight envelope verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Required air vehicle flight envelope	(1)	A	A,S	A,S	A,S	A,D, S,T

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.1.1.1)

Preflight verification for the flight envelope should be performed with a combination of analysis of design, analysis of modeling/simulation results, and analysis of wind tunnel testing results. Wind tunnel testing should be used to determine the air vehicle's lift and drag characteristics and engine installation losses to be applied to the uninstalled engine performance models. These air vehicle and engine characteristics and models should be used to predict compliance with the specified flight envelope.

Final verification for the flight envelope should be performed with a combination of analysis of design, analysis of modeling/simulation results, analysis of wind tunnel testing results, flight demonstration and flight testing. In-flight net propulsive forces and moments should be calculated from in-flight engine measurements, wind tunnel engine thrust calibrations, inlet pressure recovery determined from flight test measurements, and predicted inlet and nozzle power dependent forces and moments from wind tunnel model test data. Air vehicle drag should be determined from net propulsive forces and moments and air vehicle flight test acceleration/deceleration, rate of climb/descent. The resulting flight test drag polars should be in accordance with a thrust drag accounting system. All configurations such as clean, doors open, external stores and ferry should be tested. Final verification for compliance with 3.1.1.1 Flight envelope should be calculated using flight test drag polars, production air vehicle weight and fuel quantities, and engine uninstalled performance corrected for flight test inlet pressure recovery, bleed and horsepower extraction, and inlet/ nozzle power setting effects. The inlet/nozzle power setting effects used should be identical to those used to derive the flight test drag polars.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of air vehicle design concept indicates the specified flight envelope requirements and related mission requirements are addressed. Analysis indicates requirements have properly been allocated to air vehicle subsystem requirements.

PDR: Analysis of the preliminary air vehicle design and lower-tier specifications ensures the allocation of appropriate lower-tier requirements. Analysis of the design and flight simulation/modeling indicates that the air vehicle can achieve the specified flight envelope. This analysis, simulation, and modeling should be performed on an iterative basis as the contractor modifies his design.

CDR: Analysis of final air vehicle design, updated analysis of lower-level test/demonstration data, analysis of simulation and modeling results, and analysis of wind tunnel test results confirm the ability of the air vehicle to successfully meet the specified flight envelope.

FFR: Analysis of wind tunnel tests and simulations confirms the interim flight test envelope risks are defined. The interim flight test envelope is a specified subset of the total flight envelope deemed sufficient for demonstrating initial air vehicle capabilities.

SVR: Analysis of lower-level test, flight simulation and modeling, demonstrations, wind tunnel tests, and flight tests confirm the air vehicle can meet the specified flight envelope.

Sample Final Verification Criteria

The flight envelope requirements shall be satisfied when __(1)__ analyses, __(2)__ simulations, __(3)__ demonstrations, and __(4)__ tests confirm the air vehicle can meet the specified flight envelope.

Blank 1. Identify the type and scope of analysis required to provide confidence that the requirement elements have been met.

Blank 2. Identify the type and scope of simulations required to provide confidence that the requirement elements have been met.

Blank 3. Identify the type and scope of demonstrations required to provide confidence that the requirement elements have been met.

Blank 4. Identify the type and scope of tests required to confirm that the requirement elements have been met.

VERIFICATION LESSONS LEARNED (4.1.1.1)

To Be Prepared

3.1.1.1.1 Aerial refueling envelope

The air vehicle shall be capable of aerial refueling operations throughout the __(1)__ envelope in accordance with __(2)__.

REQUIREMENT RATIONALE (3.1.1.1.1)

This is a safety and operational compatibility requirement. The tanker and receiver air vehicles must have a similar airspeed and altitude envelope in which they can operate their aerial refueling subsystem(s) to facilitate successful aerial refueling. The specific aerial refueling procedures to be used during aerial refueling operations can dictate many of the design requirements of tanker and receiver aerial refueling subsystems. As such, it is necessary to identify the aerial refueling procedures to be employed to ensure safe and successful aerial refueling operations can be accomplished.

REQUIREMENT GUIDANCE (3.1.1.1.1)

Blank 1. Specify the envelope in terms of airspeed range (KCAS) and altitude range (pressure altitude - feet).

Blank 2. Specify the conditions that define the interfaces between the air vehicle and the aerial refueling tankers. Reference to requirements 3.4.6.2.1 Receiver interfaces and 3.4.6.2.2 Tanker interfaces could be appropriate. If it is necessary to specify procedural operations in this paragraph, as a minimum, specify NATO STANAG 3971 and Allied Tactical Publication (ATP) 56, Air-to-Air Refueling. If other procedures are also required, ensure the procedures adequately address all factors involved in the aerial refueling operations. Procedures must address day versus night conditions (with and without night vision goggles), employment versus deployment scenarios, tanker and receiver rendezvous methods, communication techniques under various threat levels for detection or intercept, tanker and receiver formation techniques under single and multiple tanker and single or multiple receiver combinations, and tanker/receiver contact process under single/multiple receiver combinations.

REQUIREMENT LESSONS LEARNED (3.1.1.1.1)

The airspeed and altitude envelope within which existing tanker and receiver aerial refueling subsystems are able to operate varies from subsystem to subsystem. There are multi-point drogue tankers which have a wing pod subsystem with an airspeed and altitude operational envelope quite different from their centerline hose reel subsystem. Each receiver has its unique airspeed and altitude envelope within which to operate its aerial refueling subsystem(s). Whether it is a new tanker aerial refueling subsystem or a receiver aerial refueling subsystem being developed, the defined airspeed and altitude envelope for each aerial refueling subsystem should be made as broad as possible to maximize operational utility of the subsystem and mission flexibility for the air vehicle.

The U.S. Government has agreed to comply with NATO STANAG 3971 without reservation or exception. As such, all new receiver/tanker air vehicles with an aerial refueling subsystem should be able to conduct aerial refueling operations per NATO STANAG 3971 procedures.

New receiver aircraft should be able to refuel using the procedures that have been established for each tanker aerial refueling subsystem on the fielded tanker. Each tanker and each tanker aerial refueling subsystem can have unique procedures associated with them. The aerial refueling procedures with USAF KC-135 tankers (boom and drogue subsystems) are provided in TO 1-1C-1-3. Aerial refueling procedures with USAF KC-10 tankers (boom and drogue subsystems) are provided in TO 1-1C-1-33. Aerial refueling procedures with USAF HC/MC-130 tankers (wing drogue subsystems) are provided in TO 1-1C-1-20. Aerial refueling procedures with US Navy/USMC tanker assets are provided in NAVAIR NATOPS 00-80T-110.

New tanker aircraft should be capable of aerial refueling fielded receiver air vehicles using procedures consistent with the receiver air vehicle's existing aerial refueling procedures. The USAF has defined aerial refueling procedures with each receiver air vehicle. These procedures are contained within a series of TOs numbered 1-1C-1-XX (XX designates a unique number for each receiver air vehicle, e.g., 1-1C-1-35 is for the C-17). Aerial refueling procedures for the U.S. Navy and USMC receivers are provided in the NATOPS flight manual for each air vehicle.

NATO STANAG 3971 (ATP 56) contains a Point of Contact (POC) list for current allied tankers and receivers. When aerial refueling support is to be provided to, or obtained from, allied air vehicles, the POC should be contacted to determine if any unique changes/exceptions to the aerial refueling procedures in the document are required to be compatible with their air vehicles. An allied country may have agreed to the STANAG with reservations or concurred with the document for future air vehicles but may have takenexception for existing air vehicles at the time of coordination.

Receiver air vehicles should not require the tanker aircrew or aerial refueling subsystem to adopt special procedures. For example, the number of tanker aerial refueling pumps being used to transfer fuel should remain constant during the aerial refueling process. In the past, some receivers have required the tanker to limit the number of pumps used to initially transfer the fuel due to fuel pressure transients. Once a steady-state flow condition was obtained, the tanker was then able to increase the number of aerial refueling pumps used to transfer the fuel. Similarly, requiring the tanker to reduce the number of aerial refueling pumps being used near the end of the fuel transfer process to alleviate fuel surge pressures should be avoided.

4.1.1.1.1 Aerial refueling envelope verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Air vehicle is capable of aerial refueling operations throughout the specified envelope	(1)	A	A	A,S		A,S, D,T, I

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.1.1.1.1)

Verification of the requirements for tanker and receiver aerial refueling operations is adequately covered by verification paragraphs for 3.4.6.2.1 Receiver interfaces and 3.4.6.2.2 Tanker interfaces. The following verification discussion is limited to the approach for verifying 3.1.1.1.1 Aerial refueling envelope.

Realizing the verification for 3.1.1.1 Flight envelope will precede 3.1.1.1.1 Aerial refueling envelope verification, the flight envelope precedent-setting requirements and verifications will become baselines for the ensuing aerial refueling envelope verifications. Therefore, any refueling features or characteristics that have not been inspected, analyzed, simulated, tested or demonstrated during the expanding verification of 3.1.1.1 Flight envelope should be conducted. This approach is intended to minimize or eliminate verification duplication of equivalent flight envelope characteristics. The objective of 3.1.1.1.1 Aerial refueling envelope verification is ultimately to verify the tanker and receiver air vehicles have a similar airspeed and altitude envelope within which they can successfully operate their aerial refueling subsystem(s). This also includes employment of the refueling boom or drogue systems, or both, that may be deployed with the air vehicle during aerial refueling.

Essentially, the verifications should be accomplished by integrating a series of analyses followed by simulations, tests, and demonstrations to verify the aerial refueling envelope.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the air vehicle design concept indicates that comparative efforts will be conducted as a function of evolving the flight envelope as compared with the aerial refueling envelope. Analysis of the proposed aerial refueling envelope indicates that the aerial refueling envelope requirement could be met.

PDR: Analyses of the preliminary air vehicle design indicates that the required aerial refueling envelope is achievable and is compatible with the overall flight envelope requirement. Analysis defines those aerial refueling simulations that may be integrated with the overall flight envelope simulations. Analysis indicates any required modeling for aerial refueling wind tunnel testing has been determined.

CDR: Analysis of completed wind tunnel modeling tests and flight and aerial refueling simulations confirms the ability of the air vehicle to achieve the specified aerial refueling envelope.

FFR: No unique verification action occurs at this milestone.

SVR: Analysis, simulations, demonstrations, inspections, and tests confirm that the aerial refueling envelope has been successfully achieved and risks have been eliminated or are consistent with the specified requirements.

Sample Final Verification Criteria

The aerial refueling envelope shall be satisfied when __(1)__ analyses, __(2)__ simulations, __(3)__ demonstrations, and __(4)__ tests of the air vehicle aerial refueling envelope and the subsequent __(5)__ inspections confirm that the aerial refueling envelope requirements have been met.

Blank 1. Identify the type and scope of aerial refueling flight and ground tests and analyses required to confirm that the air vehicle aerial refueling envelope has been met.

Analyses should include, but are not limited to, aerodynamic and structural loading of the aerial refueling equipment and attachment structure throughout the specified airspeed and altitude. Tanker and receiver controllability analysis should be performed throughout the center of gravity (c.g.) and gross weight range. Receiver analyses should include one-engine-out refueling capability (when applicable), effect of the receiver's bow wave on the boom or drogue, and specific power of the engine(s) for closure rate and climb capability. Analyses with boom systems should include controllability of the boom while both connected and disconnected from the receiver, latch forces throughout the applicable range of temperatures and disconnect rates, latch and unlatch times, and flutter analysis throughout the operational envelope. Hose and drogue systems should consider hose response and take-up rate, hose extension capability, drogue stability, and catenary curve. Ventilation analysis for vapor dilution should be conducted for all phases of the mission, including, but not limited to, static or low speed ground operations, high altitude/low air density, and other unique conditions.

Blank 2. Identify the type and scope of aerial refueling flight simulations required to confirm that the air vehicle aerial refueling envelope has been met.

Blank 3. Identify the type and scope of aerial refueling flight demonstrations required to confirm that the air vehicle aerial refueling envelope has been met.

Demonstrations should include, but are not limited to, demonstration of tanker flying qualities and receiver handling qualities throughout the altitude, airspeed, and gross weight ranges. Boom controllability and hose and drogue stability should be assessed throughout the operating envelope including evaluation of the gross weight range of the tanker and receiver. Bow wave effects of various receivers on a boom or drogue should be evaluated. For hose and drogue systems, catenary curve and hose response should be evaluated. For boom systems, latch and unlatch times must be determined. Demonstrations of receiver engine power availability for tanker closure, including one-engine-out power-level evaluations, should be performed when applicable.

Blank 4. Identify the type and scope of aerial refueling flight and ground tests required to confirm that the air vehicle aerial refueling envelope has been met.

Tests should include structural load evaluation of the aerial refueling equipment such as probe and boom loads, latch forces of boom systems at all temperatures within the operating envelope and including rigid disconnects. Other tests should be discussed in the Receiver and Tanker Interfaces verification sections of this specification. For rollover type refueling receptacles, flight tests should be conducted to ensure that opening and closing times could be met. Simulated ground tests may be applicable if all flight parameters (e.g., temperature, aero loads, and aircraft structure) can be emulated.

Blank 5. Identify the type and scope of post-flight aerial refueling inspections, if any, that should be conducted relative to ensuring that the aerial refueling envelope requirement has been met.

Inspections should include, but are not limited to, fluid leakage, UARRSI box drainage, and general equipment health including cracks, bends, and unusual wear. Hose and drogue systems should include hose damage and wear and drogue canopy damage.

VERIFICATION LESSONS LEARNED (4.1.1.1.1)

To Be Prepared

3.1.1.2 Ground performance

The air vehicle, including external stores, shall not contact the ground or shipboard deck surfaces except for __(1)__during all nonemergency landings and ground operations on runways, taxiways, ships from which the air vehicle must operate, including surface imperfections not greater than six inches, and __(2)__. The air vehicle shall be capable of turns with not greater than __(3)__ lateral acceleration without tipback or tipover. The air vehicle shall be capable of reverse braking on a __(4)__ slope for all c.g. and loading conditions. The air vehicle shall be capable of 180-degree turns without stopping, backing, or differential braking on a __(5)__ foot wide runway/taxiway. The air vehicle shall be capable of ground operations for up to __(6)__ passes over California bearing ratio (CBR) __(7)__ soft field conditions, and shall be capable of unlimited ground operations on a runway facility of load classification number (LCN) __(8)__ or greater. The air vehicle shall be able to traverse, take off, and land on repaired runways including __(9)__ runway bomb crater repair bumps.

REQUIREMENT RATIONALE (3.1.1.2)

Consistent ground performance is expected to occur collaterally with consistent flight performance. The air vehicle and all stores carried (including fuel tanks, armament, sensors) should not strike the ground or deck during normal operation and operation with failures which induce asymmetric loadings. In order to be effective, the air vehicle should be capable of rapid and efficient movement while on various runway types.

REQUIREMENT GUIDANCE (3.1.1.2)

Blank 1. Include those parts of the air vehicle such as tires, tail skids, or arresting hook that would normally be expected to touch the ground or deck during normal operations.

Blank 2. Identify the deck edge wheel stop height associated with the ships from which the air vehicle is required to operate. For CV/CVN class ships, a value of six inches is recommended. For all other class ships, a value of twelve inches is recommended.

Blank 3. Identify the lateral acceleration during turns that the air vehicle should withstand without tipback or turnover. Assure all conditions are addressed to assure safe and efficient turns. The recommended value for blank 3 is 0.5g.

Blank 4. Identify the maximum slope to which the air vehicle will be exposed and with which it will be required to use self-braking. The typical value to insert in blank 4 for land-based air vehicles is “not greather than 3 degrees,” but the value selected may be dependent on air vehicle anticipated basing. Ship-based air vehicles would require a greater anticipated deck angle pitch or roll.

Blank 5. Identify the minimum width of the runway or taxiway on which the air vehicle will be required to turn 180 degrees. This width may or may not be the minimum width of all the runways/taxiways on which the air vehicle will operate. Select the most practicable width for design based on runway/taxiway anticipated usage and air vehicle cost. The typical value used for design is 50 feet.

Blank 6. Identify the maximum number of air vehicle landings required on CBR soft field conditions. The typical design number of landings for CBR 9 soft field conditions is 50.

Blank 7. Identify the worst-case CBR landing field required with which the air vehicle should be compatible. The typical CBR value used for fixed wing air vehicles is 9.

Blank 8. Identify the load classification number for the airfield type will be utilized most of the time by the air vehicle. The typical LCN utilized for fixed wing air vehicles is 28.

Blank 9. Identify the worst-case crater type in which the air vehicle will be required to taxi. The typical design value for fixed wing air vehicles is E-type.

REQUIREMENT LESSONS LEARNED (3.1.1.2)

The ground performance disclosed in Appendixes D and E needs to be augmented to assure ground performance expectations are achieved. The 6-inch minimum deck clearance requirement for CV/CVN class ships with either armament or fuel tanks installed has been difficult to achieve. However, it needs to be stipulated early in the design process. This requirement is a safety issue and is significant during the air vehicle launch and landing cycle. During air vehicle takeoff or arrestment, any contact with the catapult or the deck can be catastrophic.

Ground or deck clearances for all parts of the air vehicle, such as propeller(s), anti-torque tail rotor, structure (exclusive of tail bumper, wheel or skid structure, arresting hook in extended position), fairings, control surfaces, flaps, speed brakes, external stores, antennae, hatches and open weapon bay doors in their most critical configurations should be considered. Clearances for failure states, such as flat tire(s), over or under-extended wheel struts, etc., should be considered. Dynamic conditions such as those experienced during ground maneuvers, particularly onboard a moving ship, must be considered.

4.1.1.2 Ground performance verification

Each requirement element should be subdivided into all specified conditions. For example, dynamic ground clearance should be measured, with and without stores, for each specified dynamic condition (lateral acceleration, turns, landing, …etc.).

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Air vehicle, including external stores, do not contact the ground or shipboard deck surfaces	Pass/Fail {no ground contact except (1)}	A	A,S	A,S	T,S, D	A,S, D,T
Air vehicle ground turn performance	Pass/Fail {(3) with no tipback or turnover, and (5) with no differential braking, stopping or backing}	A	A,S	A,S	T,S, D	A,S, D,T
Air vehicle ground braking performance	Pass/Fail with (4) for all c.g. and load conditions	A	A,S	A,S	T,S, D	A,S, D,T
Air vehicle ground operations on soft field	(6) when using (7); unlimited when using (8)	A	A,S	A,S	T,S, D	A,S, D,T
Air vehicle ground operations on repaired runways	Pass/Fail with (9)	A	A,S	A,S	T,S, D	A,S, D,T

*Numbers in parentheses in the Measurand column refer to numbered blanks in the requirement.

VERIFICATION DISCUSSION (4.1.1.2)

Verification of the ground performance requirement should be accomplished by integrating analysis with demonstrations and tests of specified static/dynamic ground and shipboard deck operations, as well as takeoffs and landings. During air vehicle developmental activities, substantial data is typically obtained that could be used to verify this requirement. Use of this type of data should be maximized to avoid the cost and schedule impacts of a formal demonstration.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analysis of the design concept indicates the design approach is considering all ground performance requirements. Any unique ground or deck requirements of the air vehicle that would tend to adversely affect the 3.1.1.2 Ground performance requirements for the air vehicle are defined.

PDR: Analysis of the preliminary air vehicle design, simulations, and lower-level demonstrations and tests indicate the air vehicle ground performance meets all specified requirements

CDR: Analysis of the final air vehicle design, simulations, and lower-level demonstrations and tests confirm that the air vehicle design is compatible with the air vehicle ground performance requirements. Any areas of incompatibility that dictate a unique design have been thoroughly researched, and trade-offs are presented for review.

FFR: Ground performance testing, simulations, and demonstrations confirm readiness for first flight.

SVR: Analysis of lower-level testing and demonstrations, as well as simulations, demonstrations, and testing of the air vehicle, confirm that specified ground performance has been met.

Sample Final Verification Criteria

The ground performance requirements shall be satisfied when __(1)__ analysis, __(2)__ simulations, __(3)__ demonstrations, and __(4)__ tests confirm that the specified requirements have been met.

Blank 1. Identify the type and scope of analysis required to provide confidence that the requirement has been satisfied for static and dynamic conditions.

Blank 2. Identify the type and scope of simulations required to provide confidence that the requirement has been satisfied for static and dynamic conditions.

Blank 3. Identify the type and scope of demonstrations required to provide confidence that the requirement has been satisfied for static and dynamic conditions.

Blank 4. Identify the type and scope of tests required to provide confidence that the requirement has been satisfied for static and dynamic conditions.

VERIFICATION LESSONS LEARNED (4.1.1.2)

To Be Prepared

3.1.2 Mission profile(s) performance

The air vehicle shall have the capability to perform the following mission profiles: __(1)__.

REQUIREMENT RATIONALE (3.1.2)

The purpose of specifying air vehicle mission performance is to bridge the gap between the operational need and the designers' need to have a quantifiable, measurable set of engineering parameters that will shape and size the resulting air vehicle. The purpose of specifying the mission profile is to define the stresses applied to the air vehicle to develop design limits, margins, reliability estimates, life, etc. This requirement represents a decomposition of an air system roles and missions requirement.

REQUIREMENT GUIDANCE (3.1.2)

The completed requirement 3.1.2 Mission profile(s) performance is intended to present narrative mission statements and associated mission profiles defining the performance the air vehicle should be designed to fulfill. The guaranteed performance statements are an expression of a need to solve a known military requirement or to counter a known or anticipated military threat during a defined time period. Requirements are supported by document(s) supplied by the user.

If an air system specification exists, it should serve as the baseline for all specified air vehicle performance. However, in the absence of an air system specification, the one document that will be the baseline for all specified performance is the approved program Operational Requirements Document (ORD). The specific conditions under which the requirement must be met need to be stated so the requirement can be verified. Conditions must be selected such that an air vehicle that meets the specification performance requirements will meet the intent of the air system specification/ORD.

Blank 1. Complete by specifying the mission profile(s) with operational requirements provided as guarantees. Refer to appendices D and E for the mission profiles to be specified under blank 1. Definitions and conditions pertaining to the performance requirements are contained in appendix D for fixed wing air vehicles, and appendix E for rotary wing air vehicles.

REQUIREMENT LESSONS LEARNED (3.1.2)

To Be Prepared

4.1.2 Mission profile(s) performance verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Air vehicle mission profile(s)	(1)	A	A,S	A,S	A,S	A,D, S,T

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.1.2)

Preflight verification for the mission profile performance should be performed with a combination of analysis of design, analysis and inspection of modeling/simulation results, and analysis of wind tunnel testing results. Wind tunnel testing should be used to determine the air vehicle's lift and drag characteristics and engine installation losses to be applied to the uninstalled engine performance models. These air vehicle and engine characteristics and models should be used to predict the air vehicle's mission profile performance capability.

Final verification for the mission profile performance capability should be performed with a combination of analysis of design, analysis and inspection of modeling/simulation results, analysis of wind tunnel testing results, flight demonstration, and flight testing using standard flight test techniques. In-flight net propulsive forces and moments should be calculated from in-flight engine measurements, wind tunnel engine thrust calibrations, inlet pressure recovery determined from flight test measurements, and predicted inlet and nozzle power dependent forces and moments from wind tunnel model test data. Air vehicle drag should be determined from net propulsive forces and moments, and air vehicle flight test acceleration/deceleration, rate of climb/descent. The resulting flight test drag polars should be in accordance with a thrust drag accounting system. All configurations such as clean, doors open, external stores, and ferry should be tested. Final verification for this requirement is compliance with 3.1.2 Mission profile(s) performance. Verification should be calculated using flight test drag polars, production air vehicle weight and fuel quantities, and engine uninstalled performance corrected for flight test inlet pressure recovery, bleed and horsepower extraction, and inlet/ nozzle power setting effects. The inlet/nozzle power setting effects used should be identical to those used to derive the flight test drag polars.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of program conceptual design ensures that the specified mission profile requirements and related mission requirements are addressed. Analysis indicates requirements have been allocated properly to all air vehicle system and subsystem requirements.

PDR: Analysis of the preliminary air vehicle design and lower-tier specifications ensures allocation of appropriate lower-tier requirements. Analysis of the preliminary design and flight simulation/modeling indicates the air vehicle's ability to achieve successful system mission profile performance. This analysis and simulation or modeling should be performed on an iterative basis as the contractor modifies his design.

CDR: Analysis of air vehicle design, updated analysis of lower-level test/demonstration data, simulation and modeling results, and analysis and inspection of wind tunnel test results confirms the air vehicle can meet all mission profile performance requirements.

FFR: No unique verification action occurs at this milestone.

SVR: Analysis of lower-level test and demonstration data, flight simulation and modeling, wind tunnel tests, and ground/flight demonstrations and tests confirms the air vehicle can meet mission profile performance requirements.

Sample Final Verification Criteria

The air vehicle mission profile performance requirements shall be satisfied when the __(1)__ analyses, __(2)__ demonstrations, __(3)__ simulations, and __(4)__ tests confirm mission profile performance.

> Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement elements have been met.
>
> Blank 2. Identify the type and scope of demonstrations required to provide confidence that the requirement elements have been met.
>
> Blank 3. Identify the type and scope of simulations required to provide confidence that the requirement elements have been met.
>
> Blank 4. Identify the type and scope of tests required to confirm that the requirement elements have been met.

VERIFICATION LESSONS LEARNED (4.1.2)

To Be Prepared

3.1.2.1 Threat environment

The air vehicle shall have the capability to conduct missions within the threat scenarios and conditions stipulated in table 3.1.2.1-I.

TABLE 3.1.2.1-I. Threat scenarios and conditions.

ID	Scenario	Role	Mission	Vignette	Mission/ Vignette Mix	Threat	Time	Remarks

REQUIREMENT RATIONALE (3.1.2.1)

This section delineates the threat scenarios against which air vehicle requirements are defined. The scenarios need to address a complete representation of the threat environment within which the air vehicle is expected to operate. These would include peacetime operations, wartime operations, and conditions other than war. While it may be impossible to predict with certainty all the conditions that an air vehicle might be called upon to perform, the descriptions provided need to be suitable for establishing a requirements/design point for air vehicle definition and be a sufficient representation for life cycle requirements and management. Without this definition of the stressing elements, the performance requirements are incomplete and the context for the allocated parameters cannot be established.

REQUIREMENT GUIDANCE (3.1.2.1)

Including thorough scenario and threat information in a table may not be feasible. If not, cite appropriate reference documents or provide the information in paragraph form.

Guidance for completing table 3.1.2.1-I follows:

ID: This requirement (and table) may be referenced from numerous locations in the document. A unique identifier (such as a line number) will assist document users in unambiguously locating the appropriate reference.

Scenario: Separate data may be needed for each unique scenario. An air vehicle may have more than one role or mission in a given scenario (or vice versa). Generally, an air vehicle must be capable of performing effectively in multiple scenarios. For example, peacetime training and wartime conflicts constitute two scenarios. Training conducted by dedicated training assets will be a different scenario than training conducted by operational units. Scenario information is not limited to bed-downs and locations. Operational factors such as decision processes rules of engagement and mission tasking can be scenario dependent also. Be sure to provide complete information.

Role: Enter the general description of the task(s) to be accomplished. For example, air-to-air, air-to-ground, aerial refueling, and training would be valid entries.

Mission: Identify the mission (e.g., combat air patrol or tanker support) to be conducted and a mission description. Appendix D can be consulted when determining mission tasks. The description includes a top-level (generic) mission profile identifying reference points (e.g., loiter reference points, orbit location(s) reference points, profile/speed/altitude change reference points). Depending on the translation of operational requirements into a system specification, the profile(s) could be as simple as "launch, climb, cruise to within XX miles of the forward line of own troops (FLOT), dash in to target area, deliver weapons, dash out from target area, cruise to descend point, descend, land." They could also be a bit more complex, identifying some minimum speed conditions and/or altitude bands; for example, "launch, climb to medium altitude (with a definition of what this altitude range is), cruise to within XX miles of the FLOT, dash at Mach XX or better in to the target area, deliver weapons at medium altitude supersonically (or leave it blank), etc." The intent is to provide sufficient information to scope the mission. The more specific the profile, the more constrained the resulting air vehicle solution would be. Provide sufficient latitude. Do not specify what is not necessary to meet operational requirements. Focus on the air vehicle characteristics that may satisfy the objective. The profile should be refined (specific speeds and altitudes) along with specific air vehicle capabilities. Missions address those planned or expected in peacetime conditions, wartime conditions, and conditions other than war.

Vignette: A vignette (sometimes referred to as a mini-scenario) can be viewed as a single-mission portion of a campaign. It is a two-sided situation that encompasses air vehicle employment conditions. It describes starting and ending conditions, the numbers of air vehicles involved, their tactics and operating conditions, the targets and their location, the relationships between air vehicles, factors of the natural environment (including weather conditions and terrain), conditions of the operational environment (including dust and smoke), and any other operationally significant factors. It must be sufficiently broad to assess the interactions between like air vehicles in the flight and accommodate the interactions with air vehicles external to the flight. Each vignette needed in the definition of the air vehicle should be incorporated into the descriptions and conditions. A vignette can also have a variety of associated conditions that describe specific characteristics of air vehicle operations to be conducted. Note that a vignette used to explore candidate air vehicle definitions at the start of initial product definition is substantively different from that used in a system specification. A mission may have multiple associated vignettes. To minimize ambiguity, repeat the mission and other information (i.e., a new line in the table) for each vignette.

Some specific survivability conditions (i.e., one-on-one survivability) to reflect in the vignettes include the overall threat distribution and density. For example, assume that the mission involves a single air vehicle penetrating enemy airspace at low altitude. Further, assume that the air vehicle would enter the engagement envelope of only ten threat systems out of the one hundred threat systems in the overall scenario. The vignette must be sufficiently encompassing to ensure that the air vehicle's threat detection capabilities are not limited to just the ten threat systems that are engaging it, but also the other ninety in the scenario. That is, the air vehicle's survival capability may be strongly influenced by its ability to assess the entire environment and focus pertinent survival equipment and operating modes on the ten percent that reflect the danger to this mission.

Mission/Vignette Mix: Enter the percentage of each mission/vignette type expected for the specified role and mission. This is the percentage of missions expected to be flown for the indicated mission.

Threat: The threats against the air vehicle are found in a threat description document validated by the intelligence community. DoD 5000.2 refers to the threat description document as System Threat Assessment Report (STAR). The table or text would describe the threat tactics for the defined threat and establish the threat environment in which the total weapon system must provide the specified performance. The campaign and engagement simulations used in design and verification of parameters should include the appropriate representation of the threat as described in the threat documents. The recommended method for specifying threat information is to attach a threat appendix (or create and reference a separate document) that defines threat characteristics and engagement rules in sufficient detail to serve as a basis for establishing conditions for lower-level requirements, design, and air vehicle verification. This extension of the STAR should have an endorsement by the user's intelligence community that the suggested implementation is consistent with the STAR and with tactics and doctrine of the enemy. The STAR extension should be the basis for all simulations and analyses. Threat data needs to include target and other information necessary to support assessment and verification of the requirements in the specification; for example, target vulnerability information to support lethality assessments; air defense numbers, locations, and capabilities to support survivability assessments and verifications; etc.

Time: In this column, enter the year in which the air vehicle is expected to be operational. Valid entries are 2000, 2010 etc.

Remarks: Enter any additional information which does not fall into the categories defined by the column titles but is necessary to further identify air vehicle constraints.

REQUIREMENT LESSONS LEARNED (3.1.2.1)

The following information may be appropriate for inclusion in this requirement:

a. A matrix, or document, which provides information on the friendly forces likely to be in the environment. The requirement may be to locate and ID friendly forces or merely to recognize and avoid ambiguities.

b. The signal environment description will be a document which lists the types, numbers, location, concept of operations, etc. of threats, blue and grey forces, as well as background signals including commercial radars, communications, satellite links, etc.

c. A list of radars, vehicles, communication nodes, etc., that the air vehicle system must be able to target.

d. A matrix or document which provides information on the friendly forces that are likely to be in the environment. The requirement may be to locate and ID friendly forces or just to recognize and avoid ambiguities.

e. The environmnet description will be a document that lists the types, numbers, location, operational concept of operations, etc., of threats, blue and grey forces. It also contains background signals including commercial radars, communications, satellite links, etc.

4.1.2.1 Threat environment verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Capability to conduct missions within the threat scenarios and conditions specified	Performance characteristics specified in other air vehicle performance requirement paragraphs	A	A	A		A

VERIFICATION DISCUSSION (4.1.2.1)

This requirement 3.1.2.1 Threat environment provides condition information that must be considered in developing all air vehicle performance requirements and verifications. In the event that threat scenarios and conditions are defined or modified in other specific section 3 air vehicle performance requirements, the text of said specific requirements should take precedence over this requirement for that particular performance. Therefore, the verification approach defined below assumes that all of the air vehicle performance in specific threat environments should be verified via the specific performance requirements.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the design concept indicates threat scenario and condition data has been considered in the development of the specified profiles for operations and missions. Analysis indicates the models and simulations to be used to verify performance elsewhere in this document incorporate the identified threat scenarios and conditions.

PDR: Analysis of the preliminary design indicates threat scenario and condition data has been considered in the development of the specified profiles for operations and missions. Analysis indicates that the models and simulations to be used to verify performance elsewhere in this document incorporate the identified threat scenarios and conditions.

CDR: Analysis of the detailed design confirms threat scenario and condition data has been considered in the development of the specified profiles for operations and missions. Analysis confirms that the models and simulations to be used to verify performance elsewhere in this document incorporate the identified threat scenarios and conditions.

FFR: No unique verification action occurs at this milestone.

SVR: Analysis confirms the threat scenarios and condition data have been incorporated in verification of requirements elsewhere in this document.

Sample Final Verification Criteria

Analysis of verification criteria for each air vehicle performance requirement specified herein confirms that the threat environment requirements have been applied in defining the specific threat environment scenarios and conditions for each air vehicle performance requirement.

VERIFICATION LESSONS LEARNED (4.1.2.1)

To Be Prepared

3.1.2.1.1 Weapons delivery

The air vehicle shall provide air-to-surface and air-to-air weapon delivery capabilities as defined in tables 3.1.2.1.1-I and 3.1.2.1.1-II, respectively. The air vehicle shall provide the capability to employ weapon types listed from all compatible internal and external weapon stations against designated targets as defined in tables below.

TABLE 3.1.2.1.1-I. Air-to-surface weapon delivery capabilities.

Target ID/Type	Number of Designated Targets	Weapon Type/Number	Time Span	Additional Information

TABLE 3.1.2.1.1-II. Air-to-air missile delivery capabilities.

Missile Type	Number of Missiles in Pre-launch State	Number of Missiles In-flight	Number of Missiles to Shoot	Time Span	Number of Designated Targets	Additional Information

REQUIREMENT RATIONALE (3.1.2.1.1)

This requirement scopes the basic capabilities to deliver ordnance against targets. Recent advances in missile technology for both air-to-air and air-to-surface applications now make it possible for an air vehicle to track and kill multiple targets. Store requirements drive design features into the air vehicle avionics architecture, sensors, software, controls, and displays. These requirements must be coordinated between the store and air vehicle contractors and should be documented in an interface control document.

REQUIREMENT GUIDANCE (3.1.2.1.1)

Complete table 3.1.2.1.1-I using the following guidance. If the table format does not provide sufficient room to include necessary detail, use table footnotes to reference additional descriptive paragraphs.

<u>Target ID/Type</u>: A unique identifier to link an air vehicle detection, identification, and track capability row in requirement 3.1.9.1 Target detection, track, identification, and designation, to the target description contained in a row of this table. A description of the target type. It can be as simple as “tank” or could include a class of vehicles. Additional information such as “parked,” “moving,” “cruise conditions,” etc., may also prove useful in communicating a fuller understanding of the conditions.

<u>Number of Designated Targets</u>: Number of targets to be targeted.

Weapons Type/Number: Identify the weapons and number released or fired for the requirement. These must be selected from those in 3.4.1.1 Store interface, table 3.4.1.1-I. In some cases it may be necessary to describe an entire class of weapons instead of a specific weapon. For example, laser guided bombs rather than just GBU-10.

Time Span: Time span over which the entire firing sequence should occur.

Additional Information: Identify additional capabilities required against each target. One example may include attack steering, which is in concert with the capabilities of the air-to-surface weaponry to be utilized versus the targets to be attacked. Make sure to identify any cooperative attack capabilities required; for example, one vehicle is the designator and the other is the shooter. Another example would be to list the number of weapons controlled simultaneously against single or multiple targets.

Complete table 3.1.2.1.1-II with the following:

General: This requirement should capture the capabilities required for a single shot against a single target, multiple shots against a single target, multiple shots against multiple targets, or multiple shots per target against multiple targets.

Missile Type: Identify the missile type (e.g., AMRAAM). All the missile types listed in this table must be selected from 3.4.1.1 Store interface, table 3.4.1.1-I. Air-to-air missiles, much like other modern systems, continually evolve to provide greater functionality and capability. Air vehicles should be designed to employ those variants consistent with mission objectives. The dilemma for the developer is having sufficient information to enable definition of a reasonable development program. It is inadequate to just cite “advanced variants” since the work cannot be costed or reasonably be expected to result in an adequately compatible development. This leaves the specification developer three choices:

a. Don’t worry about advanced variants.

b. Cite the specific advanced variant in the Stores list, table 3.4.1.1-I, and include either the interface and performance documentation or pointers to that information.

c. Cite the advanced variant as a “planned” interface and ensure the air vehicle developer is “part of the team” in the definition of the advanced weapon, for example, on the Interface Control Working Group (ICWG). This could be handled by verifications addressing interface compatibility with the planned weapon.

Number of Missiles in Pre-launch State: This is not intended to identify the number of missiles the air vehicle can carry. This identifies the number of missiles the air vehicle will need to prepare for launch.

Number of Missiles In Flight: Identify the number of missiles to support in flight (may not be applicable to some missile types).

Number of Missiles to Shoot: Number of missiles to shoot simultaneously (or near simultaneously).

Time Span: Time span over which the entire firing sequence should occur.

Number of Designated Targets: Number of targets to be targeted.

Additional Information: Additional information, such as firing orders or doctrine required to further clarify the intent of the requirement.

REQUIREMENT LESSONS LEARNED (3.1.2.1.1)

To Be Prepared

4.1.2.1.1 Weapons delivery verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Table 3.1.2.1.1- I Weapon delivery capability for each target ID/Type (1)	Value for each column	A	A,S	A,S		D,S, T
Table 3.1.2.1.1-II Weapon delivery capability for each missile/Type (1)	Value for each column	A	A,S	A,S		D,S, T

VERIFICATION DISCUSSION (4.1.2.1.1)

This is a linking requirement that integrates several other air vehicle requirements, the sum total of which provides an overall operational capability from which the designer can scope and size the system. Computer resource sizing, controls and display design, weapon integration, sensor choice, and data processing capacity and sophistication are some of the system design decisions heavily influenced by the requirements listed in table 3.1.2.1.1-I and table 3.1.2.1.1-II. Verification of this requirement not only includes confirmation of described performance, but also includes assurances that the appropriate requirement flow down to lower-tier specifications has occurred. This includes sensor and weapon performance as well as the lower-tier requirements, such as interface requirements and the other requirements mentioned.

Each 3.1.2.1.1 requirement contains several defining conditions. The sum total of all these defining conditions make some or all of these requirements difficult, if not impossible, to verify exclusively through test. Therefore, a combination of demonstration, analysis, mission-level simulation, man-in-the-loop simulation, and test, should be used. Analysis and mission-level simulation should be used to confirm that meeting other air vehicle requirements, and lower-tier, derivative requirements would result in the desired capability.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analysis indicates that air vehicle weapon delivery requirements have been decomposed to lower-tier requirements. Analysis indicates that meeting these lower-tier requirements provides the required air vehicle weapon delivery capability.

PDR: Analytical and mission-level, simulation-based predictions indicate that preliminary air vehicle designs provide the weapon delivery capability defined in tables 3.1.2.1.1-I and -II. Analysis indicates that lower-level test results have been used in formulating the predictions.

CDR: Updated analytical and simulation-based predictions indicate that air vehicle designs provide the weapon delivery capability defined in tables 3.1.2.1.1-I and -II. Simulations include more detailed test results and contain more detailed modeling of the air vehicle systems. Man-in-the-loop simulations use actual hardware and software, to the extent possible.

FFR: No unique verification action occurs at this milestone.

SVR: A combination of demonstration, mission level simulation, and test verify the weapon delivery requirements. Man-in-the-loop simulations use actual hardware and software to the extent possible. Analysis confirms that conditions listed in 3.1.2.1.1 Weapons delivery that could not be recreated on the test range and via testing conducted during those conditions are identified, and that modeling and simulation have been used to augment the verification testing.

Sample Final Verification Criteria

The weapons delivery requirement is considered to be verified when analysis, modeling, or simulation, and the minimum number of test events defined in the table below for each requirement element, confirm the specified air vehicle weapons delivery capability.

Requirement Element(s)	Analysis Method	Model and/or Simulation(s)	Number of Test Events.
Element 1	(1)	(2)	(3)
Element 2	(1)	(2)	(3)
Element 3	(1)	(2)	(3)

Blank 1. Identify the type and scope of analysis as well as methodology or methodologies used.

Blank 2. Identify the type and scope of model(s), and/or simulation(s) that should be used to supplement drop testing.

Blank 3. Identify the scope and type of test events for final verification for each requirement listed. The minimum number of test events should be determined based upon a desired confidence in the resulting weapon delivery statistics.

VERIFICATION LESSONS LEARNED (4.1.2.1.1)

To Be Prepared

3.1.3 Mission planning

The air vehicle shall provide the mission planning functions in table 3.1.3-I using information obtained pre-flight from __(1)__ and using in-flight updates to specific mission planning functions as indicated in table 3.1.3-I. The air vehicle shall provide the operator with the capability to access, transfer, and change mission plans.

TABLE 3.1.3-I. Mission planning.

Mission Planning Information	In-Flight Updates	Information Provider and Content

REQUIREMENT RATIONALE (3.1.3)

Offboard mission planning capability and the ability to transfer mission-planning data to the air vehicle is critical to mission effectiveness, both during preflight and in-flight phases of a mission. The air vehicle operator must have timely access to intelligence (threat and target), geographical (target, threat, routing) and performance (air vehicle and weapons) information in order to meet mission requirements. Air vehicle designers must consider the capability to accept mission planning inputs, such as navigation waypoints, threat areas, threat libraries, target profiles, etc.

REQUIREMENT GUIDANCE (3.1.3)

Mission requirements for interface with existing or planned mission planning system(s) should be stated here. Mission planning functions should be selectable and tailorable for the missions and mission segments by the aircrew during preflight and in-flight mission planning.

Blank 1. Identify the source(s) for pre-flight mission planning data. Typically, this should be either an existing mission planning system (e.g., AFMSS, TAMPS) (and if so, a cross-reference to an appropriate interface requirement should be included) or to a mission planning system that is developed specifically for this air vehicle.

Guidance for completing table 3.1.3-I follows:

Mission Planning Function: Identify mission functions to be provided. Such functions might include navigation (waypoints, flight corridor, time on target), threat avoidance, target assessment (weapons delivery, attack coordination, weapons type), air space management, deconfliction, raid formation and control, dynamic re-targeting, fuel management, landing location planning/re-planning, menu selection/sequencing, armament selection/programming, vehicle management and control, weight and balance. Note that these functions are rooted in other basic requirements (e.g., survivability, lethality, etc.); that is, mission planning is not just for mission planning's sake; rather, it is required to support other higher-level requirements.

In-flight updates: Indicate whether updates will be required in flight.

Information Provider and Content: Identify the information provider and information content for the in-flight updates for the particular mission planning function. For each information provider identified (e.g., Link 16), the applicable interface requirement should be referenced.

REQUIREMENT LESSONS LEARNED (3.1.3)

Mission planning must be considered early and integrated with the air vehicle and its specified weapons systems. Both onboard and offboard planning systems need to address data integrity for safety and mission effectiveness requirements. Failure to use a structured approach for mission management will result in reduced effectiveness and mission risks due to the probability of incomplete or untimely information being presented to the aircrew.

4.1.3 Mission planning verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Generation of mission planning information from defined source	Existence of table 3.1.3-1, column 1 information	A	A	A		D
In-flight generated/updated mission planning information	Existence of table 3.1.3-1, column 2 information	A	A	A		D

VERIFICATION DISCUSSION (4.1.3)

Mission planning includes weight and balance, armament selection and programming, menu selection sequencing, navigation waypoints, threat advising, threat avoidance, etc. Offboard mission planning capability and the ability to transfer mission-planning data to the air vehicle is critical to mission effectiveness, both during preflight and in-flight phases of a mission. The air vehicle must have timely access to intelligence (threat and target), geographical (target, threat, routing) and performance (air vehicle and weapons) information in order to meet mission requirements. Air vehicle designers must consider the capability to accept mission planning inputs, such as navigation waypoints, threat areas, threat libraries, target profiles, etc.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Mission planning requirements are decomposed to the physical and functional elements of the air vehicle mission planning architecture. Requirements for time to generate mission planning information are derived from the mission mix and the integrated combat turnaround time requirements.

PDR: Analysis of preliminary design of the air vehicle portion of the mission planning system confirms that the interface between the air vehicle and the mission planning system is defined and being incorporated into preliminary design solutions. The algorithms to convert mission planning data (e.g., navigation, threat, weapons) into air vehicle mission plans are defined. Definition of the functional and physical architecture for the mission planning system is complete.

CDR: Analysis of the detailed design of the air vehicle portion of the mission planning system confirms functionality of the interface between the air vehicle and the mission planning system and confirms the efficacy of the algorithms to convert mission planning data (e.g., navigation, threat, weapons, etc.) into air vehicle mission plans.

FFR: No unique verification action occurs at this milestone.

SVR: Demonstrations confirm that the mission plan/data required to perform the specified mission mix are generated. Demonstrations also confirm that the mission plan/data are available in sufficient time to enable mission accomplishment.

Sample Final Verification Criteria

Mission planning capability shall be verified by __(1)__ demonstrations. This requirement shall be deemed satisfied when demonstrations confirm that the mission data is generated within __(2)__.

> Blank 1. Identify the type and number of demonstrations required to provide confidence that the requirement has been satisfied.
>
> Blank 2. Specify the time period permitted for the air vehicle to generate the mission data. Said time should be specified to satisfy mission objectives.

VERIFICATION LESSONS LEARNED (4.1.3)

To Be Prepared

3.1.4 Reliability

The air vehicle shall meet the following mission reliability requirement: __(1)__. The air vehicle shall meet the following logistics reliability requirement: __(2)__.

REQUIREMENT RATIONALE (3.1.4)

This requirement provides the two basic reliability performance attributes for the air vehicle system that impact mission performance and logistics demand. Both mission reliability and logistics reliability are terms that express the probability that the air vehicle can perform intended function(s) for specified intervals under stated conditions. Mission reliability is the ability of the air vehicle to perform its required mission functions for the duration of a specified mission profile. Mission profile is a time-phased description of the events and environments that the air vehicle will experience from initiation to completion of the mission, including the criteria of mission success. Logistics reliability describes an attribute that controls the overall logistics demand or all actions necessary for retaining or restoring the air vehicle to a specified operating condition. (This includes both demand for manpower and demand for spares.)

REQUIREMENT GUIDANCE (3.1.4)

> Blank 1. Include one of the mission reliability parameters below to define the required air vehicle mission reliability. Selection is dependent on the requirements development process, air vehicle type, and acquisition program objectives. Note that more than one mission reliability requirement may be employed for a multi-mission air vehicle (or a minimum for all missions may alternatively be specified). A requirement may be established for each mission area (i.e., air-to-air, air-to-ground, etc.). Two mission reliability parameters are addressed below. One composite mission requirement may be used for a multi-mission air vehicle that combines all missions. The notes supporting

each parameter must be carefully crafted to ensure all desired operational characteristics are addressed.

The following describes mission reliability parameters to be used with blank 1:

Mean Time Between Mission Failure (MTBMF). The total amount of mission time, divided by the total number of mission failures during a stated series of missions shall equal or exceed _____.

Mission Reliability. The probability that the air vehicle can perform all the mission functions, when required, for the duration required, to successfully complete the desired mission, when operated in the environment and usage defined herein, shall equal or exceed ______ (expressed in percent, i.e., 95% or 0.95).

Definitions for mission time, mission(s) and mission failures may be found in 6.4.14 Reliability and maintainability definitions.

Blank 2. Specify a requirement that directs logistic support resources necessary to maintain the air vehicle. It is a key element in the air vehicle's total ownership costs. This design attribute addresses all parts of the air vehicle, including aircrew and maintainer interface.

Logistics reliability parameters to be used with blank 2 follow:

Mean Time Between Failure (MTBF). The total amount of operating time divided by the total number of failures shall equal or exceed ____.

Mean Time Between Maintenance Action (MTBMA). The total amount of operating time divided by the total number of maintenance actions shall equal or exceed _____.

Mean Time Between Maintenance Event (MTBME). The total amount of operating time divided by the total number of maintenance events shall equal or exceed _____.

Mean Time Between Removal (MTBR). The total amount of operating time divided by the total number of maintenance removals shall equal or exceed _____.

Definitions for time, failure(s), maintenance action(s), maintenance event(s), preventive maintenance, scheduled maintenance, corrective maintenance, mean time between maintenance event (MTBME), and mean time between removals (MTBR) can be found in 6.4.14 Reliability and maintainability definitions.

REQUIREMENT LESSONS LEARNED (3.1.4)

The reliability metrics will vary by air vehicle type and due to service-/agency-unique requirements.

Failures must be defined in such a way that the contractor has design influence/control over the particular failure. Failures outside the contractor's control should not be included, such as failures due to improper use, abnormally high maintenance errors, failures in GFE test equipment, abuse, negligence, acts of war, civil disobedience, and other service/agency defined exclusions, etc. Failure relevancy criteria for requirement verification should be developed and included with this specification. Service/agency and program-unique mission functions and operational measurement constraints can also be accommodated in the relevancy criteria.

4.1.4 Reliability verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Mission reliability	(1)	A	A	A	A	A,T
Logistics reliability	(2)	A	A	A	A	A,T

*Numbers in parentheses in the Measurand column refer to identical numbers in the requirement.

VERIFICATION DISCUSSION (4.1.4)

Mission reliability verification is the result of a series of efforts/tasks structured to provide increased insight into the attributes of the design, rather than the result of any single test or demonstration.

Mission reliability

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Preliminary analyses show that the design concept is compatible with requirement based on systems design, maintenance concept, levels of redundancy, reconfigurability, resource sharing, etc., and preliminary subsystem-level reliability predictions (and subcontract requirements, where available). Mission profiles (and mission mix) associated with peacetime and wartime have been defined adequately to enable design refinement (design for life). Functions required for each mission have been defined. Estimated reliability values by function, or hardware (whichever is available) are applied to mission reliability model/analysis. Consensus is reached on the verification/validation of reliability levels (whether numerical or levels of detail) at program milestones. Verification test methods and acceptance criteria based on employment of an agreed-to verification method are incorporated into schedules, facilities requirements, manpower needs, and other programmatic imperatives. Measurement and growth management of mission reliability have been integrated into program management.

PDR: Preliminary analyses show the design is compatible with the requirement based on systems design, levels of redundancy, reconfigurability, resource sharing, etc., and preliminary subsystem-level reliability predictions (and subcontract requirements, where available). A functionally based mission essential subsystem list (MESL) provides links between functions required for missions, and maintenance checklists are developed and coordinated. Required functions have been associated with supporting hardware elements. Mission reliability analysis properly integrates integrity analysis (hardware durability and life estimates). Models and analyses are updated based on changes in functionality, criticality, mission profile(s), mission mix and maintenance concept. Predicted mission reliability has been updated to include subcontractor information. Analysis/modeling correctly integrates mission reliability into higher-level requirements and analysis methods (effectiveness metrics, availability, etc.).

CDR: Failure modes effects and criticality analysis (FMECA), mission reliability, and reliability centered maintenance analysis have been accomplished based on detailed design analysis. Predicted mission reliability has been updated to include test results (where appropriate) and use of life-limited items. Functional MESL has been updated. Functions resolved into supporting hardware elements and supported by a FMECA (or acceptable like analysis) address interconnectivity of hardware and functions. FMECA addresses both internal failures of system as well as input failures to those same systems. Mission reliability analysis/modeling is updated as necessary to reflect changes to the mission profiles, mix ratios, required functions, and maintenance concept. Analysis/modeling correctly integrates mission reliability into higher-level requirements.

FFR: FMECA, mission reliability, and reliability centered maintenance analyses have been accomplished based on detailed design analysis. All scheduled or on-demand maintenance is planned and incorporated into reliability estimates. Mission reliability analysis/modeling and associated predictions are updated as necessary to reflect incorporation of test results and any changes to the mission profiles, mix ratios, required functions, and maintenance concept. This includes the effects of diagnostics/maintenance/inspection requirements required to identify the presence of any mission or safety-critical malfunctions. Functional MESL has been agreed to for maintenance release to fly. FMECA completed for all systems (at the hardware level) provided on flight test aircraft. FMECA addresses all interconnectivity of hardware and functions providing traceability of the failure propagation throughout and across subsystems. Effects of failures deemed to be critical via FMECA or subsystem safety hazard analysis (SSHA) are addressed in pilot and maintenance technical orders (TOs). Analysis/modeling correctly integrates mission reliability into higher-level requirements.

SVR: Agreed-to MESL accounts for any disparities or changes resulting from incorporation of test information. Adjustments for results of flight test information (BIT codes, compensating provisions, etc.) and other testing results have been incorporated in FMECA. Mission reliability analysis/model and associated predictions have been updated (must reflect design as described via FMECA) and include changes based on test and demonstration results, as well as changes to the maintenance concept (changes to scheduled or on-demand maintenance, etc.). Analysis of all information confirms mission reliability requirements for EMD have been met. Projections/estimates for production have been updated and provide a high degree of confidence that produced systems will provide the specified levels of mission reliability in field/deployed use. Analysis/modeling correctly integrates mission reliability into higher-level requirements.

Sample Final Verification Criteria

The mission reliability requirement shall be satisfied if analysis and flight test data generated during the __(1)__ meets or exceeds the specified mission reliability requirement. Evaluation of demonstrated reliability performance of air vehicle functions (phase of mission for which each function is required) is defined in the mission reliability math model. Failure relevancy shall be determined in accordance with the __(2)__.

Blank 1. Specify the flight test period in which the air vehicle mission reliability performance should be measured for compliance.

Blank 2. Identify the ground rules for determining the relevancy of failures.

Lessons Learned: Mature mission reliability is seldom achieved prior to SVR. Consequently, the metric to be demonstrated at this point in the program should be degraded and consistent with the logistics reliability requirement and systems design for this same period of measure.

Mission reliability is a performance parameter centered about the dependability of the air vehicle. In this sense, dependability is a measure useful to command (mission planning and force size) as well as to pilots (ability to get through mission and compensating provisions in the event of a failure). It is extremely unlikely that any one vehicle will attain the specified mission reliability requirement for every moment throughout its fielded existence. Consequently, the specified mission reliability represents an average (fleet wide), minimally acceptable requirement. Verification of such a parameter must therefore acknowledge this. There are a number of ways to verify the requirement. One method is an actual demonstration. If a demonstration is to be undertaken, then the number of sorties and aircraft (observing the number of aborted missions) must be determined so that an acceptable confidence level can be agreed upon. Another method involves modeling based on estimates, achieved performance, and an acute understanding of the systems and interactions of subsystems (usually requiring a previously agreed to mission reliability model and FMECA for accurate understanding of subsystems interactions and allowing pilot compensatory actions).

Mission reliability planning may be inherent/incorporated in master planning and scheduling delivered as contractual documents. However, these master planning documents generally do not describe interrelationships (unless CPM or PERT is used) critical to performing R&M in a manner which provides sufficient insight into progress and results of activities/tasks. Therefore, unless CPM or PERT (or some like process/analysis) is used as a development tool for the master planning, it is suggested that additional planning documents be developed to describe these interrelationships for all stages/phases of the program. This also ensures sufficient insight is provided into actual vs. planned performance vs. schedule (milestones) and the resulting implications to effectiveness measures, cost (aborted missions and training) etc. have been integrated into management. Note that all areas impacted, and the extent of impact as a result of not meeting specified levels of mission reliability at the appropriate milestone within the program, are inherent parts of program management.

The level of detail expected in design analysis varies with the milestone, phase of program, complexity of item/system, and the rate of change of technology. In this regard, one would expect a detailed landing gear design long before a detailed avionics design.

Design analysis, throughout the program, must show the design is compatible with requirement based on systems design, levels of redundancy, reconfigurability, resource sharing, etc., subsystem-level reliability predictions (subcontract requirements, where available) and any modifications. If this is not true, immediate action must be taken to address the shortfall to determine acceptable alternatives, including the possible reduction in requirements (all other impacts of such changes must be well understood before making recommendations to reduce requirements, or requirement levels).

Logistics reliability

Logistics reliability verification is the result of a series of efforts/tasks structured to provide increased insight into the attributes of the design, rather than the result of any single test or demonstration.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Preliminary analysis indicates that the design is compatible with requirement 3.1.4 Reliability based on systems design, maintenance concept, levels of redundancy, reconfigurability, resource sharing, etc., and preliminary subsystem-level reliability predictions (and subcontract requirements, where available). Mission profiles (and mission mix) associated with peacetime and wartime have been defined adequately to enable design refinement (design for life). Functions required for each mission(s) have been defined. Estimated reliability values by function or hardware (whichever is available) are applied to mission reliability model/analysis. Consensus is reached on the verification/validation of reliability levels (whether numerical or levels of detail) at program milestones . Verification test methods and acceptance criteria based on employment of an agreed-to verification method are incorporated into schedules, facilities requirements, manpower needs, and other programmatic imperatives. Measurement and growth management of logistics reliability have been integrated into program management.

PDR: Key activities include, but are not limited to the following efforts accomplished at the appropriate level of detail (basic hardware associated with functions and the integration of said hardware). Required functions have been associated with supporting hardware elements. Logistics reliability analysis properly integrates integrity analysis (hardware durability and life estimates). Models and analysis have been updated based on changes in functionality, criticality, mission profile(s), mission mix and maintenance concept. Predicted logistics reliability has been updated to include subcontractor information. Analysis/modeling correctly integrates logistics reliability into higher-level requirements and analysis methods (effectiveness metrics, availability, etc.).

CDR: Detailed design analyses (all items identified with associated analysis, logistics reliability, updated predictions/allocations, reliability centered maintenance analysis, etc.) shows that the established contract design is compatible with the requirement. FMECA (or acceptable like analysis) address interconnectivity of hardware and functions, internal failures, and input failures to those same systems. Where appropriate, results of tests/demonstrations conducted are incorporated into reliability predictions at hardware level. Predicted logistics reliability has been updated (accounts for life limited items). Analysis (and associated modeling if applicable) correctly integrates logistics reliability into higher-level requirements.

FFR: Detailed design analysis (all items identified with associated analysis, logistics reliability, updated predictions/allocations, reliability centered maintenance analysis, etc.) shows the established contract design is compatible with requirement. All scheduled or on-demand maintenance has been planned and incorporated into reliability estimates. FMECA (or acceptable like analysis) address interconnectivity of hardware and functions, internal failures, and input failures to those systems. Where appropriate, results of tests/demonstrations conducted are incorporated into reliability predictions at hardware level. Predicted logistics reliability has been updated (accounts for life limited items). Analysis (and associated modeling if applicable) correctly integrates logistics reliability into higher-level requirements.

SVR: Adjustments for results of flight test information (BIT codes, compensating provisions, etc.) and other testing results have been incorporated in FMECA. Logistics reliability analysis/model and associated predictions have been updated (most reflect design as described via FMECA) and include changes based on test and demonstration results, as well as changes to the maintenance concept. Analysis of all information provided confirms logistics reliability requirements for EMD have been met. Analysis/modeling correctly integrates logistics reliability into higher-level requirements.

Sample Final Verification Criteria

The logistics reliability requirement shall be satisfied if analysis and flight test data generated during the __(1)__ meets or exceeds the specified logistics reliability requirement. Evaluation of demonstrated reliability performance of air vehicle functions is defined in the logistics reliability model. Failure relevancy shall be determined in accordance with the __(2)__.

> Blank 1. Specify the flight test period in which the logistics reliability performance of the air vehicle should be measured for compliance.

Blank 2. Identify the ground rules for determining the relevancy of failures.

Lessons Learned: Mature logistics reliability is seldom achieved prior to SVR. Consequently, the metric to be demonstrated at this point in the program should be degraded for this same period of measure.

Logistics reliability is a performance parameter centered on the demand for manpower and spares in support of air vehicle operations. In this sense, the demand for manpower and spares is a measure useful to maintenance for manpower numbers, skills, and spares as well as depot planning, mobility, etc. It is unrealistic to expect that any one vehicle will attain the specified logistics reliability requirement for every moment throughout its fielded existence. Consequently, the specified logistics reliability represents an average (fleet wide), minimally acceptable requirement. Verification of such a parameter should, therefore, acknowledge this.

Logistics reliability planning may be inherent/incorporated in master planning and scheduling delivered as contractual documents. However, these master planning documents generally do not describe interrelationships (unless CPM or PERT is used) critical to performing R&M in a manner which provides sufficient insight into progress and results of activities/tasks. Therefore, unless CPM or PERT (or some like process/analysis) is used as a development tool for the master planning it is suggested that additional planning documents be developed to describe these interrelationships for all stages/phases of the program. This also ensures sufficient insight is provided into actual versus planned performance versus schedule (milestones) and the resulting implications to effectiveness measures, cost (aborted missions and training) etc. have been integrated into management. Note: all areas impacted and extent of impact as a result of not meeting specification levels of logistics reliability at the appropriate milestone within the program are inherent parts of program management.

VERIFICATIONS LESSONS LEARNED (4.1.4)

See Lessons Learned above for "Mission reliability" and "Logisitics reliability" requirement elements.

3.1.5 Maintainability

The air vehicle shall be capable of being maintained in an operationally ready condition within the repair time and maintenance manpower requirements specified when operated and maintained by appropriately skilled personnel using prescribed procedures, support equipment, and resources in the environment and operational usage defined herein. Maintenance repair time shall not exceed __(1)__. Maintenance manpower shall not exceed __(2)__.

REQUIREMENT RATIONALE (3.1.5)

Maintainability includes all aspects of maintenance, including both scheduled and unscheduled maintenance, required to maintain an air vehicle in a mission-capable status throughout its designed service life. The air vehicle equipment needs to be designed for ready removal and for ease of maintenance to minimize the air vehicle down time due to equipment replacement and air vehicle repair. In general, the desire for maintainability stems from a higher-level requirement for availability. Limited manpower and a desire to minimize the mobility footprint put additional burdens on design to provide a system that is readily maintainable in a mission-capable status. Air vehicle reliability is a prime driver in prioritizing accessibility and scheduled maintenance activities. As such, it is generally recommended that maintainability requirements be expressed in attributes that describe maintenance repair time and maintenance manpower to restore the air vehicle to mission-capable status.

REQUIREMENT GUIDANCE (3.1.5)

Maintainability parameters apply to the air vehicle hardware and software, including special mission kits. In general, maintainability requirements should be placed at the highest level possible to give the contractor maximum design latitude. Complete blanks 1 and 2 by selecting air vehicle maintenance repair time and maintenance manpower requirements as explained below.

Blank 1. Include one of the following maintenance repair time requirements:

<u>Mean Time to Repair (MTTR)</u>. The MTTR of the air vehicle shall not exceed ___ hours.

This requirement describes the ability of the air vehicle to be retained in, or restored to, a specified condition when maintenance is performed by personnel having specified skill levels, using prescribed procedures and resources. It is the sum of corrective maintenance times for restoration of the air vehicle divided by the total number of failures. There must be a clear understanding of what elements constitute a repair. Repair times includes all repair activities, i.e., detection, isolation, access, repair or replacement, verification, cure and application times, close or seal, and inspection of the same.

<u>Essential Systems Repair Time (ESRT)</u>. The ESRT of the air vehicle shall not exceed ___.

ESRT should be specified in terms of hours per flight hour (or per sortie) that support the required levels of availability (often provided as a Sortie Generation Rate (SGR)). ESRT per flight hour is defined as the elapsed time, in clock hours, required to repair and or replace any mission essential equipment in order to return an aircraft to mission-capable status (includes all repair activities; i.e., detection, isolation, access, repair and or replacement, verification, cure and application times, close and or seal and inspection of same) divided by the total number of flight hours (or sorties) accumulated over a specified measurement period. ESRT should not be exceeded if availability requirements at the system level are to be achieved. ESRT directly relates the air vehicle's R&M capabilities to that of the system requirements.

Blank 2. Include one of the following maintenance manpower requirements:

<u>Maintenance Manhours per Flight Hour (MMH/FH)</u>. The air vehicle MMH/FH shall not exceed ____.

This requirement describes the air vehicle's demand for maintenance manpower at a prescribed level of maintenance (defined by the user). The sum of maintenance man hours spent performing maintenance (preventive, scheduled, or corrective) divided by the total number of air vehicle flight hours. Definitions for preventive maintenance, scheduled maintenance, and corrective maintenance can be found under 6.4.14 Reliability and maintainability definitions. Maintenance definitions can also be categorized as air vehicle maintenance levels. There must be a clear understanding of what elements constitute maintenance manhours.

<u>Spaces Per Aircraft (SPA)</u>. The air vehicle maintenance manpower SPA shall not exceed ____, where maintenance manpower includes personnel who perform the following functions: ____.

For the first blank, identify the number of personnel required to maintain and service the air vehicles in a mission condition status divided by the total number of air vehicles in the operating unit. For the second blank, identify the maintenance and service functions (e.g., repair, servicing, weapons loading, refueling, inspections, back shop personnel, and test) included in the manpower personnel SPA in the first blank. These manning levels take into account human factors, skill codes and levels, and number of aircraft being supported. SPA need not be addressed at the air vehicle level if it is already covered at the air system level.

REQUIREMENT LESSONS LEARNED (3.1.5)

The maintainability metrics will vary with air vehicle type and due to service-/agency-unique requirements. Additional clarification regarding specific maintenance activities that may not be directly related to subsystem maintainability should be clearly explained. For instance, requirements for gun or seat remove and replace times are based on foreign object damage and usage/cleaning more than they are on reliability. To provide the contractor/designer a clearer understanding, state that the gun is cleaned at the end of each day during which it has been fired, and that the seat is removed and replaced once per month to remove foreign object damage. This provides the designer with more options by allowing flexibility to address problems while still prioritizing the efforts and maintainability impacts. Providing a seat remove-and-replace time would not give credit to the designer should he develop a means of eliminating foreign objects from getting under the seat. Areas that would benefit from additional access frequency information, beyond that incorporated into reliability, are engine bays, guns, weapons bays, weapons pylons, seats and cockpit areas. Maintainer interfaces should physically and functionally accommodate the 5th percentile female through the 95th percentile male.

4.1.5 Maintainability verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Repair time	(1)	A	A	A	A,I	A,D, T
Maintenance manpower	(2)	A	A	A	A,I	A,D, T

*Numbers in parentheses in the Measurand column refer to numbered blanks in the requirement.

VERIFICATION DISCUSSION (4.1.5)

Maintainability parameters define the air vehicle maintenance design attribute. At the air vehicle level, verification activities must encompass all of the air vehicle's systems, subsystems, and equipment, and must address air vehicle operations and all levels of maintenance, from organizational on-aircraft through depot.

Mature maintainability is seldom achieved until sometime post-initial operational capability (IOC). Consequently, demonstrated values during development may be degraded and consistent with the logistics reliability requirement, maintenance learning curves, and systems design for this same period of measure. A normal recommendation would be 90% based on final 500 flight hours with production-compatible equipment in test.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analysis indicates the air vehicle design concept is compatible with the maintainability requirement based on the air vehicle systems design, maintenance concept, and a combination of preliminary subsystem-level reliability predictions and maintenance/accessibility analysis. Analysis indicates that the methodology, tools, models, and mock-ups are structured to provide the necessary level of insight into maintenance capability required to maintain fully functional air vehicles. This maintenance analysis should ascertain that support equipment and preliminary maintenance interface concepts are agreed upon, have been developed, and are used in the design/refinement process. Analysis indicates that estimated maintainability values by function or hardware (which ever is available) are applied to the maintainability model. Consensus is reached on the verification/validation of maintainability levels (whether numerical or levels of detail) at program milestones. Analysis indicates that verification test/demonstration methods and acceptance criteria, based on agreed-to verification methods, are employed and are incorporated into schedules, facilities requirements, manpower needs, and other programmatic imperatives. Analysis indicates that measurement and growth management of maintainability have been integrated into program management.

PDR: Analysis indicates the air vehicle preliminary design is compatible with the requirement based on air vehicle design, accessibility, and preliminary subsystem-level maintainability predictions (and subcontract requirements, where available). Analysis indicates that the maintainability requirements can be achieved through a structured set of efforts/tasks designed to provide the necessary level of insight into the attributes of the design, and the design refinement process. Efforts and tasks include, but are not limited to, the following efforts accomplished at the appropriate level of detail (basic hardware associated with functions, and the integration of said hardware):

a. Maintenance Time-Line Analysis has been performed for major tasks.

b. Maintenance task analysis is linked to diagnostics and failure modes effects and criticality analysis (FMECA).

c. Functionally based mission essential subsystem list (MESL) provides links between functions required for missions, and maintenance checklists are developed and coordinated.

d. The integrity analysis (hardware durability and life estimates) is properly integrated.

e. Analytical models are updated based on changes in reliability, accessibility, integrity, and maintenance concept.

f. Predicted maintainability model is updated to include subcontractor information.

g. Analysis/modeling integrates maintainability into higher-level requirements and analysis methods (effectiveness metrics, availability, manpower requirements, deployment, etc.).

CDR: Analysis of detailed design confirms maintenance time line analysis, maintenance task analysis, and reliability centered maintenance analysis have been accomplished. Predicted maintainability is updated. These updates include demonstration results (where appropriate) and usage of life-limited items. Analysis confirms that the functional MESL has been updated. Accessibility and support equipment are integrated into maintenance analysis/modeling, including equipment needed for deployment (with consideration for the environments to be encountered under maintenance). Maintenance task and time line analysis, when combined with reliability predictions, support availability and manpower requirements for deployment.

Maintenance models and demonstrations provide for readily repeatable results. Failure modes effects and criticality analysis (FMECA) includes appropriate compensating provisions. Technical order (TO) development is based on maintenance task analysis and is tied to FMECA. Maintainability analysis/modeling updated as necessary to reflect changes to reliability, accessibility, integrity, and maintenance concept. Analysis/modeling correctly integrates maintainability into higher-level requirements.

FFR: Maintenance time line analysis, maintenance task analysis, and reliability centered maintenance analysis based on detailed design analysis indicate that the air vehicle reliability is acceptable for first flight. Maintenance task analysis indicates that all scheduled or on-demand maintenance has been planned and incorporated into reliability estimates. Inspection indicates that TOs are available for all safety-critical maintenance. Maintainability analysis/modeling and associated predictions have been updated as necessary to reflect changes to the reliability, accessibility, integrity, and maintenance concepts. Analysis of the effects of failures deemed to be critical via FMECA or subsystem safety hazard analysis (SSHA) is addressed in pilot and maintenance technical orders. Analysis/modeling correctly integrates maintainability into higher-level requirements.

SVR: Analysis confirms that the agreed-to MESL accounts for any disparities or changes resulting from incorporation of test information provided. Analysis confirms that adjustments for results of flight test information (BIT codes, compensating provisions, etc.) and other testing results have been incorporated in FMECA, maintenance task analysis, and TOs. Maintainability analysis/model and associated predictions updated (must reflect design as described via FMECA). Includes changes based on test, and demonstration results, as well as changes to the maintenance concept (changes to scheduled or on-demand maintenance, etc.). Analysis of all information provided confirms maintainability requirements for this phase of the program have been met. Projections/estimates for production are updated and provide a high degree of confidence that produced systems will provide the specified levels of maintainability in field/deployed use. Analysis/modeling correctly integrates maintainability into higher-level requirements.

Sample Final Verification Criteria

The maintainability requirement shall be satisfied when analysis and flight test data generated during the __(1)__ and associated demonstrations, meets or exceeds the specified maintainability requirement. Evaluation of demonstrated maintainability performance is defined in an agreed-to maintainability or availability model. Maintenance relevancy will be determined in accordance with __(2)__.

> Blank 1. Specify the flight test period in which the air vehicle should be measured for compliance. An example would be the final 500 flight hours.
>
> Blank 2. Identify the ground rules for determining the maintenance relevancy (Joint Reliability Maintainability Evaluation Team Charter scoring criteria or other such criteria)

VERIFICATION LESSONS LEARNED (4.1.5)

Maintainability incremental verification does not occur through any one test or demonstration but rather through the results of efforts/tasks structured to provide increased insight into the attributes of the design. This is accomplished through a series of efforts and combined through analysis to ensure insight at the appropriate levels for management of the design refinement and acquisition process.

Maintainability is a performance parameter centered on the ability to rapidly maintain and/or restore an air vehicle to specified performance. It is extremely unlikely that any one vehicle will attain the specified maintainability requirement for every moment throughout its fielded existence. Consequently, the specified maintainability represents an average (fleet wide), minimally acceptable requirement. Verification of such a parameter must, therefore, take this into account. There are a number of ways to verify the requirement. One method is an actual demonstration. If a demonstration is to be undertaken, then the number of sorties and aircraft must be determined so that an acceptable confidence level can be agreed on. Another method involves modeling based on estimates, achieved performance, demonstrations, and an acute understanding of the systems and interactions of subsystems as relayed through diagnostics and technical orders.

Maintainability planning may be inherent or incorporated in master planning and scheduling delivered as contractual documents. However, these “master planning” documents generally do not describe interrelationships (unless CPM or PERT is used) critical to performing R&M in a manner which provides sufficient insight into progress and results of activities/tasks. Therefore, unless CPM or PERT (or some like process/analysis) is used as a development tool for the “master planning” it is suggested that additional planning documents be developed to describe these interrelationships for all stages/phases of the program. This also ensures sufficient insight is provided into actual vs. planned performance vs. schedule (milestones) and the resulting implications to effectiveness measures, cost (aborted missions and training) etc. have been integrated into management. Note: all areas impacted and extent of impact as a result of not meeting specification levels of maintainability at the appropriate milestone within the program are inherent parts of program management.

The level of detail expected in design analysis varies with the milestone, phase of program, complexity of item/system, and the rate of change of technology. In this regard, one would expect a detailed landing gear design long before a detailed avionics design.

Design analysis, throughout the program, must show the design is compatible with requirements based on systems design, accessibility, maintenance concepts, fault detection and isolation capability, skill levels and codes, numbers of maintainers, etc. If this is not true, immediate action must be taken to address the shortfall to determine acceptable alternatives, including the possible reduction in requirements (all other impacts of such changes must be well understood before making recommendations to reduce requirements, or requirement levels).

3.1.6 Integrated combat turnaround time

For the __(1)__ mission, the elapsed time required to conduct an integrated combat turnaround, starting with an air vehicle without any mission-critical failures, shall be not greater than __(2)__ when equipping the vehicle with the assets and quantities identified in table 3.1.6-I. These requirements shall be met under __(3)__ conditions. Timing begins __(4)__ and ends at pilot acceptance. Integrated combat turnaround time __(5)__ includes time needed for general turnaround inspection and servicing, replacement of mission data, and replacement or replenishment of needed fluids, gases, and agents.

The air vehicle shall meet stated requirements under the limitations of __(6)__, using __(7)__ power source and while located in __(8)__.

The integrated combat turnaround shall require not greater than __(9)__ ground personnel and/or aircrew members consistent with the skills defined in requirement 3.4.3.2

Maintainer/vehicle interface. The support equipment available to support the combat turnaround is identified in table 3.1.6-II.

The above requirements shall be met for __(10)__ integrated combat turnaround.

TABLE 3.1.6-I. Integrated turnaround time quantities.

Item	Quantity at Start	Quantity at End	Remarks

TABLE 3.1.6-II. Integrated combat turnaround support equipment.

Support Equipment Description	Maximum Quantity Available at the Turnaround Site	Remarks

REQUIREMENT RATIONALE (3.1.6)

The ability to rapidly return an air vehicle to a combat-ready status is a critical factor for combat air vehicles, especially fighter aircraft and shipboard-based aircraft. This requirement establishes the maximum time it will take to fully arm and ready a combat air vehicle for another mission immediately after it has returned from a previous mission.

Sortie rate requirements can be used to help bound a time allowed for turning a combat air vehicle around based on nominal conditions (average rates, squadron or larger size pool of air vehicles to draw from, etc.). They do not, in themselves assure that all critical system capabilities are achieved. Five-, ten-, or thirty-day average sortie rates do not communicate that there are critical conditions that demand air power immediately, not in xx hours. For example, if a twelve-hour operating day and a 3-sortie/day requirement were used to set the turnaround requirement, the required time would be 5 hours assuming one-hour mission duration. Such a fallout capability may be unacceptable for some types of systems and operating conditions, especially for lead elements deployed to counter “surprise” hostile actions and in high intensity combat situations. At the same time, this requirement can be a significant design (and cost) driver. It should not be applied arbitrarily. The most operationally flexible time is near-instant turnaround, clearly unachievable and prohibitively expensive. The objective in establishing this requirement should be in determining what is desired, assessing the design and cost impacts then examining excursions that relax various portions of the requirement and conditions to determine the costs and effectiveness of the alternatives and selecting the most reasonable (satisfies the warfighter and is affordable) alternative requirement/conditions.

REQUIREMENT GUIDANCE (3.1.6)

Blank 1. Enter the mission(s) for the air vehicle. This may include turnaround of the air vehicle for the same mission for which it was previously configured, or reconfiguration of the air vehicle for a new mission(s).

Blank 2. Enter the maximum allowable turnaround time. This time is usually expressed in minutes.

Blank 3. Enter the environmental conditions (including the chemical and biological factors) under which the performance is to be satisfied. It may be necessary to develop different performance numbers for different environmental conditions. A reference to program-specific source material can be used provided the material is intended for contractual application.

Blank 4. State the starting conditions when the timing begins. The allowed support equipment (table 3.1.6-II) and any restrictions or limitations on what equipment may be used at a given point in the process must be stated. For example, loaders, power carts, fuel trucks, portable fire extinguishers, etc. Additionally, note (in the remarks) whether or not the identified support equipment items are available infrastructure items (if so, they should also be identified in the interface requirements section), whether or not they may be missionized/program peculiar versions of such items.

Blank 5. State whether general turnaround inspection and servicing, and replacement of fluids, gases, agents, and mission data must be accomplished within the required time. The suggested approach is to delete blank 5 if the actions are to be part of the turnaround and must be completed within the time specified in blank 2. If such tasks are not included, enter “does not” in blank 5.

Blank 6. The air vehicle functions to which the integrated combat turnaround applies must be clearly defined. It is also necessary to specify simultaneous actions along with any operational or safety limits of the same, where such exist. For example, is refueling with engine(s) operating an allowed condition?

Blank 7. State clearly the conditions under which an auxiliary power unit (APU) or external power source is permitted.

Blank 8. Specify if any or all turnaround actions are to take place within a particular type of shelter, or in a particular deck location for a ship-based air vehicle.

Blank 9. Specify the number for all ground personnel and aircrew.

Blank 10. Indicate to what conditions the performance numbers apply. For many air vehicles, there are two sets of conditions under which integrated turnaround times may be specified: a hot or cold turnaround. A hot turnaround is one in which refueling is performed with aircraft propulsion engine(s) operating (provides an instantaneous taxi capability). A cold turnaround is one in which refueling is performed with the (APU) or external power unit and aircraft propulsion engine(s) not operating. If both conditions are significant and the time in blank 1 is different for each condition, repeat the requirement if the entry for quantities, other start conditions, ground personnel, or support equipment is different. When the remaining conditions (blanks) have the same content for either turnaround condition, another option is to delete the last sentence (“The above requirements ____ ”) and in blank 1 use language such as, “X minutes for a hot integrated combat turnaround and Y minutes for a cold integrated combat turnaround.”

Guidance for completing table 3.1.6-I follows:

The requirement must state all conditions under which the turnaround time is to be demonstrated. Table 3.1.6-I may be expanded to identify different sets of equipment available for different turns.

<u>Item</u>: Identify the item to be replenished, e.g., Mark 84 bombs, laser-guided bombs, ammunition, pallets, etc.

Quantity at Start: Identify the quantity of the item on-board the air vehicle at the start of the combat turn.

Quantity at End: Identify the quantity of the item on-board the air vehicle at the end of the combat turn.

Remarks: Identify other items relevant to the items in the integrated combat turn.

Guidance for completing table 3.1.6-II follows:

Support Equipment Description: Identify all the support equipment required at the site to support integrated combat turn. If there is not a program requirement to constrain support equipment required for integrated combat turn at the time of EMD contract award, enter TBD to denote that the list will be established during EMD.

Maximum Quantity Available at the Turnaround Site: Identify the maximum number of support equipment items required in order to meet this requirement.

Remarks: Identify other constraining characteristics associated with the support equipment utilized for integrated combat turn.

REQUIREMENT LESSONS LEARNED (3.1.6)

To Be Prepared

4.1.6 Integrated combat turnaround time verification

Requirements Element(s)	Measurand	SFR/ SRR	PDR	CDR	FFR	SVR
Time to complete a cold ICT	Minutes		A	A		A,D
Time to complete a hot ICT	Minutes		A	A		A,D
Personnel required to perform an ICT	Number		A	A		A,D

VERIFICATION DISCUSSION (4.1.6)

Integrated combat turnaround (ICT) stresses the ability to service the air vehicle and do corrective maintenance in a very short defined time interval. Mission scenarios are usually defined that indicate the amount of fuel, types and quantities of weapons to be loaded, etc. during the ICT. Cold and hot ICTs are indicated that determine methods to be used to perform the servicing and maintenance. Simultaneous ICTs indicate the number of air vehicles that undergo the ICT at the same time which somewhat dictates the quantity of both support personnel and equipment required to service the air vehicle. The number of personnel required to perform an ICT should be determined. If multiple missions are to be verified, it is typically appropriate to evaluate the worst case scenario that would drive ICT requirements.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: No unique verification action occurs at this milestone.

PDR: Analysis indicates that the specified ICT can be achieved utilizing the specified scenarios, personnel, environmental conditions, and support equipment.

CDR: Analysis using refined and updated design data indicates that the air vehicle is capable of meeting the ICT requirements as specified.

FFR: ICT is not a factor that relates to first flight of an air vehicle.

SVR: Demonstrations and analysis of all ICT scenarios and conditions confirm that the air vehicle is capable of being serviced and readied for flight with the support equipment and personnel listed within the time and environmental constraints specified.

Sample Final Verification Criteria

__(1)__ analyses and __(2)__ demonstrations confirm that the ICT can be performed in the allotted timeframe with the number of personnel under the scenarios and conditions specified.

> Blanks 1 and 2. Identify the type and scope of analyses and demonstrations required to provide confidence that the requirement elements have been satisfied. Typically, demonstrations address the worst case scenario(s) which would drive ICT requirements.

VERIFICATION LESSONS LEARNED (4.1.6)

To Be Prepared

3.1.7 Communication, radio navigation, and identification

The air vehicle shall be capable of transmitting and receiving digital and analog data through the resources identified in 3.4.2 Communication, radio navigation, and identification interfaces with performance as specified in table 3.1.7-I.

TABLE 3.1.7-I. Communication, radio navigation, and identification performance.

Analog and Digital Capability	Characteristic	Transmission Performance	Reception Performance	Conditions

REQUIREMENT RATIONALE (3.1.7)

This requirement establishes the air vehicle analog and digital communication performance required to support interoperability and mission requirements. These requirements pertain to performance external to the air vehicle and do not include internal communications, such as those between crewmembers.

REQUIREMENT GUIDANCE (3.1.7)

Guidance for completing table 3.3.1.7-I follows:

Analog and Digital Capability: Include communication functions required for mission performance. Sometimes communication requirements are expressed in terms of the design implementations to pass information in various bands or to specific receivers. Therefore, based on current communication implementations, the following list of example voice and data communication types are potential items to be identified in this column (this is not all inclusive):

a. Ultra High Frequency-Amplitude Modulation (UHF-AM)

b. Very High Frequency-AM (VHF-AM)

c. VHF-Frequency Modulation (VHF-FM)

d. High Frequency (HF)

e. Link-16

f. UHF-SATCOM

g. Super High Frequency-SATCOM

h. MILSTAR

i. Common Data Link (CDL)

j. Emergency Locator Transponder

k. VHF Data Link (global air traffic management (GATM) requirement)

l. Integrated Broadcast Service (IBS)

m. VHF Omnidirectional Ranging (VOR)

n. Instrument Landing System (ILS)

o. Identification Friend or Foe (IFF)

Characteristics: Identify special functional requirements. For example, identify whether a communication function is secure, nonsecure, jam resistant, analog voice, video or digital data. Other examples include 8.33 kHz channel spacing for VHF functions and FM immunity for VOR, ILS and VHF-AM functions to comply with global air traffic management (GATM) requirements.

Transmission Performance: For each communication function, provide some measure of link reliability based on communicating with a standard external interface at the required distance. For example, data links may require a maximum bit error rate or message reliability. Identify the minimum distance at a specified field of regard (FOR) and reliability (e.g., 100-mile range for a FOR of 360 degrees with a message reliability of xxx) to satisfy mission needs for the function identified.

Reception Performance: Identify the minimum distance from which a signal can be received and the reliability of maintaining that performance over a specified FOR. For each communications function, provide some measure of link reliability based on communicating with a standard external interface at the required distance. Identify the minimum distance at a specified FOR and reliability (e.g., 100 mile range for a FOR of 360 degrees with a message reliability of xxx) to satisfy mission needs for the communication function identified.

Conditions: Provide worst-case conditions (rain rate, etc.) under which the function is intended to operate, based on mission scenarios.

REQUIREMENT LESSONS LEARNED (3.1.7)

To Be Prepared

4.1.7 Communication, radio navigation, and identification verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Functional requirement characteristic (a) for specified conditions	Level of minimum acceptable performance (Transmission and/or Reception Performance columns from table 3.1.7-I)	A,I	A,I	A,I	I,A, D,T	A,D, T
Functional requirement characteristic (b) for specified conditions	"	A,I	A,I	A,I	I,A, D,T	A,D, T
Functional requirement characteristic (c) for specified conditions	"	A,I	A,I	A,I	I,A, D,T	A,D, T

VERIFICATION DISCUSSION (4.1.7)

A verification table similar to the one above should be developed for each communication, radio navigation, and identification system required. The elements of this table are derived from table 3.1.7-I. For example, a particular table may be labeled UHF-AM if the first entry in column one of table 3.1.7-I is UHF-AM. The Requirement Element column in the verification table would break out each of the characteristics in table 3.1.7-I. For example, Functional Requirement (a) in the verification table may be air-to-air, secure voice communications transmission. Functional Requirement (b) may be air-to-ground nonsecure voice communications reception. Functional Requirement (c) may be air-to-ground secure data communications transmission, etc. In addition, each characteristic will include any applicable special conditions from table 3.1.7-I, such as rain rate. The measurand would be the transmission performance or reception performance depending on the characteristic in column one. The table should indicate at which stage(s) of the program each requirement element should be verified.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Inspection of program documentation indicates that the system functional and performance requirements characterize a system design approach that satisfies the user needs regarding external communications, radio navigation, and identification systems. Analysis indicates requirements have been derived from the ORD and are properly allocated to the requirements of air vehicle subsystems.

PDR: Inspections and analyses of the preliminary air vehicle design and lower-tier specifications indicate derivation of appropriate lower-tier requirements. Analysis indicates ability to achieve transmission or reception performance under specified characteristics and conditions. An example of this for a data link system is a link analysis. A link analysis uses the parameters of the system, such as antenna gain, line losses, transmitter power outputs, and other characteristics, to determine the maximum range of the link given a certain message error rate. Conversely, such an analysis could determine a maximum message error rate given a certain link range. This should be an iterative process as the contractor modifies his design.

CDR: Inspections of air vehicle design information and updated analysis of lower-level test/demonstration data indicate the capability of the air vehicle to achieve required transmission or reception performance under specified characteristics and conditions. For example, the contractor would probably have refined the link analyses and should also have some form of antenna pattern analysis for each of the systems. The antenna pattern analysis will assess whether or not any serious holes exist in the antenna pattern that would cause inadequate communications at some aircraft aspect angles with respect to the other end of the link. Further iterations of analyses from previous stages of the program may need reassessing since some parts of the system may have changed from previous milestone dates.

FFR: Analyses, demonstrations, inspection of the air vehicle design, and tests of communication, radio navigation, and identification functions confirm that flight critical functions are available for flight.

SVR: Demonstrations, air vehicle tests, and analyses of lower-level test and demonstration data confirm the ability to achieve transmission or reception performance under specified characteristics and conditions.

Sample Final Verification Criteria

The communication, radio navigation, and identification requirements shall be satisfied when __(1)__ analyses, __(2)__ tests, and __(3)__ demonstrations confirm achievement of the performance specified in table 3.1.7-I.

Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement elements have been met.

Blank 2. Identify the type and scope of tests required to provide confidence that the requirement elements have been met.

Blank 3. Identify the type and scope of demonstrations required to provide confidence that the requirement elements have been met.

VERIFICATION LESSONS LEARNED (4.1.7)

To Be Prepared

3.1.8 Survivability

3.1.8.1 Susceptibility

3.1.8.1.1 Signature requirements

3.1.8.1.1.1 Radar cross section

The radar cross section (RCS) signature shall not exceed __(1)__.

REQUIREMENT RATIONALE (3.1.8.1.1.1)

In order for the air vehicle to achieve adequate survivability during the performance of its intended mission, the air vehicle design is required to incorporate features and technologies to control RCS.

REQUIREMENT GUIDANCE (3.1.8.1.1.1)

Blank 1. Complete by inserting equivalents of one or more of the following tables based on the guidance provided.

The requirements should be driven by the vehicle mission and the overall requirements of the vehicle. The required RCS levels for threat-related mission phases can be derived from weapon-system-level survivability analyses and/or knowledge derived from operational tests of similar systems.

RCS requirements. - (Example table)

ELEVATION Degrees	AZIMUTH Degrees			
	315-45 *****	45-135 *****	135-225 *****	225-315 *****
15-20				
10-15				
5-10				
0-5				
(-5)-0				
(-10)-(-5)				
(-15)-(-10)				
(-20)-(-15)				

* Azimuth and elevation sectors are for example only. Specific sectors shall be based on operational requirements and analysis.

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Implementation of this requirement should be coordinated with the following offices to obtain current policy and direction. Navy: Commander, Naval Air Systems Command, Attn: Ken Goff (AIR4.1.8), Building 2187, Room 1144, Suite 1180, 48110 Shaw Road, Unit 5, 20670 -1906; (301) 342-0142. Air Force: ASC/ENAD, 2530 Loop Rd. West, Wright-Patterson AFB OH 45433-7101; (937) 255-9286.

REQUIREMENT LESSONS LEARNED (3.1.8.1.1.1)

RCS requirements should not be replaced by an air vehicle mission probability of survival (P_S) or requirements tied directly to a P_S, which is scenario dependent and difficult to evaluate through actual testing.

4.1.8.1.1.1 Radar cross section verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Air vehicle radar cross section (RCS)	(1)	A	A,S	A,T		T

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.1.8.1.1.1)

Verification of the RCS requirement should be accomplished via a combination of RCS analysis, RCS testing of components and scale models, RCS simulation and testing of full-scale models, and static and dynamic RCS testing of the actual air vehicle.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the design concept, including predictions, air vehicle scale models, and/or simulations, indicates the RCS requirements are achievable.

PDR: Analysis of the preliminary design indicates the RCS requirements are achievable. RCS simulation and analysis of lower-level testing of actual prototype components indicate that budget allocation and overall RCS budget analysis are met.

CDR: Analysis of detailed design including RCS simulation of subsystems (inlet, radar/radome, etc.) and RCS testing of a scale RCS model or significant components confirms the air vehicle will meet the RCS requirement.

FFR: No unique verification action occurs at this milestone.

SVR: RCS measurement testing confirms the air vehicle meets the RCS signature requirement.

Sample Final Verification Criteria

The radar cross section requirement shall be satisfied when __(1)__ analyses, __(2)__ simulations and __(3)__ tests confirm that the air vehicle RCS is no greater than specified.

Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement element has been met.

Blank 2. Identify the type and scope of simulations required to provide confidence that the requirement element has been met.

Blank 3. Identify the type and scope of tests required to provide confidence that the requirement element has been met. This could include pole testing and/or dynamic in-flight testing.

VERIFICATION LESSONS LEARNED (4.1.8.1.1.1)

To Be Prepared

3.1.8.1.1.2 Infrared signature

The air vehicle infrared (IR) signature shall be not greater than __(1)__.

REQUIREMENT RATIONALE (3.1.8.1.1.2)

Current generation and advanced development IR missiles employ increasingly sophisticated spectral, spatial and temporal counter-countermeasure (CCM) capability. In order that the weapon system has adequate survivability while performing its intended mission, the IR signature may have to be limited. The purpose of this section is to set the limits of the IR signature. Before any specification limits can be established for air platform IR signature, the primary air platform missions and operational scenarios, employment doctrine and tactics, and threats likely to be encountered must be determined.

REQUIREMENT GUIDANCE (3.1.8.1.1.2)

The total infrared signature of an air vehicle is comprised of the infrared signature from various sources including solar reflection, hot parts and engine plume.

IR signature limits. - (Example table)

Signature type _____ (W/SR)   Band _______(microns)

Operating conditions - airspeed, vehicle configuration, altitude, environmental conditions

	Degrees																		
	Nose																		Tail
Top	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
90																			
45																			
30																			
20																			
10																			
5																			
0																			
-5																			
-10																			
-20																			
-30																			
-45																			
-90																			

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REQUIREMENT LESSONS LEARNED (3.1.8.1.1.2)

Having a common table format (including common operating conditions) is necessary to properly understand and make decisions regarding the IR signature, in addition to its purpose of comparing the design to the requirements.

For most fixed-wing vehicles, there are generally three components of the overall IRS; they include the airframe, the engine hot parts and the engine plume. The three components of the IRS can be specified individually and/or in the aggregate as an overall IRS.

4.1.8.1.1.2 Infrared signature verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Air vehicle infrared signature (IRS)	(1)	A	A	A		T

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.1.8.1.1.2)

Verification of IR signature requirement consists of IR signature analysis, IR signature testing of the full-scale engine and exhaust system and IRS signature testing of the actual air vehicle under static and dynamic conditions, including the IR signature of engine exhaust/vapor trail.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the design concept, including predictions and/or simulations, indicates the IR signature requirements are achievable.

PDR: Analysis of the preliminary design indicates the IR signature requirements are achievable. IR signature simulation and analysis of lower-level testing of actual prototype components indicate that budget allocation and overall IR signature budget analysis are met. Computer model predictions of IR signature under specified conditions, and infrared testing of developmental engine and exhaust system budget allocations indicate that overall IR signature requirements can be achieved.

CDR: Analysis of the final air vehicle design confirms that the air vehicle meets IR signature requirements under specified conditions. Analysis should include the results of infrared testing of the engine, unique engine exhaust systems, and heated aircraft surfaces.

FFR: No unique verification action occurs at this milestone.

SVR: IR signature testing confirms the air vehicle meets the IR signature requirement.

Sample Final Verification Criteria

The infrared signature requirements shall be satisfied when __(1)__ analyses and __(2)__ tests confirm that the air vehicle IR signature is no greater than specified.

Blank 1. Identify the type and scope of analysis required to provide confidence that the requirement elements have been met.

Blank 2. Identify the type and scope of tests required to provide confidence that the requirement elements have been met.

VERIFICATION LESSONS LEARNED (4.1.8.1.1.2)

To Be Prepared

3.1.8.1.1.3 Visual signature

The air vehicle visual signature shall be not greater than __(1)__.

REQUIREMENT RATIONALE (3.1.8.1.1.3)

In order for the air vehicle to achieve survivability requirements during the performance of its intended mission, visual signature is required to be limited. Additionally, for training air vehicle (e.g., air vehicles designed specifically for and used solely as basic flight trainers), visual detectability should be maximized.

REQUIREMENT GUIDANCE (3.1.8.1.1.3)

The visual signature requirements should be determined from trade studies of the total weapons systems platform. The visual signature for the trade studies will be based on the observer's capability, sensitivity, and performance for all appropriate threats (e.g., air interceptor (AI), anti-aircraft artillery (AAA), and surface to air missiles (SAM).) and the determined or derived subset of mission scenarios and mission profiles for which the visual detection is considered important.

A table such as the following or an equivalent using the guidance provided, can be used to specify the visual signature in terms of source, apparent, or contrast signature.

Visual specification source signature. - (Example table)

	Degrees																		
	Nose																		Tail
Top	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
90																			
45																			
30																			
20																			
10																			
5																			
0																			
-5																			
-10																			
-20																			
-30																			
-45																			
-90																			

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REQUIREMENT LESSONS LEARNED (3.1.8.1.1.3)

When specifying an air vehicle visual signature, its luminance source signature, apparent signature or contrast could be used to determine the desired detection range envelope. The source luminance signature inherently characterizes the air vehicle signature, but its measurement is relatively complex. Both the apparent and contrast signatures are relative values. The apparent signature characterizes the air vehicle at a range while the contrast signature characterizes the air vehicle at a range against a background.

4.1.8.1.1.3 Visual signature verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Air vehicle visual signature	(1)	A	A,S	A,S, T		A,S, T

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.1.8.1.1.3)

Verification of the air vehicle visual signature requirement is based on the need for the determination of visual spectrum detection ranges for worst case detection scenarios. This is accomplished by visual signature analysis, computer model simulation and visual testing of surface structural shape and surface coatings and testing of the visual signature of the actual air vehicle under specified operational conditions.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the design concept, including predictions, air vehicle scale models, and/or simulations, indicates the visual signature requirements are achievable.

PDR: Analysis of the preliminary design indicates the visual signature requirements are achievable. Visual signature simulation and analysis of lower-level testing of actual prototype components indicate that budget allocation and overall visual signature budget analysis are met.

CDR: Analyses of the final design, including computer simulation model predictions of the visual signature under specified operational conditions, and subsystem visual testing of air vehicle surface structural shape and coatings, confirm that the air vehicle meets the specified visual signature requirements.

FFR: No unique verification action occurs at this milestone.

SVR: Analyses of the final air vehicle design, including computer simulation model predictions of visual signature under specified conditions, and testing of air vehicle visual signature under specified operations and atmospheric and visibility conditions, confirm that the air vehicle meets specified visual signature requirements

Sample Final Verification Criteria

The visual signature requirement shall be satisfied when the __(1)__ analyses, __(2)__ simulations and __(3)__ tests confirm that the air vehicle visual signal levels for all specified conditions are within the specified levels.

> Blank 1. Identify the type and scope of analysis required to provide confidence that the requirement elements have been met.
>
> Blank 2. Identify the type and scope of computer model simulations required to provide confidence that the requirement elements have been met.
>
> Blank 3. Identify the type and scope of subsystem and air vehicle tests required to provide confidence that the requirement elements have been met.

VERIFICATION LESSONS LEARNED (4.1.8.1.1.3)

If visual tracking for conduct of first flight is required, high visual signature coatings and markings may be employed.

3.1.8.1.1.4 Acoustic signature

The air vehicle acoustic signature shall be not greater than __(1)__.

REQUIREMENT RATIONALE (3.1.8.1.1.4)

As other signatures of air vehicles are reduced the acoustic signature could become a significant method of detection. Since sound travels relatively slowly compared to the speed of some air vehicles, the acoustic signature is not a good source to use to track an air vehicle. It is used as a source of warning that an air vehicle is approaching or has passed some point, and for course tracking of slow moving air vehicles at low altitude(s).

REQUIREMENT GUIDANCE (3.1.8.1.1.4)

Blank 1. Complete by including a table using the following table example for guidance.

Acoustic signature. – (Example table)

Freq (Hz)	High Speed High Alt 0 NM Offset	High Speed High Alt 5 NM Offset	High Speed High Alt 10 NM Offset
20			
25			
31.5			
40			
-			
-			
-			
3150			
4000			
5000			

Acoustic signatures are usually specified in sound pressure level (SPL). The common reference for frequency range is in one-third octave bands with the center frequency denoting the band. The signature can be specified at the source, some nominal distance, or at the detector.

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REQUIREMENT LESSONS LEARNED (3.1.8.1.1.4)

When specifying acoustic requirements for survivability, a balanced approach should be used. In other words the detectability due to noise should be based on the detectability of the aircraft by other means (RF, IR, visual).

4.1.8.1.1.4 Acoustic signature verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Acoustic signature	SPL at the detector (1)	A	A,S	A		A,D, T

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.1.8.1.1.4)

Acoustic signature verification is performed through analysis, demonstration and testing to confirm that the air vehicle acoustic signature, for a varying number of anticipated (air vehicle to detector) encounter scenarios and a full range of specified atmospheric environments and SPL. The verification should be done on an iterative basis as the contractor modifies his design.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the design concept, including predictions and/or simulations, indicates the acoustic signature requirements are achievable.

PDR: Analysis of the preliminary design indicates the acoustic signature requirements are achievable. (See Appendix F for further guidance.)

CDR: Analysis of air vehicle design, and updated analysis of lower-level test/demonstration data, confirm acoustic signatures are within specified levels under all specified encounter conditions.

FFR: No unique verification action occurs at this milestone.

SVR: Analysis of lower-level test and demonstration data, air vehicle demonstrations, and test confirm that the acoustic signature requirements are achieved.

Sample Final Verification Criteria

The acoustic signature requirements shall be satisfied when __(1)__ analyses, __(2)__ demonstrations, and __(3)__ tests confirm that the air vehicle acoustic levels do not exceed the specified levels.

Blank 1. Identify the type and scope of analysis required to provide confidence that the requirement elements have been met.

Blank 2. Identify the type and scope of demonstrations required to provide confidence that the requirement elements have been met.

Blank 3. Identify the type and scope of tests required to provide confidence that the requirement elements have been met.

VERIFICATION LESSONS LEARNED (4.1.8.1.1.4)

To Be Prepared

3.1.8.1.1.5 Emission control

The air vehicle shall have the capability to inhibit unintentional electromagnetic radiated emissions to levels not greater than __(1)__ at a distance of __(2)__ in any direction from the air vehicle over the frequency range of __(3)__. The air vehicle shall be capable of activation and deactivation of the emission control (EMCON) function via a single control instruction.

REQUIREMENT RATIONALE (3.1.8.1.1.5)

Operations onboard and near Naval ships are frequently conducted in electromagnetic silence, which is the most stringent state of EMCON. After aircraft have been launched from the ship, EMCON is frequently used to avoid detection of the aircraft and the ship from which it was launched.

Army surface systems impose EMCON requirements to minimize detection and provide inter-platform compatibility between one system's radios and another system's unintentional emissions.

REQUIREMENT GUIDANCE (3.1.8.1.1.5)

> Blank 1 and blank 2. Complete with values in accordance with current operational EMCON requirements. MIL-STD-464 cites values of "–110 dBm/m^2 at a distance of one nautical mile in any direction from the air vehicle" (or "–105 dBm/m^2 at a distance of one kilometer in any direction from the air vehicle").
>
> Blank 3. Complete with the required operational EMCON frequency range. MIL-STD-464 cites 500 kHz to 40 GHz. Refer to MIL-STD-464 for further guidance on appropriate sensitivity values.

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REQUIREMENT LESSONS LEARNED (3.1.8.1.1.5)

Radio silence, now called EMCON, was used very effectively during World War II to hide the location of naval ships from the Japanese. EMCON was used by naval forces in the Vietnam and Korean Wars to deploy aircraft over the forward edge of the battle area. These tactics continue today in modern naval forces.

4.1.8.1.1.5 Emission control verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Capability to inhibit unintentional electromagnetic radiated emissions	(1), (2), (3)	A	A	A		A,T
Activation/deactivation of EMCON	Pass/Fail	A	A	A		A,T

*Numbers in parentheses in the Measurand column refer to numbered blanks in the requirement.

VERIFICATION DISCUSSION (4.1.8.1.1.5)

For air vehicle subsystems and equipment which is required to meet the radiated emission limits of MIL-STD-461, verification should provide assurance that the overall air vehicle will comply with the EMCON requirement for any emission contributions from this equipment at most frequencies of interest. When other EMI standards are imposed, analysis is necessary to determine whether the requirements are adequate for EMCON at the air vehicle level.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to each of the requirement elements specified in the verification table.)

SRR/SFR: Analysis of the preliminary design concept indicates that emission control has been addressed and will be capable of meeting EMCON requirements for the specified frequency range and distance.

PDR: Analysis of the preliminary air vehicle design indicates that the EMCON requirements are addressed and will be met, and that a single control function addresses the requirement to activate/deactivate EMCON.

CDR: Analysis of the critical air vehicle design and its components confirms that the EMCON requirements are addressed and will be met, and that a single control function can effectively activate/deactivate EMCON.

FFR: No unique verification action occurs at this milestone.

SVR: Emission analysis of lower-level component design and testing as well as EMCON testing of the entire air vehicle confirms that the specified emission control requirements have been met for the specified frequency range and distance, and that a single control function can activate/deactivate EMCON.

Sample Final Verification Criteria

The emission control requirement shall be satisfied when the __(1)__ analyses, and __(2)__ tests confirm that the air vehicle's unintentional emission levels for specified operational and encounter conditions are within the specified levels, and that activation and deactivation of EMCON function via a single control instruction is achieved.

Blank 1. Identify the type and scope of analysis required to provide confidence that the requirement elements have been met.

Blank 2. Identify the type and scope of tests required to provide confidence that the requirement elements have been met. Tests could include antenna stand or anechoic chamber types of tests.

VERIFICATION LESSONS LEARNED (4.1.8.1.1.5)

To Be Prepared

3.1.8.1.1.6 Electronic protection

Air vehicle intentional and unintentional electromagnetic radiated emissions in excess of the EMCON limits shall preclude the classification and identification of the air vehicle such that operational performance requirements are met. The air vehicle shall be capable of activation and deactivation of the electronic protection (EP) function via a single control instruction.

REQUIREMENT RATIONALE (3.1.8.1.1.6)

The EP requirement allows transmissions with the intention of denying detection by the use of space, time or energy level.

REQUIREMENT GUIDANCE (3.1.8.1.1.6)

Refer to MIL-STD-464 for further guidance on appropriate sensitivity values.

REQUIREMENT LESSONS LEARNED (3.1.8.1.1.6)

To Be Prepared

4.1.8.1.1.6 Electronic protection verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Preclusion of system classification/ identification	Pass/Fail	A	A	A		A,T
Activation/deactivation of EP	Pass/Fail	A	A	A		A,T

VERIFICATION DISCUSSION (4.1.8.1.1.6)

The verification of the electronic protection requirement consists of EM emissions control analysis and emissions testing of an actual air vehicle in the environment in which it will operate, and the determination whether the emissions in excess of EMCON levels preclude the identification and classification of the air vehicle. Analysis and testing are used to verify the single control function for activation/deactivation of the electronic protection function. Operational testing of EP modes is very restrictive and costly. Maximum effort should be made during bench and system laboratory testing to minimize the operational testing.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to each of the requirement elements specified in the verification table.)

SRR/SFR: Analysis of the preliminary design concept indicates that electronic emission protection has been addressed and that intentional/unintentional emissions in excess of EMCON levels preclude air vehicle identification/classification and that a single control function addresses the requirement to activate/deactivate electronic protection.

PDR: Analysis of the preliminary design indicate that the EMCON requirements are addressed and will be met, and that emissions in excess of EMCON levels preclude air vehicle identification/classification. Analysis of the preliminary design indicates incorporation of a single control which can activate/deactivate the electronic protection function.

CDR: Analysis of the critical design and its components confirms that the EMCON requirements are addressed and will be met, and that emissions in excess of EMCON levels preclude air vehicle identification/classification. Analysis of the critical design confirms a single control function for the requirement to activate/deactivate the electronic protection function.

FFR: No unique verification action occurs at this milestone.

SVR: Emission analysis and testing of lower-level components as well as EMCON testing of the entire air vehicle confirms that emissions in excess of EMCON levels preclude the identification/classification of the air vehicle. Testing confirms that a single control can activate/deactivate the electronic protection function

Sample Final Verification Criteria

The electronic protection requirement shall be satisfied when __(1)__ analyses, and __(2)__ tests confirm that the air vehicle’s intentional/unintentional emission levels in excess of EMCON levels, for specified operational and encounter conditions, preclude the identification/classification of the air vehicle, and that activation/deactivation of the electronic protection function via a single control instruction is achieved.

> Blank 1. Identify the type and scope of analysis required to provide confidence that the requirement elements have been met.
>
> Blank 2. Identify the type and scope of tests required to provide confidence that the requirement elements have been met. Tests could include antenna stand or anechoic chamber types of tests.

VERIFICATION LESSONS LEARNED (4.1.8.1.1.6)

To Be Prepared

3.1.8.2 Vulnerability reduction

3.1.8.2.1 Threat detection, identification, prioritization, awareness, and response

The air vehicle shall be capable of detecting, identifying, locating, and prioritizing threats (including unknowns) described in table 3.1.8.2.1-I at any point in the mission using both onboard and offboard assets in the threat environment/scenario specified in 3.1.2.1 Threat environment in accordance with table 3.1.8.2.1-II. The air vehicle shall be capable of unambiguous correlation of information from on-board sources. The air vehicle shall be capable of unambiguously correlating onboard information with information from offboard sources to the accuracy limits of the offboard source. The offboard assets applicable to this requirement are __(1)__. The aircrew shall be presented the threat situation awareness including the criticality of the priority threats and cued with the available responses.

TABLE 3.1.8.2.1-I. Threat description.

Threat ID #	Threat Type	Threat Activity	Threat Signature	Threat Counter-Measures	Threat Mode

TABLE 3.1.8.2.1-II. Threat identification/location prioritization capabilities.

Threat ID #	Capability Probability	Location Accuracy	FOR	Range	Timeline	Currency	Conditions
	P_{Detect} $P_{Identify/Detect}$						

REQUIREMENT RATIONALE (3.1.8.2.1)

This requirement is applicable to air-to-air and air-to-surface threat location and evaluation, and establishes the air vehicle's capability to provide the aircrew with tactical situational awareness. Situational awareness promotes survivability and mission accomplishment by ensuring the aircrew is fully cognizant of the dynamic operational environment.

REQUIREMENT GUIDANCE (3.1.8.2.1)

While this requirement has been written in a fashion to allow specification of capabilities against airborne, ground-based, and sea-based threats in a single table, it may be prudent to replicate this requirement to address the acquisition of airborne, surface, and undersea targets in separate requirements.

The prioritization should be based upon the lethality of the threat and efficacy of the threat countermeasures or avoidance tactic.

Requirement 3.1.2.1 Threat environment identifies the total threat environment including friendly, neutral, threat, and background signals.

List the sources of offboard threat acquisition information (e.g., intra-flight, AWACS/E-2C, etc.). Identify the paragraph in the interface section that identifies the specifics of the information and quality of information passed to the air vehicle.

Fill in table 3.1.8.2.1-I Threat description with the threats that the aircrew must remain cognizant of, along with the key parameters and conditions that will help identify each particular threat.

<u>Threat ID #</u>: A unique identifier to link this table with the threat tables of 3.1.2.1 Threat environment and with table 3.1.8.2.2-II below.

<u>Threat Type</u>: A description of the threat type. It can be as simple as “SAM” or could identify a specific model of a vehicle such as “F-14,” “MIG-29,” “M-60A3,” “ZSU-23-4,” “SA-8,” etc.

<u>Threat Activity</u>: A description of what the threat is doing. This could be “stationary,” “cruising at Mach 0.8 at 20,000 feet,” “cruising at 20 kts in sea state 3,” etc. Add any information useful for describing the conditions for which detection, acquisition, and identification capabilities are required.

<u>Threat Signature</u>: Typical signatures include RF, RCS, IR, Visual, and Acoustic. There are three basic choices for filling in the threat signature information. One option is to define the specific signature at various azimuths and elevations for each threat the air vehicle must operate against. This will necessitate defining the threat acquisition information versus each such threat. Another option is to use generic, reference signatures (e.g., 10 square meter target at frequency XXX, or 1 square foot presented area, etc.) for each class of threat. The classes may only be differentiated by threat background or for special cases deemed not appropriate for “extrapolation” from a generic, reference signature. Again, for each threat, define the threat acquisition information. Lastly, a single set of generic, reference signatures could be used. Where practicable, signature information should be entered for each type of signature thereby enabling the developer to define the best “suite” of sensors needed to provide the needed acquisition capabilities. If there are other signature types of interest/utility, then add those to the table. For specific threats (e.g., MIG-21), a document may exist that defines the specific signature characteristics of that threat that could be referenced in lieu of filling in the table with specific numbers. An example of some signature characteristics that may be entered are

a. Radio Frequency: Enter the RF signal emissions from the threat to enable detection by devices such as radar warning receivers. RF emissions should be characterized by both power and frequency.

b. Radar Cross Section: Enter the radar cross section by frequency.

c. Infrared: Enter the infrared signature by frequency/frequency band.

d. Visual Signature: Enter the visual signature, nominally a presented area.

e. Acoustic Signature: Enter the acoustic signature.

<u>Threat Countermeasures</u>: Define the countermeasures that potential threats might use to degrade acquisition capability. This can take the form of jamming capabilities, camouflage, and so forth. For specific threats (e.g., MIG-21), a document may exist that defines the specific countermeasure capability of that threat. The document could be referenced in lieu of specific details.

<u>Threat Mode</u>: Some threats have multiple modes in which they can engage; for example, search, track, launch; radar and electro-optical; or tracking and missile guidance.

Table 3.1.8.2.2-II, Threat identification/location/prioritization capabilities, should be populated with the threats of which the aircrew must remain cognizant, along with the key threat prioritization parameters and conditions. Complete this table as follows:

Threat ID#: A unique identifier to link an air vehicle detection, identification, and track capability row in this table to the threat description contained in table 3.1.8.2.1-I Threat description above.

Capability Probability: There are nominally three options for defining various acquisition capabilities. One option is to specify the value of the parameter at a given range (nominally, the range identified at the range in the table). Another option is to utilize the field-of-view and range information specified in the table and enter a percentage for the parameter (e.g., Detect 99 percent of the threats meeting one or more of the threat signature values within a volume defined by the field-of-view and range). The third option would be to describe the value of the parameter as a function of range. All of these capabilities represent the autonomous capabilities of a single air vehicle. The probability should be based on past studies/experience and analyses and allocation of the survivability requirements in the air system specification. Trade-offs are likely alternatives (e.g., P_{ID} vs. FOR) when determining final specification values.

a. P_{Detect}: Capability to detect a single threat, or detecting some percentage of the threats within a volume defined by the FOR/range. Examples:

(1) Detect 99 percent of the threats meeting one or more of the threat signature values within the volume defined by the FOR.

(2) Probability of detecting a single threat within the FOR at a range (e.g., 0.XX at YY NM).

(3) Probability of detecting a single threat within the FOR as a function of range (enter either a probability of detection versus range table or curve).

b. $_{PIdentify/Detect}$: Enter the probability of identifying the threat. This should be based on past studies/experience and analyses and allocation. Tradeoffs are likely (e.g., range vs FOR) when determining final specification values.

Location Accuracy: List the accuracy requirement for each threat specified.

Field of Regard (FOR): The maximum azimuth and elevation limits that the air vehicle must be capable of examining. Generally complete spherical coverage is desired, however, lesser coverage may be more reasonable and FOR should be based on previous studies/experience and analyses, and may be different for different threat modes. The capabilities, accuracy, and timelines may be different for different FOR. Tradeoffs are likely (e.g., range vs FOR) when determining final specification values.

Range: The range at which the air vehicle must be capable of identifying, locating, or prioritizing threats. This may be a specific number or an entry such as 1.5 times the lethal range of the weapon associated with the threat. Coverage required should be based on previous studies/experience and analyses. Tradeoffs are likely (e.g., range vs FOR) when determining final specification values.

Timeline: The maximum time taken to identify, locate, or evaluate the threat. This needs to be tied tightly with the countermeasures capability and avoidance tactics. The required timeline should be based on previous studies/experience and analyses. Tradeoffs are likely (e.g., range vs countermeasures capability vs time) when determining final specification values.

Currency: The “refresh” rate of target information within the FOR. This parameter is based on targeting and weapon support requirements for both single weapon and multiple weapon attacks. Threat information updates should occur consistent with situation awareness needs as related to countermeasure employment requirements and avoidance tactics.

Conditions: Specify the conditions of measurement for the requirement and other factors that bear on the achievement of the requirement. These conditions should be in concert with those defined under 3.2 Environment . Such factors include

a. Weather

b. Operational environment (e.g., pulse density, smoke and other obscurants)

c. Terrain and sky (threat background e.g., sea state)

REQUIREMENT LESSONS LEARNED (3.1.8.2.1)

To Be Prepared

4.1.8.2.1 Threat detection, identification, prioritization, awareness, and response verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Detecting, identifying, locating, and prioritizing threats	Table 3.1.8.2.1-I & II	A	A	A,S		A,S, D,T
Unambiguous correlation of information from on-board sources	Correct correlation	A	A	A,S		A,S, D,T
Unambiguous correlation of information from off-board sources	Correct correlation using offboard sources identified in (1)	A	A	A,S		A,S, D,T
Priority threat cueing	Correct cueing for identified threats	A	A	A,S		A,S, D,T

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.1.8.2.1)

The elements of this requirement are focused on gathering information about the threat environment around the air vehicle, determining which are threats of interest and which are not, and based threat priority and on pilot's decisions and inputs, providing offensive and/or defensive functions to allow the pilot to engage or avoid those threats. In other words, detect, track, ID, locate, prioritize, and defeat. The requirement should be verified through a combination of in-process inspection, analysis, simulation, demonstration, and test. The Tier 3 Avionics JSSG contains additional guidance on verification methods.

The selection of test, analysis, simulation, demonstration or inspection or some combination to demonstrate a particular requirement is generally dependent on the degree of confidence in the results of the particular method, technical appropriateness, associated costs, and availability of assets. For example, subsystem and equipment-level testing must be accomplished, because analysis tools are not available which will produce credible results.

Analysis, simulation, and testing often supplement each other. Prior to the availability of hardware, analysis will often be the primary tool being used to ensure that the design incorporates adequate provisions. Testing may then be oriented toward validating the accuracy and appropriateness of the models used. If model confidence is high, testing may then be limited.

Simulations and models should be used throughout the verification process. The sensor models should be used to develop the sensor algorithms and verify the sensor requirements. They will also be used to develop and verify the avionic subsystem algorithms. The real time interface emulators are used to develop the avionic functions and to assure timing and threat recognition requirements are met. Once the avionic level algorithms are developed, the accurate sensor models should be used with the avionic algorithm simulations to evaluate the avionic level performance. Eventually, the actual algorithms should be hosted on the target hardware and should be stimulated by the environment simulations as part of the verification process. Interface emulators of weapons or other avionics are used to develop and evaluate the interface and communications with support jamming subsystem. The Full Mission Simulation (FMS) is primarily used to evaluate pilot-in-the-loop operation. The purpose of simulations/models is to evaluate/verify requirements when either it is impractical to create the environment for the requirement (e.g., providing the specification numbers of entities and pulse densities in an actual flight test) and/or the requirement is statistical in nature and requires many data points to verify the requirement (e.g., probability of detection, root mean square (rms) track accuracy). Use of simulations allows testing of the algorithms under conditions that may be difficult to replicate in a laboratory or field environment. Reliance on simulations alone, however, should be cautioned due to the purity of the modeled parameters. (For example, often in modeling receiver algorithms, a model will assume ideal filters, lack of spurious signals in the environment, pure signal characteristics of the threat waveform, absence of interfering signals, such as friendly signals, onboard radar, wingman avionics, etc. It is important that simulation data be verified by testing of the end item.) Hardware-in-the-loop and flight test data from a limited set of the scenarios used in the simulations should be used to validate these simulations/models.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analysis indicates that definition of required events, establishment of tailored requirements for sub-elements of the air vehicle based on the overall design concept, and development of a documentation trail for verification such as lower-level specifications are being considered. Analysis shows that the process of allocating requirements to lower-level elements of the air vehicle has been initiated and addresses both hardware and software. Initial analysis of the threat environment identifies the threats of interest and necessary signal characteristics needed to support this function. Analysis indicates that operational requirements are flowed to the system level specification, and that a threat/signal walkthrough to address signal processing through the air vehicle has been accomplished.

PDR: Analyses of lower-level simulations indicate that issues such as the sensitivity of the sensors, projected timeline for the sensor tuning/data latency, identification parameters, location accuracies (and the associated conditions) are considered. Analysis indicates that requirements allocated to lower-level elements of the air vehicle have been updated based upon the latest design information, and that design risks and appropriate courses of action have been identified.

CDR: Simulations and analyses accomplished for PDR have been updated and refined, and confirm that the requirement will be met. Analysis of limited lower-level testing (such as determinations of receiver sensitivity, bandwidths, etc.) have been completed.

FFR: No unique verification action occurs at this milestone.

SVR: The overall verification process consisting of analysis of the accumulated audit trail, including analyses, tests, demonstrations, and inspections that establish compliance with requirements for all subsystems and equipment installed, confirms that the air vehicle will meet the threat detection, identification, prioritization, awareness, and response requirement for the conditions stated.

Sample Final Verification Criteria

The threat detection, identification, prioritization, awareness, and response requirement shall be satisfied when __(1)__ confirm the air vehicle meets performance specified in the requirement under the conditions as stated.

> Blank 1. Identify the type and scope of tests, analyses, simulations, demonstrations, and/or inspections required to provide confidence that the requirement has been satisfied. The selection of test, analysis, simulation, demonstration or inspection or some combination to verify a particular requirement or requirement element is generally dependent on the degree of confidence in the results of the particular method, technical appropriateness, associated costs, and availability of assets. For example, subsystem and equipment-level testing must be accomplished, because analysis tools are not available which will produce credible results.

VERIFICATION LESSONS LEARNED (4.1.8.2.1)

To Be Prepared

3.1.8.2.2 Defensive countermeasures

The air vehicle shall have the capability to defensively counter threats as defined in table 3.1.8.2.2-I.

TABLE 3.1.8.2.2-I. Defensive countermeasures.

Threat	Threat Engagement Mode	Threat ID	Pre-launch Effectiveness	Post-launch Effectiveness	Conditions

REQUIREMENT RATIONALE (3.1.8.2.2)

Countermeasures are part of a combination of capabilities that, when working together, allow an air vehicle to perform its mission and survive. Countermeasures can be used in concert with air vehicle observables, speed, altitude, maneuver, route planning, and other characteristics/capabilities to provide the high survivability needed for mission accomplishment and sustaining a viable force for continued operations against hostile forces. Such capabilities need to be carefully balanced and properly employed to achieve the overall survivability needed. For example, air vehicles that rely on constantly emitting power to defeat threats are at risk of denying other factors necessary for combat effectiveness, such as providing raid warning information to hostile forces.

This requirement works in conjunction with 3.1.2.1 Threat environment and assumes that the air vehicle is within the engagement parameters of the threat system.

REQUIREMENT GUIDANCE (3.1.8.2.2)

Complete table 3.1.8.2.2-I as follows:

Threat: Identify the threat to be countered. Threats would include air-to-air and surface-to-air threats including engagement systems and supporting systems (e.g., command and control).

Threat Engagement Mode: Some threats have multiple modes in which they can engage, for example, radar and electro-optical. The countermeasure effectiveness may be different for each engagement mode of a given threat.

Threat ID: This can be entered as a simple “Yes” or “No.” Some countermeasures may be effective given that the threat system was properly identified but can also operate at a lower level of effectiveness in cases of misidentification or no identification.

Pre-launch Effectiveness: The word “launch” is used loosely and captures the events necessary for the threat to take action (launch, open fire, pass targeting information, etc.). Such actions would normally include detection, track, and acquisition (designation). This parameter can be entered as a probability or a percentage. For example, countermeasures could have a 90 percent pre-launch effectiveness meaning that it denies detection, track, and acquisition in 90 percent of the engagements. In other words, when the countermeasure is effective, it works very well (works 90 percent of the time). Another way of treating this parameter is as a degraded capability (e.g., increase in position uncertainty). With either way of defining the parameter, the description of the required effect should be described in the conditions column.

Post-launch Effectiveness: The word “launch” is used loosely and captures the events that take place after launch, open fire, pass targeting information, etc. Such actions could include guidance and terminal effects. Countermeasures can be used to defeat the guidance of a missile or the threat system “guiding” the missile. Additionally, the lethal element of the threat (e.g., the missile) may be degraded by expendables. For some threat systems, countermeasures may only be effective in the “pre-launch” state of the threat. Post-launch effectiveness addresses both ECM and expendables.

Conditions: Include any conditions bearing on the effectiveness. Conditions could include a description of the required effect. They also include other factors, such as weather, operational environment, and so forth.

REQUIREMENT LESSONS LEARNED (3.1.8.2.2)

To Be Prepared

4.1.8.2.2 Defensive countermeasures verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Countermeasures effectiveness	Table 3.1.8.2.2-I	A	A,S	A,S		I,A, S,T

VERIFICATION DISCUSSION (4.1.8.2.2)

The requirement and the information needed in the associated table is best treated as an integrated whole. The requirements for this template are focused on gathering information about the threat environment around the aircraft, determining which are threats of interest and which are not, and based on threat priority and pilot's decisions and inputs, providing defensive functions to allow the pilot to engage those threats

The selection of test, analysis, simulation, demonstration, inspection, or some combination to demonstrate a particular requirement is generally dependent on the degree of confidence in the results of the particular method, technical appropriateness, associated costs, and availability of assets. Analysis, simulation, and testing often supplement each other. Prior to the availability of hardware, analysis will often be the primary tool being used to ensure that the design incorporates adequate provisions. Testing may then be oriented toward validating the accuracy and appropriateness of the models used. If model confidence is high, testing may then be limited.

Simulations and models should be used throughout the verification process. The air vehicle sensor models should be used to develop the sensor algorithms and verify the sensor requirements. Simulations and models will also be used to develop and verify the air vehicle (e.g., avionic) subsystem algorithms. The real time interface emulators are used to develop the air vehicle subsystem functions and to assure timing and threat recognition requirements are met. Once the air vehicle subsystem (e.g., avionic) level algorithms are developed the accurate sensor models should be used with the subsystem algorithm simulations to evaluate the air vehicle level performance. Eventually, the actual algorithms should be hosted on the target hardware and should be stimulated by the environment simulations as part of the verification process. Interface emulators of weapons or other air vehicle subsystems are used to develop and evaluate the interface and communications with support jamming subsystem. Use of simulations/models is to evaluate/verify requirements when either it is impractical to create the environment for the requirement (e.g., providing the specified numbers of entities and pulse densities in an actual flight test) and/or the requirement is statistical in nature and requires many data points to verify the requirement (e.g., probability of detection, rms track accuracy). Use of simulations allows testing of the algorithms under conditions that may be difficult to replicate in a laboratory or field environment. Reliance on simulations alone, however, should be cautioned due to the purity of the modeled parameters. For example, often in modeling receiver algorithms, a model will assume ideal filters, lack of spurious signals in the environment, pure signal characteristics of the threat waveform, absence of interfering signals, such as friendly signals, onboard radar, wingman avionics, etc. It is important that simulation data be verified by testing of the end item. Hardware-in-the-loop and flight test data from a limited set of the scenarios used in the simulations should be used to validate these simulations/models.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of design concepts indicate hardware and software requirements have been allocated to lower-level elements of the air vehicle. A documentation trail for verification has been defined. Analysis of the initial threat environment has been performed and the threats of interest and necessary signal characteristics needed to support this function are identified. Analysis identifies necessary threat vulnerability and countermeasures opportunities. Assessments of air vehicle signature and expected jamming power/spectral power needed to defeat the threats have been included. Operational requirements have been flowed to the subsystem-level requirements. A threat/signal analysis to address signal processing requirements has been conducted.

PDR: Analysis of preliminary simulations which address such issues as the sensitivity of any sensors supporting the countermeasures function, projected timeline for the sensor tuning/data latency, identification parameters, location accuracies (and the associated conditions) and countermeasures initiation indicate compliance with the requirements. Requirements allocated to lower-level elements of the air vehicle have been updated based upon the latest design information. Design risks and appropriate courses of action have been identified. A preliminary threat/signal walkthrough to address signal processing through the air vehicle has been conducted.

CDR: Analysis of simulation results based on limited subsystem testing (such as determinations of receiver sensitivity, bandwidths, etc.) confirms the detailed design meets specified performance. A threat/signal walkthrough to address signal processing through the air vehicle has been updated.

FFR: No unique verification action occurs at this milestone.

SVR: Analysis of lower-level inspections, simulations, demonstrations, and ground and flight testing confirm that the air vehicle meets specified performance.

Sample Final Verification Criteria (4.1.8.2.2)

Air vehicle defensive countermeasures shall be satisfied when __(1)__ inspections, __(2)__ simulations, __(3)__ demonstrations, and __(4)__ tests confirm specified effectiveness for countering of threats.

Blank 1. Identify the type and scope of inspections required to provide confidence that the requirement element has been met.

Blank 2. Identify the type and scope of simulations required to provide confidence that the requirement element has been met.

Blank 3. Identify the type and scope of demonstrations required to provide confidence that the requirement element has been met.

Blank 4. Identify the type and scope of ground and flight tests required to provide confidence that the requirement element has been met.

VERIFICATION LESSONS LEARNED (4.1.8.2.2)

To Be Prepared

3.1.8.2.3 Terrain following/terrain avoidance

The air vehicle shall be capable of __(1)__ terrain following/terrain avoidance (TF/TA) including the transition of the air vehicle from cruise altitudes and course to the aircrew selected TF altitude and mission designated flight plan. The air vehicle shall operate to a minimum set clearance altitude of __(2)__ feet over __(3)__ terrain. A minimum set clearance altitude of __(4)__ feet shall be permitted over __(5)__ terrain. When crossing predominant peaks, set clearance altitude shall be maintained to within (+) __(6)__ / (-) __(7)__ and flight path angle shall be 0 (+) __(8)__ / (-) __(9)__ degrees. The air vehicle shall be capable of maneuvering with __(10)__ degrees per second turn rate and at bank angles up to __(11)__ degrees during TF operation. TF performance shall be maintained when operating the air vehicle in the operational environments specified in 3.1.2.1 Threat environment and electronic warfare environments defined by 3.2.1 Electromagnetic environmental effects, and in the presence of towers as defined in __(12)__. The air vehicle shall execute a safe exit (fly-up) from TF altitudes after any loss or degradation of the terrain-following function or safety-critical function. The false alarm fly-up rate shall be not greater than __(13)__.

REQUIREMENT RATIONALE (3.1.8.2.3)

A terrain following/terrain avoidance (TF/TA) capability provides significant aircrew workload reduction and increased safety when mission/survivability requirements call for low altitude penetration.

REQUIREMENT GUIDANCE (3.1.8.2.3)

Automatic and/or manual TF requirements should be driven by customer preference. Meeting the low-level mission requirements of the air vehicle should drive the required aircraft configurations including gross weight, c.g., and weapons loads. The mission requirements may also help drive the mach/airspeed envelope for TF operations. A letdown from cruise to TF altitudes is necessary for two reasons. First, it is much safer than requiring the aircrew fly the aircraft down to low altitudes then initiate TF. Second, it allows the TF system to self-test and sequence the TF mode into full operation as the aircraft descends.

Complete the blanks in the requirement as follows:

Blank 1. Indicate whether the TF/TA will be “automatic” or “manual,” or capable of both.

Blanks 2-5 and 10-11. TF performance requirements such as altitudes, speeds and maneuver limits should flow down from the mission/survivability requirements of the air vehicle. Establishing these requirements a priori could result in a system that is either over or under specified. Take advantage of higher set clearance altitudes in mountainous terrain, if practical.

Blanks 6-7. Allowable deviations above the set clearance altitude should come from mission/survivability considerations. Safety considerations will define allowable deviation below the set clearance altitude. Deviations below set clearance altitude are typically specified in terms of percentage of set clearance altitude.

Blanks 8-9. Flight path angle deviations at peak crossings should be minimized. A positive flight path angle at peak crossing will result in the aircraft “ballooning” over the peak and a negative flight path angle could put the aircraft in danger if there is a plateau or another peak behind the first. Key challenges of any TF system design are operation in weather (rain and snow), against towers, power lines, and in an Electronic Warfare (EW) environment. Overcoming these “environmental” challenges are key to a viable TF system. When flying low level at night, there is very little time to recognize system failures and effect a safe recovery. As such, it is necessary for the system to have a robust self-monitoring capability that recognizes the fault and initiates an automatic recovery.

Blank 12. Describe the towers to be encountered by the air vehicle.

Blank 13. Insert the maximum false alarm fly-up rate in terms of "per sortie" or "per flight hour." The false alarm fly-up rate requirement should be selected as the lower of two maxima. The first being the maximum tolerable rate from a pilot-crew physiological and psychological consideration, that is, the rate at which fatigue and physical discomfort are manifest or the rate at which diminishing crew confidence in the TF/TA performance can be detected. The second being the maximum rate tolerable from a mission performance and survivability perspective, that is, the rate at which fly-up maneuvers would degrade mission performance as a result of disruption of the payload delivery functions or would decrease survivability due to increased probability of detection and threat effectiveness resulting from increased signature during the maneuvers. Since the TF/TA function of the Fly-up Maneuver is safety of flight critical, the function requires successful detection of terrain or climatic conditions and of degradation of air vehicle functional performance which would result in catastrophic loss, with near certainty (10^{-8} probability of failure to detect and act). To obtain this level of performance requires extreme sensitivity from the sensor suite (including on-board diagnostics) and very fast computational and data rates. The phenomena, of both natural and manufactured systems, that increased sensitivity (probability of detection) accompanies increased false alarms (probability of detection in the absence of the target stimulus) dictates avoidance of a false alarm rate requirement for which a design solution cannot obtain.

REQUIREMENT LESSONS LEARNED (3.1.8.2.3)

In early TF system designs, manual TF was implemented either as a degraded capability or out of convenience (too hard to implement auto capability). Specific system failures could result in loss of auto TF but not the manual capability. This would generally not be the case with current digital flight control equipped aircraft. It was not the case for the B-2 system. As such, the customer should determine if there is an operational need for manual and/or auto TF prior to establishing the requirement. Although the design differences between auto and manual TF is not great, there are flight test requirements for both which can be costly. When evaluating TF set clearance requirements against survivability requirements, also consider terrain types (flat, rolling and mountainous). Take advantage of higher set clearance altitudes in mountainous terrain if practical. Allowable deviation below the set clearance altitude may be specified in terms of percentage of set clearance altitude. The B-2 required that the ground clearance always be at least 80 percent of the set clearance altitude. Flight path angle at peak crossing is one of the most critical parameters to consider when specifying performance. Ballooning over a peak exposes the aircraft significantly more than crossing the peak a few feet too high. However, pushing over the peak too aggressively can put the aircraft into a potential unrecoverable situation depending on the terrain on the backside of the peak. Consider 0 +/- 5 degrees or less when establishing this requirement. The avionics spec guide should go into some detail on rain rates for nominal performance and degraded (fly high) performance. The guide should also specify tower detection, classification, and measurement requirements being careful not to over specify the measurement requirement. For a TF system with a minimum 200-ft set clearance altitude, a measurement requirement of tower height +/- 100-ft would be adequate to assure vehicle safety. The electronic warfare environments defined in 3.2.1 Electromagnetic environmental effects should be consistent with other air vehicle requirements and prohibit the occurrence of invalid dive commands due to electronic attack activity. Give special attention to systems that ignore terrain detection based on a rain cloud declaration; these algorithms require high confidence and can be difficult to develop. A numerical requirement for fail safety is recommended. This would be an allocation of the total air vehicle loss rate to TF operations. The B-2 requirement defined aircraft loss rate to not exceed 5 x 10^{-6} for a 10 hour mission with 2 hours in TF. Typical terrain avoidance information includes a topographical map shaded to indicate terrain above/below aircraft level, planned aircraft flight path, and aircraft turn limits. Consideration should be given to combining the terrain avoidance display with other situational awareness functions supported by the air vehicle.

4.1.8.2.3 Terrain following/terrain avoidance verification

Requirement Element(s)	Measurand*	SRR/ SFR	PDR	CDR	FFR	SVR
Transition to minimum clearance altitude in specified operational environment	(1), (2), (4) Elapsed time to transition	A	A,S	A,S	A,S	A,S, T
Nominal TF performance in specified operational environment	(1), (2), (4), (6), (7), (8), (9), (10), (11)	A	A	A,S	A,S	A,S, T
Fly-up functionality	Fly-up performance, condition detection	A	A,S	A,S	A,S	A,S, T
False alarm rate	(13)	A	A	A,S		A,T

*Numbers in parentheses in the Measurand column refer to numbered blanks in the requirement.

VERIFICATION DISCUSSION (4.1.8.2.3)

Transition to Minimum Clearance Altitude in Specified Operational Environment

The transition from cruise to minimum clearance altitude is characterized by a sequence of events that starts with selection of the TF mode at cruise altitude and concludes with capture of the selected set clearance altitude with a fully functioning TF capability. Verification of this requirement consists of executing the following sequence: execution of self-test (to the extent required for fail safety), switching the TF system to full operation, and subsequent maneuver of the air vehicle to the minimum clearance altitude while maintaining the required flying/ride quality requirements. Data used to verify this requirement will likely include time history information of message traffic between the TF controller and the supporting subsystems. This message traffic will verify that appropriate mode commands were sent and subsystem responses were received. Overall verification of the transition will likely include a spectrum of aircraft configurations, initial conditions (altitudes, airspeeds, autopilot modes), set clearance altitudes, and operational environments (natural environment, terrain, towers, electromagnetic environment, etc.). Only a sample of these conditions should be required for verification of this specific requirement. The remainder of the test points will satisfy flight test progression requirements and verify maneuver performance.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis establishes the transition maneuver profile, the required events (maneuvers, subsystem test, system test, subsystem moding, etc.), their sequence and required timelines, the required crew actions during the transition maneuver, and the limiting operational environments.

PDR: Initial analyses/simulations demonstrate the transition from cruise to TF altitude. All required steps and timelines should be analyzed/simulated.

CDR: Pilot-in-the-loop simulations demonstrate the transition from cruise altitude to minimum set altitude. Necessary crew actions evaluated along with the system feedback to the crew. Simulation represents actual aircraft architecture and subsystem performance.

FFR: Pilot-in-the-loop simulations using actual flight hardware (iron bird) accomplished to demonstrate transition. Analysis of flying test bed or development aircraft flight tests of the sensor accomplished to verify performance requirements are met or can be met within the TF system development timeline.

SVR: Flight test results verify required transition performance. Pilot comments indicate acceptable flying/ride qualities during the transition maneuver. Simulator is updated to match flight test results prior to simulations that verify any conditions not accomplished in flight test.

Sample Final Verification Criteria

Transition to minimum clearance altitude shall be verified through __(1)__ flight test transition maneuvers and __(2)__ simulations in the __(3)__ representative operational environments. Said transitions shall result in achieving set clearance altitudes within __(4)__% of specified requirements while maintaining flying qualities specified in paragraph 3.3.11.1.1.1.

> Blank 1. Identify the quantity of transition maneuvers to be performed during the flight test program. The minimum quantity should be the number of maneuvers necessary to calibrate the simulator.
>
> Blank 2. Identify the type and scope of simulations that will be performed to supplement the flight test program in verifying this requirement.
>
> Blank 3. Identify the unique operational environments (natural environment, terrain, towers, electromagnetic environment, etc.) that cover the range of possible operating environments.
>
> Blank 4. Identify the acceptable transition performance in terms of a percentage of the specified requirement.

Lessons Learned: A successful transition from cruise to the TF altitude is critical for operational acceptance of the TF capability. A typical transition maneuver consists of pushing the aircraft nose over to an established flight path angle and subsequently executing a recovery that levels the aircraft at the selected set clearance altitude. The push over and recovery maneuvers should be smooth with critically damped captures (little or no undershoot) of the flight path angle or set clearance altitude. In a mission scenario, the letdown maneuver would be accomplished just prior to penetration of the threat area. As such, active aircrew involvement in the transition should be minimized; however, status information to the crew indicating successful execution of intermediate steps will provide necessary confidence in system performance. Straight flight letdowns to the highest set clearance altitude should be the safest and least challenging to accomplish in-flight test.

Nominal Terrain Following Performance in Specified Operational Environment

Nominal operation of the TF system includes pitch axis commands to control flight path over terrain within the established TF envelope. Verification should include confirmation that lateral control provided by the TF/TA function is consistent with TF turn rate and bank angle limits. Set clearance altitude and flight path angle measured at predominant peak crossings are key measures of acceptable performance. Maneuver characteristics between peak crossings should comply with applicable flying qualities requirements. Verification should include a variety of terrain types including flat, rolling, mountainous, isolated peaks and successive/hidden peaks. Performance should be measured in straight flight, transitions in and out of turns and in steady turning flight in automatic and manual (if required) TF.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis establishes the operational terrain projections and the limiting operational environments (natural environment, terrain, towers, electromagnetic environment, etc.).

PDR: Analysis confirms that the sensor/feedback information necessary to accomplish terrain following within acceptable criteria is defined. Key sensor/feedback parameters may include aircraft attitudes, velocities (airspeed and ground speed), position, accelerations, height above ground, and terrain profile. Accuracy, resolution, frequency, and range will all be defined. Analysis confirms that flying qualities design criteria supports TF functional requirements.

CDR: Initial simulations demonstrate terrain following performance. Analysis/simulation updated as necessary based on sensor/flight control system design progression.

Pilot-in-the-loop simulations demonstrate automatic and manual (if required) terrain following. Simulation should represent actual aircraft architecture and subsystem performance. Necessary crew actions evaluated along with the system feedback to the crew. Manual terrain following includes pilot evaluation of the flight director mechanization.

FFR: Pilot-in-the-loop simulations using actual flight hardware (iron bird) accomplished to demonstrate terrain following performance. Off nominal (within fail-safe thresholds) performance demonstrated with analysis and simulation. Analysis of flying test bed or development aircraft flight tests of the sensor accomplished to verify performance requirements are met or can be met within the TF system development timeline.

SVR: Flight test results verify required nominal terrain following performance. Pilot comments indicate acceptable flying/ride qualities during nominal terrain following. Simulator is updated to match flight test results prior to simulations that verify any conditions not accomplished in flight test.

Sample Final Verification Criteria

Nominal terrain following performance shall be verified through __(1)__ flight test maneuvers and __(2)__ simulations in the __(3)__ representative operational environments. Said maneuvers shall result in maintaining set clear altitudes within __(4)__% of specified requirements while maintaining flight path angles within __(5)__% of specified requirements. Maneuvers shall also demonstrate capability to achieve turn rate and bank angles within __(6)__ % of specified requirements while maintaining flying qualities specified in 3.3.11.1.1.1 Allowable levels for air vehicle normal states.

Blank 1. Identify the quantity of terrain following maneuvers to be performed during the flight test program. The minimum quantity should be the number of maneuvers necessary to calibrate the simulator.

Blank 2. Identify the type and scope of simulations that will be performed to supplement the flight test program in verifying this requirement.

Blank 3. Identify the unique operational environments (natural environment, terrain, towers, electromagnetic environment, etc.) that cover the range of possible operating environments.

Blank 4. Identify the acceptable terrain following performance in terms of a percentage of the specified requirement.

Blank 5. Identify the acceptable flight path angle performance in terms of a percentage of the specified requirement.

Blank 6. Identify the acceptable turn rate and bank angle performance in terms of a percentage of the specified requirement.

Lessons Learned: During analysis/simulation verification activities, careful attention needs to be given to unique terrain and maneuvering scenarios such as shadowed terrain (terrain that is hidden behind or shadowed by a predominant terrain feature) and turn transitions. An aggressive push over a predominant peak will minimize exposure from a survivability perspective but can result in a low crossing altitude over a second (or hidden) peak. Verification must show a safe letdown on the backside of predominant peaks under all conditions. TF systems with forward-looking sensors that transition from a straight to a turning scan pattern will need to verify performance in turn transitions. Verification requires extensive knowledge of the timing of the sensor and performance of the aircraft. Flight test of the TF system should be accomplished with an envelope expansion approach starting with nominal terrain and the highest set clearance altitude and progress stepwise towards lower altitudes and more aggressive terrain. This results in the most challenging conditions to be accomplished late in the program. It is therefore, necessary to maintain a robust simulation capability to minimize the risk of unexpected results late in the program.

Considerable emphasis needs to be placed on risk reduction flight test relative to these requirements. TF system level flight test progression will not allow verification of these capabilities until late in the flight test program. However, risk reduction testing of the forward-looking sensor on either the developmental aircraft or on a flying test bed can validate the quality and safety of the terrain profile. Rain performance should be verified in a variety of rain rates and characteristics, such as continuous, isolated, and nonuniform. Tower performance should be verified with a nominal number of runs against a large sample of real world towers rather than a statistically significant number of runs against one or two towers.

Fly-Up Functionality

A fly-up maneuver may be initiated due to the following: a failure that compromises safe TF performance has been reported, the system and/or a critical subsystem is operating outside normal thresholds with no failure reported, or the vehicle is in an unsafe condition (e.g., below XX% Set Clearance Plane (SCP)). The numeric TF system fail-safety thresholds dictate the robustness of this logic and should be allocated from the air vehicle loss rate requirement. The fly-up functionality requirement should be validated with proper engagement and disengagement of this function. Engagement of the fly-up is typically automatic and disengagement may be automatic (if the condition self clears) or aircrew initiated. Aircrew initiated disengagement's should be free of transients. Performance of the air vehicle in the fly-up should be based on structural capability, vehicle climb performance, flying qualities and expected latency in failure reporting. Data used to verify this requirement will include time history information of message traffic and vehicle "miss distance" relative to terrain. The message traffic will verify the insertion of a failure, the appropriate failure annunciation and initiation of the fly-up. The bulk of the verification should be accomplished via failure modes and effects testing. During flight test, only limited verification can be accomplished. It is neither cost effective nor prudent to insert actual failures, however, failures can be simulated by manually switching off subsystems. Additionally, the aircraft can be manually flown to an altitude (XX % SCP) necessary to trigger a fly-up. Otherwise flight test verification should consist of continuous monitoring of the message traffic during flight test and documenting real failures and the subsequent system reaction.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis establishes the fly-up maneuver profile, the required events that trigger fly-up (vehicle in unsafe condition, system failures, limiting operational environment, etc.), their sequence and required timelines, and the required crew actions during the fly-up maneuver.

PDR: Analysis of preliminary TF system design confirms the TF system architecture minimizes latency in reporting failures and assures that the fly-up function will continue to operate under all TF failure conditions and all but the most remote flight control system failures. The logic and control actions required to automatically and/or manually disengage from the fly-up maneuver should be defined. Simulations of fly-up maneuvers using cockpit simulators establish pilot workloads and control/display implementation of recovery from the fly-up maneuver. Detection ranges, function reaction to stimuli, and computation/data rates are determined.

CDR: Initial simulations demonstrate fly-up functionality. In addition, system/subsystem hard/soft failures, determined from failure modes and effects analysis, with the TF system engaged and the aircraft at critical points in the TF profile, are injected into simulations to demonstrate TF system tolerance and the adequacy of the fly-up functionality.

FFR: Pilot-in-the-loop simulations using actual flight hardware (iron bird) accomplished to demonstrate fly-up performance. Off nominal (within fail-safe thresholds) performance demonstrated with analysis and simulation. Analysis of flying test bed or development aircraft flight tests of the sensor accomplished to verify performance requirements are met or can be met within the TF system development timeline.

SVR: Flight test results verify required fly-up performance. Pilot comments indicate acceptable flying/ride qualities during fly-up. Simulator is updated to match flight test results prior to simulations that verify any conditions not accomplished in flight test. Actual failures encountered during the conduct of TF flight testing with associated fail-safety performance tracked and anomalies analyzed.

Sample Final Verification Criteria

Fly-up performance shall be verified by conduct of __(1)__ flight tests whereby __(2)__ TF/TA failures and loss of __(3)__ safety-critical functions are simulated in the __(4)__ representative operational environments. Fly-up performance shall be verified by conduct of __(5)__ simulations whereby __(6)__ TF/TA failures and loss of __(7)__ safety-critical functions are simulated in the __(8)__ representative operational environments. Flight tests/simulations shall confirm that the air vehicle executes a safe fly-up in the presence of all simulated failure conditions.

Blank 1. Identify the quantity of flight tests to be performed in demonstrating fly-up performance in the presence of failure conditions.

Blank 2. Identify the number and type of TF/TA system failures to be inserted during the blank 1 flight tests.

Blank 3. Identify the number and type of safety-critical functions, the loss of which should be simulated during the blank 1 flight tests.

Blank 4. Identify the unique operational environments (natural environment, terrain, towers, electromagnetic environment, etc.) that cover the range of possible operating environments to be simulated during the blank 1 flight tests.

Blank 5. Identify the type and scope of simulations that will be performed to supplement the flight test program in verifying this requirement.

Blank 6. Identify the number and type of TF/TA system failures to be inserted during the blank 5 simulations.

Blank 7. Identify the number and type of safety-critical functions, the loss of which should be simulated during the blank 5 simulations.

Blank 8. Identify the unique operational environments (natural environment, terrain, towers, electromagnetic environment, etc.) that cover the range of possible operating environments, to be simulated during the blank 5 simulations.

Lessons Learned: Fail-safety needs to be an integral and early part of the TF system development process. Adding a TF fail-safety requirement to an existing architecture will increase risk and may drive complex solutions to fail-safety issues. The B-2 TF system designers chose to place the fly-up function in the quad-redundant flight control system. This allowed a functioning TF Fly-up in the event of a dual TF processor failure or communication failure. A typical fly-up maneuver consists of a pull-up to a specified load factor until capture of a specified flight path angle. This maneuver is typically the most aggressive of the TF maneuvers. The fly-up may use up to maximum aircraft load factor with significant overshoots of target flight path angle. Fail-safety analysis will aid in establishing the aggressiveness of this maneuver. TF Probability of Loss of Aircraft (PLOA) is the probability that a TF system anomaly will result in loss of aircraft and is measured in terms of occurrences per flight hour. The numerical value for PLOA may be allocated from the aircraft loss rate requirement. A system level model should be used to compute this probability. When designing the model consider all subsystems, built-in-test coverage, cross-checking of critical parameters, and TF usage.

False Alarm Fly-Up Rate

A high rate of false alarm indications in the TF/TA system will reduce pilot confidence in its capabilities, and will potentially lessen the value of the TF/TA system as a vulnerability reduction aid.

The false alarm fly-up rate is verified by observation and analysis of TF/TA flight test performance. False alarm fly-up is defined as an unwarranted fly-up maneuver initiated by the TF/TA function. The maneuver is initiated because of a TF/TA perceived functional degradation/loss or because sensors interpret observed atmospheric or physical (terrain) conditions incorrectly. During flight test verification of the TF/TA function, false alarm fly-ups should be observed and the cause determined. The number of false alarms, at the end of the flight test activity, can be used to statistically assert that the requirement is satisfied. The sample of observed false alarms should be censored, eliminating those that are fully explained and for which corrective action (hardware or software changes) has been verified.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of physiological and psychological pilot performance data and mission/threat analyses confirms the specified false alarm rate is appropriate. Loss rate allocation to the function is consistent with the required false alarm rate.

PDR: Preliminary design of TF/TA system analyzed and false alarm rates predicted.

CDR: Man-in-the-loop simulations, using iron bird/mission systems simulators, verify the fly-up rates that are acceptable from a mission performance and pilot/crew standpoint.

FFR: No unique verification action occurs at this milestone.

SVR: Analysis of flight test data determines that the observed false alarm fly-up rate is consistent with the requirement.

Sample Final Verification Criteria

The false alarm fly-up rate shall be verified by analysis of reported, unwarranted fly-ups during the TF/TA flight test program. This requirement shall be satisfied when the hypothesis that the calculated false alarm fly-up rate is equal to the specified rate can be rejected in favor of the hypothesis that calculated rate is not greater than __(1)__ of the specified rate. Hypothesis test should be conducted utilizing available flight test incident reports and a Chi-Square Test with Alpha equal __(2)__ and Beta not greater than __(3)__.

Blank 1. False alarm rate that sets sensitivity of hypothesis test (recommend 1.20).

Blank 2. Alpha error, type I risk, producer risk, probability of rejection when hypothesis is TRUE (recommend .01 to .05).

Blank 3. Beta error, type II error, consumer risk, probability of accepting hypothesis when the actual population exhibits blank 1 false alarm rate. (Recommend 0.30 to 0.40).

VERIFICATION LESSONS LEARNED (4.1.8.2.3)

See Lessons Learned above for "Transition to minimum clearance altitude in specified operational environment," "Nominal terrain following performance in specified operational environment," "Fly-up functionality," and "False alarm fly-up rate" requirement elements.

3.1.8.2.4 Ballistic threat survivability

The air vehicle, including aircrew, shall not exceed the single engagement probability of kill given a hit specified in table 3.1.8.2.4-I. The air vehicle shall retain sufficient flight capability such that, in the event of damage less lethal than KK kill level, the air crew is provided sufficient time for assessment, ejection decision, and ejection.

TABLE 3.1.8.2.4-I. Engagement probability of kill given a hit.

Threat Class	Threat System Name	Damage Source	Engagement Probability of Kill Given A Hit			Single Engagement Characteristics		
			__(1)__ Kill Level	__(2)__ Kill Level	__(3)__ Kill Level	Impact Velocity (Ft/Sec)	Number of Impacts	Attack Aspects

REQUIREMENT RATIONALE (3.1.8.2.4)

Combat air vehicles need the basic capability of withstanding ballistic impact. The ability of damaged air vehicles to return to base/carrier will significantly increase the number of available air vehicles in a sustained conflict. The ability of damaged air vehicles to maintain flight for 30 minutes enables the aircrew to eject over friendly forces, versus becoming a prisoner of war. The ability of damaged air vehicles to suppress combat induced explosions or structural failures will reduce the number of aircrew killed in combat.

The pilot vulnerability is defined to ensure the pilot is considered more important than a simple piece of equipment.

REQUIREMENT GUIDANCE (3.1.8.2.4)

Guidance for completing table 3.1.8.2.4-I follows:

<u>Threat Class</u>: Identify the type of threat the air vehicle is expected to encounter, e.g., guns, SA proximity missile, air-to-air (AA) proximity missile, MANPADS, etc. See System Threat Assessment Report (STAR) for the official list of program office threats. The design specification may only contain a subset of these threats.

<u>Threat System Name</u>: Identify the specific threat, e.g., SA-2, etc. and/or projectile type

<u>Damage Source</u>: Identify the damage source the threat imposes on the air vehicle. Examples are impact of a 23-mm armor piercing incendiary (API) projectile from a ground-to-air gun, 30-mm high explosive incendiary (HEI) projectile from an air-to-air and/or ground-to-air gun, fragment impact from SA-2 at TBD feet of standoff, missile impact at engine nozzle.

<u>Engagement Probability Of Kill Given A Hit</u>: For blanks 1, 2, and 3, identify the kill levels (KK, K, A, B, Pilot, Landing/Recovery). (See the kill level definitions/objectives provided below.) Under each kill level, identify the probability of kill given a hit.

Single Engagement Characteristics:

Impact Velocity: Identify the threat impact velocity of the identified threat damage source, e.g., round velocity, fragment velocity, missile velocity at impact.

Number of Impacts: Identify the anticipated number of impacts from the identified threat. For example, for gun systems use 1 (single shot probability of kill given a hit), for fragment warheads use the fragment density times the air vehicle presented area, for contact warheads use 1.

Attack Aspects: Identify the attack aspect orientation of the damage source with respect to the air vehicle. This is sometimes specified as an average of 26 views (elevation and azimuth sectors) of the air vehicle for which the single shot (or missile fuzing event) probability of kills have been developed for each elevation and azimuth sector. If necessary (and appropriate), multiple sets of elevation and azimuth sectors could be specified to allow control over the vulnerability in those specific air vehicle sectors.

The vulnerability of an air vehicle is dependent upon the threat type. Generally, single projectiles shot by air-to-air or ground-to-air guns directly impact the air vehicle as the damage source. These guns typically shoot API or HEI projectiles. Air-to-air or ground-to-air missiles are either contact or proximity fuzed. Man Portable Air Defense System (MANPADS) missiles are typically contact fuzed.

Single engagement probability of kill given a hit for projectiles (guns) is defined as the ratio of total vulnerable area (Av) divided by the total presented area (Ap). The equation to calculate single shot probability of kill given a hit (Psek/h) for a projectile is shown: Psek/h = Av/Ap. For multiple projectile hits, the equation is Psek/h = 1-(1-Av/Ap)**N, Where N is the number of hits. The vulnerable and presented areas are analyzed based upon an attack from typically 26 orientations.

Single engagement probability of kill given a hit, for air-to-air or ground-to-air missiles, is defined by three parameters: total vulnerable area (Av); total presented area (Ap); and fragment density. The fragment density depends upon the missile and typical offset distance (the distance between the missile and air vehicle at the time the missile warhead fuzes). The typical offset distance needs to be consistent with the signature, Electronic Counter Measures (ECM), the maneuver capability of the air vehicle and/or the fuzing distance of the warhead. The equation to calculate the single engagement probability of kill given a hit (or fuzing event) for multiple missile fragments is shown: Psek/h = 1 – (1- Av/Ap) ** (Ap * fragment density). The vulnerable area term is dependent upon fragment impact velocity and this velocity is dependent upon the fuzing distance. The vulnerable and presented areas are normally analyzed based upon an average of attacks from 26 orientations. Damage from blast, missile debris, and direct missile body impacts also need to be considered.

Currently, no standardized method of developing the specification values for MANPADS impacts have been established. Early requirement analyses should be used to establish the numerical values for use in the single engagement probability of kill given a hit (or missile fuzing event) table. Considerable study is needed to determine the engagement probability of kill levels within the table. One should carefully select which threats need to be specified. The entire list of threats with all combinations of impact velocities and attack orientations may not be appropriate for specification purposes, but may be appropriate for use in survivability assessments. In addition, the time before the air vehicle loses functional capability is needed. This time determines whether the aircrew is killed, the aircrew ejects over enemy forces, or the air vehicle is lost. The typical time related kill levels are mapped to warfighter objectives shown below.

Kill level description/objectives:

Kill Level	Typical Kill Levels Description	Warfighter Objectives
KK	Disintegrate immediately upon being hit	Immediate removal of aircraft and loss of air crew
K	Fall out of powered/manned controlled flight within 30 seconds of being hit	Sufficient time for air crew assessment, ejection decision, and ejection
A	Fall out of manned control within 5 minutes after being hit (attrition)	Sufficient capability for the air vehicle to returned to friendly forces
B	Fall out of manned control within 30 minutes after being hit (mission)	Sufficient capability for the air vehicle achieve mission objectives and returned to friendly forces
Landing/ Recovery	Fall out of manned control while landing/recovering	Sufficient capability for the air vehicle to return to base/carrier

REQUIREMENT LESSONS LEARNED (3.1.8.2.4)

Significant vulnerability reduction (i.e., reducing the ratio of the vulnerable to the presented areas) can be achieved in a cost-effective manner, if meaningful requirements are specified to influence the design. Retrofitting vulnerability reduction features is much less cost-effective.

In the past, we used vulnerable area as a metric. The vulnerable area metric does not provide management, warfighters, and higher-level models analysts (i.e., mission and campaign) adequate insight about the significance of vulnerability reduction. The single engagement probability of kill given a hit (or fuzing event) supports our customers vulnerability information needs. The single engagement probability of kill given a hit (or missile fuzing event) integrates multiple effects that directly relate to the combat capability of the air vehicle. This transition from the vulnerable area metric to single engagement probability of kill given a hit (or missile fuzing event) is not easy, but necessary.

4.1.8.2.4 Ballistic threat survivability verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Air vehicle and aircrew shall not exceed the single engagement probability of kill given a hit as specified in table 3.1.8.2.4-I	Probability of kill	A	A	A		A
The air vehicle shall retain sufficient flight capability such that, in the event of critical damage less than KK kill level, the aircrew is provided sufficient time for assessment, ejection decision and ejection	Time	A	A	A		A

VERIFICATION DISCUSSION (4.1.8.2.4)

Air vehicle level of assessment requires a systematic system engineering build-up of design data implemented within computer models supported and validated with test data.

Detail simulations, simulators, and tests are used to develop data to feed specific modeling issues to the analyses. The usage of these test data is typically completed in an incremental means to verify the analysis data and models results correlate adequately. Usage of this model, test, model approach results in a validated assessment. This process can demonstrate that the design, data, and/or model need to be altered.

The Live Fire Test & Evaluation (LFT&E) Law requires that major weapon systems be tested prior to full rate production. The LFT&E Law requires full-up system level testing, unless the Secretary of Defense signs a waiver package (cover letter and "Alternative Test & Evaluation Plan") prior to starting Milestone II. The Alternative Test & Evaluation Plan defines what testing and analyses should be accomplished to fully demonstrate the vehicle is suitable for combat. Obtaining a waiver requires considerable effort and planning. A program should not proceed into Milestone II until this issue is resolved since the resources (time and money) to conduct LFT&E is significant. A well designed LFT&E program will provide data needed to support the design verification.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analysis of the design concept identifies specific vulnerability reductions and impacts to other design requirements. Analyses indicate allocated design requirements are well understood (both prime contractor and vendors). Vulnerability analysis of the design concept (air vehicle, aircrew, weapons, stores, cargo, and passengers) indicates compliance with ballistic survivability requirements. Analysis indicates modeling and simulation (M&S) tools, including air vehicle and threat databases, have been established utilizing all available test data (including live fire lower-level testing). Analyses indicate that live fire test planning has been initiated/updated.

PDR: Vulnerability analysis of the preliminary design (air vehicle, aircrew, weapons, stores, cargo, and passengers) establishes the adequacy of the current design to meet ballistic survivability requirements. Live fire test planning and development test results have been integrated into the vulnerability analysis.

CDR: Updated vulnerability analysis of the final design (air vehicle, aircrew, weapons, stores, cargo, and passengers) establishes the adequacy to meet ballistic survivability requirements. Live fire test planning and development test results have been integrated into the analysis.

FFR: No unique verification action occurs at this milestone.

SVR: Analysis of modeling and simulation, augmented with live fire and development test results confirm that ballistic survivability requirements have been met.

Sample Final Verification Criteria

The ballistic threat survivability requirement shall be satisfied when the __(1)__ analyses confirm achievement of the specified performance requirements

Blank 1. Identify the type and scope of analysis required to provide confidence that the requirement elements have been met. Analyses include the results of live fire and development test, modeling and simulation and lower-level testing.

VERIFICATION LESSONS LEARNED (4.1.8.2.4)

To Be Prepared

3.1.8.2.5 Directed energy threat survivability

3.1.8.2.5.1 Electromagnetic threat survivability

The air vehicle shall withstand the exposure to the electromagnetic threats in table 3.1.8.2.5.1-I, without loss or degradation of mission or safety functions subsequent to the exposure at or beyond the slant ranges specified therein. The air vehicle shall maintain a minimum of Level 2 flying qualities while exposed to electromagnetic threats.

TABLE 3.1.8.2.5.1-I. Electromagnetic threat.

Characteristics	Threat System __(1)__	Threat System __(2)__	Threat System __(3)__
Slant Range Distance (NM) at which requirements are met (100% point)			
Band Type (Wide or Narrow)			
Frequency (GHz)			
Peak Power (MW)			
Pulse Duration (ns)			
Dwell time			
Pulse Repetition Frequency (Hz)			
Antenna Gain			

REQUIREMENT RATIONALE (3.1.8.2.5.1)

Combat air vehicles need the basic capability of withstanding exposure to electromagnetic threats. The likelihood of being exposed to electromagnetic threats has increased significantly over the past decade.

Modern air vehicles are highly unstable and are dependent upon the flight control computer systems to maintain controlled flight. Electromagnetic threats generate environments that can upset or damage electronic equipment directly through coupling to antennas or indirectly through coupling of induced signals into aircraft wiring, potentially resulting in loss of controlled flight or mission abort.

REQUIREMENT GUIDANCE (3.1.8.2.5.1)

Populate blanks 1, 2, 3, etc. with the appropriate threat systems from the System Threat Assessment Report.

The vulnerability of an air vehicle is dependent upon the threat type. The effects of electromagnetic threats can be divided into two classes: back door and front door. The back door effects introduce energy into the electrical system by coupling energy into aircraft wiring, while front door effects couple energy directly into antennas. Fly-by-light rather than fly-by-wire control systems tend to mitigate many of the back door design issues. As DOD moves to more commercial off-the-shelf (COTS) procurements this threat needs to be seriously considered. Current military design practices used for electromagnetic environmental effects (E^3) provide significant inherent hardness against electromagnetic threats.

The electromagnetic threats must be examined with respect to their ability to put energy on target, track time, and tracking ability. If the threat system cannot track its intended target with sufficient accuracy, because of other reductions in IR, RCS or visual signature, the electromagnetic threats may be ineffective.

Early requirement analyses should be used to establish the required mission slant range distance from the threat. The distance to the threat depends upon the threat and mission. The required mission slant range distance needs to be consistent with the concepts of operation for each mission type, air vehicle signature, and maneuver capability of the air vehicle. Considerable study is needed to establish the required mission slant range distance. One should carefully select which threats need to be specified.

REQUIREMENT LESSONS LEARNED (3.1.8.2.5.1)

The electromagnetic threat table defines the slant range and threat power at the antenna, which can be converted to power on the target air vehicle. E^3 analysts and system designers convert power of target into energy coupled into the air vehicle. This subject table provides a complete audit trail from the System Threat Assessment Report to E^3 flow down requirements.

4.1.8.2.5.1 Electromagnetic threat survivability verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Threat system (1)	No degradation of mission or safety functions Level 2 flying qualities	A	A,S	A,S		A,S, T
Threat system (2)	No degradation of mission or safety functions Level 2 flying qualities	A	A,S	A,S		A,S, T
Threat system (…)	No degradation of mission or safety functions Level 2 flying qualities	A	A,S	A,S		A,S, T

VERIFICATION DISCUSSION (4.1.8.2.5.1)

Verification activities will rely heavily on analysis and simulation with final verification accomplished through a combination of high fidelity models (both man and hardware in-the-loop), ground test, and flight test.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the design concept, including predictions and/or simulations, indicates the electromagnetic threat survivability requirements are achievable.

PDR: Analysis indicates the preliminary air vehicle design has the ability to withstand exposure to the identified electromagnetic threats without loss of degradation of mission or safety functions and the ability of the air vehicle to maintain a minimum of Level 2 flying qualities. Analysis of preliminary air vehicle design failure modes and effects and criticality (FMECA) indicate all possible failure modes of critical components or subsystems, the likely modes in which each failure can occur, the cause of each failure mode, and the effect of each failure on air vehicle flight and mission capabilities. Analysis of preliminary air vehicle flight and mission-critical functions (FCMFA) identifies critical functions and related air vehicle subsystems required to maintain controlled flight and to accomplish specified mission(s). Analysis of the preliminary air vehicle design identifies damage modes and effects (DEMEA) for each primary and secondary threat. This analysis should link the failures identified in the FMECA with the ability of the primary and secondary threat weapon to cause such failures. Analysis identifies preliminary air vehicle design vulnerable areas. Analysis indicates trade studies associated with the air vehicle physical design (air vehicle weight, performance, cost, safety, reliability, maintainability, etc.) have been accomplished which address achievement of the electromagnetic survivability requirement.

CDR: Analysis of updated air vehicle design FMECA indicate all possible failure modes of critical components or subsystems, the likely modes in which each failure can occur, the cause of each failure mode, and the effect of each failure on air vehicle flight and mission capabilities. Analysis of updated air vehicle FCMFA identifies critical functions and related air vehicle subsystems required to maintain controlled flight and to accomplish specified mission(s). Analysis of updated air vehicle identifies DEMEA for each primary and secondary threat. This analysis should link the failures identified in the FMECA with the ability of the primary and secondary threat weapon to cause such failures. Analysis identifies updated air vehicle design vulnerable areas. Analysis indicates trade studies associated with the air vehicle physical design (air vehicle weight, performance, cost, safety, reliability, maintainability, etc.) have been accomplished which address achievement of the electromagnetic survivability requirement. Simulations of the air vehicle indicate the updated air vehicle design has the ability to withstand exposure to the identified electromagnetic threats without loss of degradation of mission or safety functions and the ability of the air vehicle to maintain a minimum of Level 2 flying qualities. Analysis of air vehicle subsystem test results confirm the ability of the updated air vehicle design to withstand exposure to the identified electromagnetic threats without loss or degradation to the identified mission or safety functions, and the ability of the air vehicle to maintain a minimum of Level 2 flying qualities.

FFR: No unique verification action occurs at this milestone.

SVR: Analysis of lower-level test results, simulations, ground and flight tests confirm the air vehicle can withstand exposure to the identified electromagnetic threats without loss or degradation to the identified mission or safety functions, and maintain a minimum of Level 2 flying qualities.

Sample Final Verification Criteria

Operation during and subsequent to exposure to the identified electromagnetic threats shall be satisfied when __(1)__ analysis, __(2)__ simulations, and __(3)__ tests confirm no loss or degradation to mission or safety functions, and the air vehicle maintains a minimum of Level 2 flying qualities.

Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement element has been met.

Blank 2. Identify the type and scope of simulations required to provide confidence that the requirement element has been met.

Blank 3. Identify the type and scope of ground and flight tests required to provide confidence that the requirement element has been met.

VERIFICATION LESSONS LEARNED (4.1.8.2.5.1)

To Be Prepared

3.1.8.2.5.2 Laser threat survivability

The air vehicle shall withstand the exposure to the laser radiation threats in table 3.1.8.2.5.2-I, without loss or degradation of mission or safety functions, including effects on the air crew, subsequent to the exposure at or beyond the slant ranges specified therein for both day and night operations. The air vehicle shall maintain a minimum of Level 2 flying qualities while exposed to laser radiation threats.

TABLE 3.1.8.2.5.2-I. Laser radiation threat.

Characteristics	Threat System (__1__)	Threat System (__2__)	Threat System (__3__)	Threat System (__4__)
Slant Range Distance (NM) at which requirements are met (100% point)				
Wavelength (nm)				
Pulsed Laser Irradiation Level (J/cm^2) or Peak Power Density ($Watts/cm^2$)*				
Beam Dispersion (TBD)				
Aperture Size (TBD)				

* Power density ($Watts/cm^2$) can also be used for CW energy if the exposure duration is specified.

REQUIREMENT RATIONALE (3.1.8.2.5.2)

Combat air vehicles need the basic capability of withstanding exposure to laser threats. The likelihood of being exposed to laser devices has increased significantly over the past decade. Low power laser threats can significantly degrade the aircrew’s ability to perform air-to-ground ordnance delivery missions. Low power, multiple frequency lasers can flash blind the aircrew resulting in aborting the mission.

The energy levels required to injure the aircrews are significantly less than that for air vehicle structure and availability of laser targeting devices has flourished and become easily obtainable.

REQUIREMENT GUIDANCE (3.1.8.2.5.2)

Complete blanks 1, 2, 3, 4, etc. with the appropriate threat systems from the System Threat Assessment Report.

The vulnerability of an air vehicle is dependent upon the threat type. The laser threat can function in the pulsed or continuous wave (CW) mode. The laser threat can be grouped in low-, medium-, or high-power laser categories. Low-power lasers are very portable, while high-power lasers are much less portable.

Low-power lasers can damage the aircrew's eyes or optical sensors. Neither the eye nor a sensor can react in time to shield itself from the laser's damaging effects. Therefore, the shielding or hardening (in case of a sensor) must be available at all times when in potential range from the threat. Additionally, the aircrew's eye protection needs to be compatible with helmet-mounted and crew station controls and displays.

High-power lasers are designed to physically damage the vehicle structure by means of a high-energy shock impulse or, in the CW case, thermally damaging the structure. Threshold levels of radiation to cause structural damage will vary significantly with the materials being irradiated, the reflectivity, the laser mode of operation and the beam power density. A careful threat assessment should be carried out prior to expending significant effort and funds to increase the survivability of the air vehicle to the high power laser threat. The high power laser threat must be examined with respect to its ability to put energy on target, time to deposit its energy, and tracking ability. If the threat system cannot track its intended target with sufficient accuracy, because of other reductions in IR, RCS or visual signature, the directed energy beam may be ineffective.

Early requirement analyses should be used to establish the required mission slant range distance from the threat. The distance to the threat depends upon the threat and mission. The required mission slant range distance from the threat needs to be consistent with the concepts of operation for each mission type, air vehicle signature, and maneuver capability of the air vehicle. One should carefully select which threats need to be specified.

Medium- and high-powered lasers can damage crewmembers, external coatings, and structure. Military deployable medium- and high-powered laser systems require significant physical size. Cost benefit and risk analyses should be accomplished to establish the need for appropriate requirements prior to expending resources to harden air vehicles. For example, the military option to destroy the laser system with standoff missiles may be preferred.

REQUIREMENT LESSONS LEARNED (3.1.8.2.5.2)

The integration of crew eye laser protection with crew station equipment has a history of questionable capability. Crew eye laser protection requires full integration with night-vision and on-board displays and controls.

It can be difficult to make laser protective devices compatible with color displays. Dual coding (shape and color) of symbology has proven to be an effective means of dealing with loss of color when the aircrew is wearing laser protective devices. Special consideration should be given to ensure that laser protective devices are compatible with life support gear and helmet-mounted displays, as applicable.

4.1.8.2.5.2 Laser threat survivability verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Threat system (a)	No degradation of mission or safety functions Level 2 flying qualities	A	A,S	A,S		A,S, T
Threat system (b)	No degradation of mission or safety functions Level 2 flying qualities	A	A,S	A,S		A,S, T
Threat system (…)	No degradation of mission or safety functions Level 2 flying qualities	A	A,S	A,S		A,S, T

VERIFICATION DISCUSSION (4.1.8.2.5.2)

The laser threat survivability verification is focused on ensuring that the design and procedures maintain protection and allow for the accomplishment of mission tasks within a laser environment. Verification activities rely heavily on analysis and simulation with final verification accomplished through a combination of high fidelity models (both man and hardware in-the-loop), ground test, and flight test.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of design concept indicates the level of hardness and protection for the air vehicle and aircrew to satisfy the varying mission phases and allocation to the appropriate subsystems is accomplished. Inspection of air vehicle laser threat analyses and specifications indicates that the control of air vehicle survivability has been factored into the systems engineering process.

PDR: Analysis indicates the preliminary air vehicle design has the ability to withstand exposure to the identified laser threats without loss or degradation of mission or safety functions and the ability of the air vehicle to maintain a minimum of Level 2 flying qualities. Analysis of preliminary air vehicle design failure modes and effects and criticality FMECA indicate all possible failure modes of critical components or subsystems, the likely modes in which each failure can occur, the cause of each failure mode, and the effect of each failure on air vehicle flight and mission capabilities. Analysis of preliminary air vehicle flight- and mission-critical functions FCMFA identifies critical functions and related air vehicle subsystems required to maintain controlled flight and to accomplish specified mission(s). Analysis of preliminary air vehicle design identifies damage modes and effects (DEMEA) for each primary and secondary threat. This analysis should link the failures identified in the FMECA with the ability of the primary and secondary threat weapon to cause such failures. Analysis identifies preliminary air vehicle design vulnerable areas. Analysis indicates trade studies associated with the air vehicle physical design (air vehicle weight, performance, cost, safety, reliability, maintainability, etc.) have been accomplished which address achievement of the laser survivability requirement.

CDR: Analysis of updated air vehicle design failure modes and effects and criticality FMECA indicate all possible failure modes of critical components or subsystems, the likely modes in which each failure can occur, the cause of each failure mode, and the effect of each failure on air vehicle flight and mission capabilities. Analysis of updated air vehicle flight and mission-critical functions FCMFA identifies critical functions and related air vehicle subsystems required to maintain controlled flight and to accomplish specified mission(s). Analysis of updated air vehicle identifies DEMEA for each primary and secondary threat. This analysis should link the failures identified in the FMECA with the ability of the primary and secondary threat weapon to cause such failures. Analysis identifies updated air vehicle design vulnerable areas. Analysis indicates trade studies associated with the air vehicle physical design (air vehicle weight, performance, crew protection, cost, safety, reliability, maintainability, etc.) have been accomplished which address achievement of the laser survivability requirement. Simulations of the air vehicle indicate the updated air vehicle design has the ability to withstand exposure to the identified laser threats without loss of degradation of mission or safety functions and the ability of the air vehicle to maintain a minimum of Level 2 flying qualities. Analysis of air vehicle subsystem test results, including results of crew mounted equipment testing, confirm the ability of the updated air vehicle design to withstand exposure to the identified lasers without loss or degradation to the identified mission or safety functions, and the ability of the air vehicle to maintain a minimum of Level 2 flying qualities.

FFR: No unique verification action occurs at this milestone.

SVR: Analysis of lower-level test results, simulations, ground and flight tests confirm the air vehicle can withstand exposure to the identified lasers without loss or degradation to the identified mission or safety functions, and maintain a minimum of Level 2 flying qualities.

Sample Final Verification Criteria

Operation during and subsequent to exposure to the identified laser threats shall be satisfied when __(1)__ analysis, __(2)__ simulations, and __(3)__ tests confirm no loss or degradation to mission or safety functions, and maintains a minimum of Level 2 flying qualities.

> Blank 1: Identify the type and scope of analyses required to provide confidence that the requirement element has been met.
>
> Blank 2: Identify the type and scope of simulations required to provide confidence that the requirement element has been met.
>
> Blank 3: Identify the type and scope of ground and flight tests required to provide confidence that the requirement element has been met. It is not envisioned that air vehicle level vulnerability test of a laser threat would be conducted.

VERIFICATION LESSONS LEARNED (4.1.8.2.5.2)

To Be Prepared

3.1.8.2.6 Chemical and biological threat survivability

3.1.8.2.6.1 Chemical and biological hardening

The air vehicle shall withstand exposure to the chemical and biological (CB) threat agents defined in table 3.1.8.2.6.1-I, for the frequency of exposure and time prior to complete decontamination identified, with no degradation in __(1)__.

TABLE 3.1.8.2.6.1-I. Chemical and biological concentration threat.

Agent Type	Form	Agent Name	Size	95th Percentile CT	Concentration	Frequency of Exposure	Time Prior	Assets Available
							to Complete Decontamination	

REQUIREMENT RATIONALE (3.1.8.2.6.1)

Combat air vehicles need the basic capability of withstanding exposure to CB threats. Chemical and biological hardness is a measure of the ability of the air vehicle to resist degradation by chemical and biological warfare agents. The accelerated proliferation of the CB threat since the fall of the Soviet Union has increased the likelihood that US military personnel and weapon systems will be exposed to CB contaminants on the battlefield. There has been a resulting increased emphasis on air vehicle survivability in a CB environment. Modern air vehicles are being made of higher fractions of composite materials. These composite materials, if unprotected, can absorb chemical agents such that they may never be sufficiently decontaminated; therefore, requiring maintenance personnel to wear protective gear.

REQUIREMENT GUIDANCE (3.1.8.2.6.1)

> Blank 1. Complete by identifying the essential air vehicle performance capabilities required after exposure but prior to decontamination. Examples of capabilities include mission function, material properties, service life, operating capability, mission requirements, structural characteristics, lethality, etc.

The CB threats should be examined with respect to the enemy's ability to put agent on target. The duration of the vapor agent should be stated in terms of the worst case predicted 95th percentile vapor threat CT (Concentration x Time in units of mg min/m^3). The worst case predicted 95th percentile liquid threat level should be stated in terms of a surface density (g/m^2). If a detail assessment is not completed, NATO standard concentrations are available. Threat agents to be specified in table 3.1.8.2.6.1-I should be carefully selected using the following guidance:

<u>Agent Type</u>: Identify whether the agent is chemical or biological.

<u>Form</u>: Identify whether the agent is liquid or vapor.

<u>Agent Name</u>: Identify the nomenclature of the agent, e.g., mustard gas, spores-formers, viruses, toxins, etc.

Size: Identify the size of the agent to be encountered, e.g., droplet of XX mm, etc.

95th Percentile CT: Identify the worst-case predicted 95th percentile vapor threat CT (Concentration X time in units of mg min/m^3) in terms of volume. If a detail assessment is not completed, NATO standard concentrations are available.

Concentration: Identify the concentration of the agent to be encountered, e.g., XX g/m^2.

Frequency of Exposure: Identify the number of times the air vehicle will be exposed to the CB agent in a given time period: for example, once per day or three times per week. It can be critical in determining the interfacing support requirements as well as personnel protection requirements.

Time Prior to Complete Decontamination: The time period between initial exposure and complete decontamination. This impacts the durability of the air vehicle to agents as well as the duration of operations in CB gear.

Assets Available to Complete Decontamination: Identify whether or not decontamination assets will be available for air vehicle decontamination. The column can be filled in with a simple “Yes” or “No” or it can document the specific assets available. The intent is to capture requirements to operate from austere locations where decontamination assets may not be available (scenario dependent).

The duration requirement (time prior to complete decontamination) stated in days is the time from when the air vehicle exposure to CB agents to when the air vehicle is robustly decontaminated. Less robust decontamination activities, described below, will occur as soon as possible to decrease personnel hazard; however, a complete decontamination is expected to require more time than is available soon after a CB attack. Therefore, the air vehicle is required not to degrade over an extend duration.

The following discussion describes activities that must occur in order to achieve the above requirement. This discussion highlights many basic design issues that must be addressed to obtain a hardened air vehicle.

The physical properties of nonmetallic materials may be altered by exposure to the agent. A structural member or skin panel may be weakened, or the polycarbonate canopy may become hazed. Alteration of observable characteristics is a potential concern for air vehicles employing stealth capabilities.

In general, it is not practical to select structural materials based upon chemical hardness. The only practical approach is to use a chemical agent resistive coating for those materials that are not inherently resistant to the chemical threat. Inherent resistance to chemical agents implies both functional damage resistance and the ability to be decontaminated. If materials do not have the ability to be decontaminated at the coupon level, then decontamination at the component and air vehicle level is not possible. A proper selection of coatings can greatly reduce decontamination problems in the field.

Chemical and biological concentration threat. - (Example table)

Agent Type	Form	Agent Name	Size	95th Percentile CT	Concen-tration	Frequency of Exposure	Time Prior to Complete Decontamination	Assets Available to Complete Decontamination
Chemical	Liquid	TBD	Droplet of TBD(mm)	N/A	TBD (g/m^2)			
		TBD	Droplet of TBD(mm)	N/A	TBD (g/m^2)			
		TBD	Droplet of TBD(mm)	N/A	TBD (g/m^2)			
	Vapor	TBD	N/A	TBD (mg min/m^3)	N/A			
		TBD	N/A	TBD (mg min/m^3)	N/A			
		TBD	N/A	TBD (mg min/m^3)	N/A			
Biological	Liquid	Spores-formers, Viruses, Toxins	TBD (mm)	N/A	TBD (10^6 particles/ml of liquid)			
	Vapor	Spores-formers, Viruses, Toxins	TBD (mm)	N/A	TBD (10^6 CFU/liter of air)			

As structural properties of materials are well understood, the structural hardness criteria are straightforward. Simply stated, if exposure to an agent reduces a property such as tensile strength in excess of a set percentage, the material will be considered susceptible. The specific percentages depend on the function of the material. Signature requirements are stated in terms of changes in electromagnetic reflectivity, transmittance, or other observability characteristic.

The vulnerability of an air vehicle is dependent upon the threat type. Chemical agents can be divided into two classes: liquid and vapor. The physical state of the chemical agent exposes different portions of the air vehicle. Regions internal to the air vehicle will be faced with a vapor challenge. Any component or surface exposed to air is open for exposure to a vapor agent. Proper operational procedures should prevent liquid agents from entering the crew station, so it will be considered in this category. The external mold line of the air vehicle, including the canopy, engine inlets, engine exhaust nozzles, radome, wheel wells and skin, will be exposed to the liquid agent. Figure 3.1.8.2.6.1-1 shows the interrelationship of air vehicle regions and chemical agent physical state.

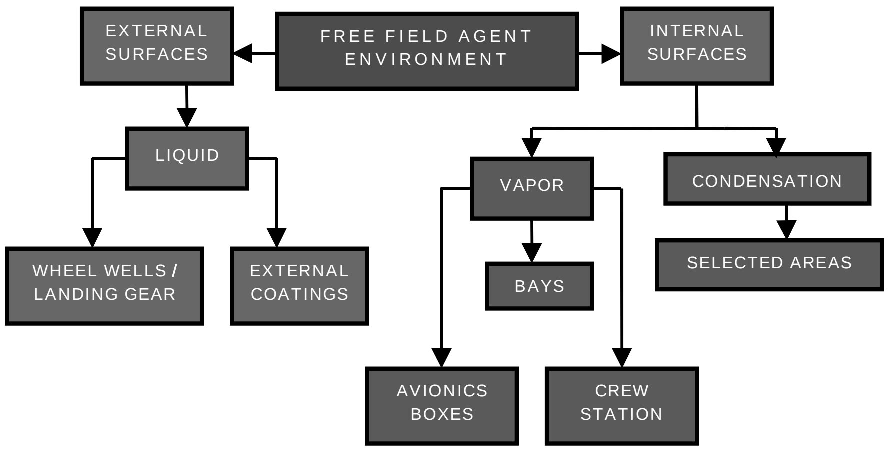


FIGURE 3.1.8.2.6.1-1. Air vehicle regions & physical state of the chemical agent.

Agents can reside on the surface of a material or can be absorbed. Elimination of cracks, gaps, crevices, and the selection of resistive, nonabsorbing materials and coatings during the design process can significantly reduce hardening and decontamination issues. Selection of hardened materials and coating must include considerations for decontamination. Therefore, all exposed materials must be assessed for both hardness and decontaminability.

Materials should be selected based on their resistance to agent absorption. Limited data is available on rates of, absorption or desorption. For certain types of materials, generic data are available by which materials can be ranked according to their tendency to absorb agents.

REQUIREMENT LESSONS LEARNED (3.1.8.2.6.1)

Past experience has shown that if a "retrofit" approach is taken to CB hardening, the cost and performance reductions associated with alternatives such as back-fitting filters or changing existing materials are prohibitive.

4.1.8.2.6.1 Chemical and biological hardening verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Air vehicle ability to withstand chemical and biological exposure in accordance with table 3.1.8.2.6.1-I	No degradation to (1)	A,I	A,I	A,I		A,T

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.1.8.2.6.1)

Chemical and biological hardness verification confirms that the specified air vehicle performance capabilities are not degraded before full decontamination occurs, for the full set of anticipated threat conditions. Subsystem and coupon test results should be included in the full system analysis.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the design concept indicates that appropriate chemical and biological hardness requirements are identified and properly allocated to air vehicle subsystem requirements. Inspection of air vehicle chemical/biological analyses and specifications indicate that the control of system hardness has been factored into the systems engineering process.

PDR: Analyses and inspections of the preliminary design and lower-tier specifications indicate applicable lower-tier requirements have been derived. Analysis of the preliminary design indicates the air vehicle achieves successful chemical/biological performance of the air frame and materials under all specified encounters. Air vehicle analysis is typically supported by lower-level testing (i.e., coupon testing) and subsystem assessments / simulations. Inspection of analysis indicates any air vehicle level chemical/biological requirements that have not yet been considered.

CDR: Analyses and Inspections of detailed design information and updated lower-level test/simulation/demonstration data confirm the specified air vehicle performance withstands the chemical/biological exposure of table 3.1.8.2.6.1-I.

FFR: No unique verification action occurs at this milestone.

SVR: Analysis of lower-level test/demonstration data and test results of the total air vehicle chemical/biological hardness, confirms the specified air vehicle performance withstands the chemical/biological exposure of table 3.1.8.2.6.1-I.

Sample Final Verification Criteria

The chemical and biological hardness requirement shall be satisfied when __(1)__ analyses and __(2)__ tests confirm the specified air vehicle performance withstands the chemical/biological exposure of table 3.1.8.2.6.1-I.

> Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement elements have been met. Analysis might evaluate results of coupon tests utilizing live agents and subsystem assessments/simulations.
>
> Blank 2. Identify the type and scope of tests required to provide confidence that the requirement elements have been met. Example tests might include use of stimulant agents to evaluate specified performance for the total air vehicle under contaminated conditions.

VERIFICATION LESSONS LEARNED (4.1.8.2.6.1)

To Be Prepared

3.1.8.2.6.2 Chemical and biological personnel protection

The air vehicle shall provide aircrew protection throughout ingress, mission phases, and egress and shall limit hazard (e.g., skin, ocular, and respiratory), for the specified exposure duration and concentration, in accordance with table 3.1.8.2.6.2-I.

TABLE 3.1.8.2.6.2-I. Maximum allowable hazard concentration.

Agent Type	Form	Agent Name	5th Percentile Miosis Threshold Criteria	5th Percentile Vapor Per-cutaneous	Contact Threshold Criteria	Residual Decontamination Hazard**	
						Maintenance Personnel Exposure Duration	Aircrew Exposure Duration
Chemical	Liquid	TBD	N/A	TBD (mg-min/m^3)	TBD (g/m^2)	TBD (hrs)	TDB (hrs)
		TBD	N/A	TBD (mg-min/m^3)	TBD (g/m^2)	TBD (hrs)	TBD (hrs)
		TBD	N/A	TBD (mg-min/m^3)	TBD (g/m^2)	TBD (hrs)	TBD (hrs)
	Vapor	TBD	TBD (mg-min/m^3)	TBD (mg-min/m^3)	N/A	TBD (hrs)	TBD (hrs)
		TBD	TBD (mg-min/m^3)	TBD (mg-min/m^3)	N/A	TBD (hrs)	TBD (hrs)
		TBD	TBD (mg-min/m^3)	TBD (mg-min/m^3)	N/A	TBD (hrs)	TBD (hrs)
Biological	Liquid	Spore-formers, Viruses, Toxins	N/A	N/A	TBD	N/A	N/A
	Vapor	Spore-formers, Viruses, Toxins	N/A	N/A	TBD	N/A	N/A

** This column will be utilized in requirement 3.1.8.2.6.3 Chemical and biological decontamination.

REQUIREMENT RATIONALE (3.1.8.2.6.2)

Third world countries have demonstrated the will to expose civilian and military populations to CB agents. Aircrew members need the basic capability of withstanding exposure to chemical and biological threats.

REQUIREMENT GUIDANCE (3.1.8.2.6.2)

Personnel may be protected through individual protection, collective protection, or a combination of the two. Individual protection is an ensemble worn by the individual crewman. Historically, collective protection provides protected air vehicle spaces through filtration, coverings and over pressurization.

Materials used for personnel protection are highly resistant to agent infiltration. Over time (hours) small quantities of CB agents can penetrate the air vehicle materials, joints, edges, filters, and/or the personnel mask filter to the extent that the usage life is exceeded, and replacement may be required. Therefore, the personnel exposure time needs to be defined. This duration needs to reflect the warfighters combat environment.

The allowable exposure level for human skin, ocular and respiratory systems should be defined as threshold criteria. The table contains the maximum level of CB contamination that can be seen by the human system. The air vehicle design will ensure that the allowed CB exposure contamination for an expected duration of exposure does not exceed the requirements of the table. The air vehicle must limit vapor exposure to less than the 5th percentile miosis and percutaneous threshold criteria for a given duration and is stated in terms of a CT (concentration x time in units of mg min/m^3). Compliance to the miosis criteria ensures compliance with the percutaneous protection threat, as it is the most rigorous. The air vehicle must limit liquid exposure to less than the 5th percentile contact hazard criteria for a given duration and is stated in terms of a surface density (g/m^2).

Most air vehicles must expect to fight dirty. Therefore, aircrew must be protected at all times. The CB protection system must provide for both head and body protection. For aircrew ensembles, body coverage should address thermal cooling. Thermal cooling would reduce the heat stress associated with wearing a full coverage suit, but must be supplied from a CB-free source to prevent the percutaneous threat and should consider internal and external air vehicle use. The eyes and respiratory tract are the most susceptible on the human. Any coverage of the eye needs to address fogging, probably requiring a clean, demist air source. The oxygen supply for the crew ensemble needs to be filtered for CB agents, and any garments that tie into the respiratory line must be hardened to prevent infiltration of agents. Aircrew transition to and from the air vehicle must be considered (i.e., portable air sources, removable overgarments for liquid exposure, maintenance assistance.)

Guidance for completing table 3.1.8.2.6.2-I follows:

(The entries for Agent Type, Form, and Agent Name should mirror the entries in table 3.1.8.2.6.1-I CB concentration threat above. Historically, values from NATO AEP-7 NBC Defense Factors in Design, Testing & Acceptance of Military Equipment are used for miosis, vapor and contact threshold criteria.)

Agent Type: Identify whether the agent is chemical or biological. (Refer to CB concentration threat table above.)

Form: Identify whether the agent is liquid or vapor. (Refer to CB concentration threat table above.)

Agent Name: Identify the nomenclature of the agent, e.g., Mustard Gas, Spore-formers, Viruses, Toxins, etc. (Refer to CB concentration threat table above.)

5th Percentile Miosis Threshold Criteria: The allowable exposure level for human, ocular and respiratory systems should be defined as threshold criteria. The human is most susceptible to CB agents through the ocular and respiratory pathways. The 5th percentile miosis criteria reflects the maximum vapor level (Concentration x Time in units of mg min/m^3) that the human should be exposed to preclude miosis onset.

5th Percentile Vapor Percutaneous: Vapor percutaneous is similar to 5th percentile miosis threshold except it is for human skin. This value is considerably higher than the Miosis criteria, and generally is met with compliance to the Miosis criteria. The 5th percentile vapor percutaneous criteria reflects the maximum vapor level (Concentration x Time in units of mg min/m^3) that the human should be exposed to preclude agent absorption through the skin.

Contact Threshold Criteria: The contact threshold criteria is the maximum liquid level exposure preventing the 5th percentile contact hazard. The criteria is stated in terms of a surface density (g/m^2).

Residual Decontamination Hazard:

Maintenance Personnel Exposure Duration: Identify the maximum allowable time for exposure of maintenance personnel. This time should be the maximum time it would take to complete maintenance in routine operational conditions.

Aircrew Exposure Duration: Identify the maximum allowable time for exposure of aircrew. This should be the maximum time the aircrew will see operating the air vehicle under routine operational conditions.

REQUIREMENT LESSONS LEARNED (3.1.8.2.6.2)

Historically, personnel protection has exclusively been achieved through individual protection, which creates an impact on mission performance, duration and success. Individual protective creates heat stress, dehydration, fatigue, discomfort, reduced vision and restricted mobility, all of which deteriorate aircrew performance and limit exploitation of full air vehicle performance. CB contamination exceeding the table criteria will create a health hazard that will effect performance, but may cause death. The F-22 is the first AF Air Vehicle with CB requirements. The upfront requirements allowed for some of the personnel protection to be accomplished through the aircraft, reducing the individual's encumbrance and enhancing operational performance.

4.1.8.2.6.2 Chemical and biological personnel protection verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Aircrew chemical and biological protection throughout ingress, mission phases, and egress	Protection for the specified duration and concentration in table 3.1.8.2.6.2-I	A,I	A,I	A,I		A,D

VERIFICATION DISCUSSION (4.1.8.2.6.2)

The chemical and biological personnel protection verification confirms that the air vehicle design ensures aircrew protection from ingress through egress and allow for the accomplishment of mission tasks within a chemical/biological environment.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the air vehicle design concept indicates that the appropriate requirements are identified and allocated for protection of aircrew personnel across all air vehicle mission phases. Analysis of the design concept indicates that the CB pathways through the air vehicle system have been predicted, aircrew tasks requiring accomplishment in the CB threat have been identified, and the maximum allowable hazard concentrations for system compliance to table 3.1.8.2.6.2-1 have been allocated to the subsystems (crew-mounted and air vehicle). Inspection of air vehicle specifications and processes indicate that aircrew system protection is factored into the design and procedures for the systems engineering.

PDR: Analyses and inspections of the air vehicle preliminary design and lower-tier specifications indicate applicable lower-tier requirements have been derived. Analysis of the preliminary design indicates that the man-mounted and air vehicle designs are achieving successful CB protection of the aircrew and critical integration. Air vehicle analysis is typically supported by data from part-task simulations, lower-level testing (i.e., coupon testing) and subsystem assessments/simulations. Analyses indicate any air vehicle level CB requirements that have not yet been considered.

CDR: Analyses and inspections of detailed air vehicle design information and updated lower-level test/simulation/demonstration data confirm the specified aircrew protection, both man and air vehicle mounted, comply with table 3.1.8.2.6.2-I. Inspection of lower-level tests and simulation data, including full-mission and subsystem simulations, confirm that the man-mounted and air vehicle subsystem performance is obtained and mission tasks can be completed.

FFR: No unique verification action occurs at this milestone.

SVR: Analysis of lower-level test/demonstration data and air vehicle test results confirm the air vehicle provides aircrew protection in accordance with table 3.1.8.2.6.2-I. Demonstration of the air vehicle in a simulated ground CB threat, with aircrew performing all necessary tasks and procedures from ingress through egress and functionality of air vehicle mounted protection, confirms compliance with the specified requirements. Analysis of lower-level CB material and subsystem simulation results should be used to supplement the demonstration data.

Sample Final Verification Criteria:

The chemical and biological personnel protection requirement shall be satisfied when __(1)__ analyses, __(2)__ demonstrations, and __(3)__ tests confirm the air vehicle provides the aircrew with protection throughout ingress, mission phases, and egress for the specified exposure duration and concentration.

Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement elements have been met. Analysis might evaluate results of coupon tests utilizing live agents and subsystem performance assessments/simulations. Additionally, analysis of aircrew performance during cockpit full mission simulations with man-mounted equipment should be considered. Analysis might also include lower-level CB tests of man-mounted equipment performance or material hardness.

Blank 2. Identify the type and scope of demonstrations required to provide confidence that the requirement elements have been met. Demonstration should be the optimum methods of verification. Demonstrations should include a ground simulation of a CB threat utilizing operational procedures. In-flight demonstration of mission operation and performance with man mounted and air vehicle mounted devices installed can be accomplished as a nondedicated assessment during the flight test program.

Blank 3. Identify the type and scope of tests required to provide confidence that the requirement elements have been met. Example tests might include use of stimulant agents to evaluate specified performance for the total air vehicle under contaminated conditions. CB tests of man-mounted equipment performance or material hardness should be utilized to assist in verifying compliance with the exposure specified.

VERIFICATION LESSONS LEARNED (4.1.8.2.6.2)

CB testing of air vehicle systems is extremely limited. F-22 has the most complete CB requirements levied across the weapon system, but to date the verification is not complete. CB verification often must be deferred until late in the EMD program, as initial air vehicle often have not incorporated the CB design components.

3.1.8.2.6.3 Chemical and biological decontamination

The air vehicle shall be capable of being decontaminated to the levels identified in 3.1.8.2.6.2 Chemical and biological personnel protection, table 3.1.8.2.6.2-I. Maximum allowable hazard concentration, both internally and externally, without degrading air vehicle performance below the levels present immediately prior to decontamination. Determination that a chemical and biological (CB) hazard has been reduced to allow MOPP level 0 gear shall be a function of __(1)__.

REQUIREMENT RATIONALE (3.1.8.2.6.3)

During exposure to a liquid or vapor agent, the air vehicle materials will absorb agent. It will later off-gas, creating a possible personnel hazard even after some forms of decontamination. The amount of agent absorbed and the subsequent off-gassing rate varies according to the agent, material, and temperature. Each off-gassing component contributes a different amount to the overall personnel dose.

The air vehicle must have the capability to be decontaminated to allow sustained land and shipboard operations.

REQUIREMENT GUIDANCE (3.1.8.2.6.3)

Blank 1. Complete with support equipment, the air vehicle, or a combination of both.

The air vehicle design requires the ability to support initial surge sortie generation rates while wearing Mission Operational Protection Posture (MOPP) Level 4. This requires special design considerations to enable the maintainer to perform tasks while wearing this protective gear. Inducing damage to the MOPP Level 4 gear while maintaining a contaminated air vehicle could be life threatening.

While it is desirable to perform decontamination as quickly as possible to reduce the potential of a residual hazard, it is not always possible. Decontaminability is required even under a “fight dirty” concept of operations in which field expedient or hasty decontamination may be performed when full decontamination is not possible.

The air vehicle design requires the ability to support sustained surge sortie generation rates while wearing MOPP Level 2. Use of MOPP Level 2 assumes significant decontamination has occurred. Gross qualities of liquid agent can be removed from the surface by sustained high-speed flight and/or washing the air vehicle with soap and water. Subsequent desorption creates a residual vapor hazard to personnel.

The aircrew and maintainer require a means to verify the CB hazard has been reduced to allow MOPP Level 0. At some point in time, the air vehicle must be robustly cleaned. Some equipment may never be sufficiently clean; therefore, it must be removed then destroyed.

The allowable personnel exposure for a decontaminated air vehicle, defined in 3.1.8.2.6.2 Chemical and biological personnel protection, table 3.1.8.2.6.2-I, establishes how clean is clean.

Past experiments have reported the percent of agent removed. This is a relative measure only; 97 percent decontamination may still leave dangerous levels of agent. A relative criterion is unacceptable. An absolute criterion is required to achieve an acceptable hazard level.

The aircrew and maintainer operating around the post decontaminated air vehicle must be exposed to less than the 5th percentile miosis, vapor per cutaneous and contact threshold criteria at the completion of the maximum exposure durations. An exposure time of 12 to 16 hours is believed to be realistic and achievable. Due to the measurement technology, extended exposure durations are not testable. If exposure times beyond 16 hours are required, ground personnel may need additional protective equipment for the eye, lung, and/or hand protection, MOPP Level 4 is unacceptable. However, the goal remains no special protective equipment.

The use of point vapor detectors can provide a monitoring capability which when used in conjunction with decontamination procedures can indicate that acceptable hazard levels have been reached. Prior to returning decontaminated parts to the re-supply system, all parts must be robustly cleaned.

Standard decontaminating solutions, such as DS2, STB, and HTH, are corrosive to typical air vehicle materials. Several decontamination agents and processes are used, such as detergents, soaps, and hot forced air. The effect of candidate decontaminating solutions must be evaluated for specific materials. To date, no decontamination agent or process has been fully successful. The usage of a decontamination agent or process is even more difficult when applied to air vehicles operating on a carrier.

Technical information on the decontamination is contained in NAVAIR A1-NBCDR-OPM-000 “Naval Aviation NBC Defense Resource Manual”; Air Force TO 1-1C15-1-3 “Chemical Warfare Decontamination, Detection and Disposal of Decontaminating Agents”; and Army Field manual (FM) 3-5.

REQUIREMENT LESSONS LEARNED (3.1.8.2.6.3)

Low-level residual CB agent offgassing from coatings is a significant concern for the long-term health of maintainers and aircrew.

The ability to decontaminate an air vehicle requires proper selection of internal and external coatings.

Equipment inside the aircraft will be contaminated with significant levels of agent concentration.

4.1.8.2.6.3 Chemical and biological decontamination verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Air vehicle is capable of being decontaminated	MOPP level 0 (No performance degradation)	A,I	A,I	A,I		D

VERIFICATION DISCUSSION (4.1.8.2.6.3)

CB decontamination verification confirms that decontamination reduces exposure of the threats to specified levels, allowing for operations to resume to a MOPP Level 0-gear condition as demonstrated by the specified functions. Additionally, the verification confirms that the decontamination process does not degrade the specified air vehicle performance. Subsystem and coupon test results should be included in the full system analysis.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analyses of the design concept indicates that the specified MOPP Level 0 functions and the chemical and biological pathway through the air vehicle are understood, and proper allocation to the air vehicle subsystem requirements for decontamination and nondegraded performance are identified. Inspection of air vehicle chemical/biological analyses and specifications indicate that the control of air vehicle decontamination has been factored into the systems engineering process.

PDR: Analyses and inspections of the preliminary design and lower-tier specifications indicate applicable lower-tier requirements have been derived. Analysis of the preliminary design indicates the air vehicle achieves successful CB decontamination, without air vehicle performance degradation, and completion of MOPP Level 0 gear functions. Air vehicle analyses are typically supported by lower-level testing (i.e., coupon testing) and subsystem assessments/simulations that confirm the ability to decontaminate or prevent contamination. Analyses results identify air vehicle level chemical/biological decontamination requirements that have not yet been considered.

CDR: Analyses and Inspections of detailed design information and updated lower-level test/simulation/demonstration data confirm the air vehicle decontamination satisfies 3.1.8.2.6.2 Chemical and biological personnel protection, table 3.1.8.2.6.2-I, provides for MOPP Level 0 gear functions and maintains air vehicle performance.

FFR: No unique verification action occurs at this milestone.

SVR: Air vehicle demonstrations and analysis of lower-level test/demonstration data and test results of the air vehicle CB decontamination confirms the compliance with 3.1.8.2.6.2 Chemical and biological personnel protection, table 3.1.8.2.6.2-I, with no degradation in air vehicle performance.

Sample Final Verification Criteria

The chemical and biological decontamination requirement shall be satisfied when __(1)__ analyses and __(2)__ demonstration confirm the specified air vehicle performance withstands the CB decontamination to requirements of 3.1.8.2.6.1 Chemical and biological hardening, table 3.1.8.2.6.1-I and specified functions are achievable in MOPP Level 0 gear.

> Blank 1. Identify the type and scope of analysis required to provide confidence that the requirement elements have been met. Analysis might evaluate results of coupon tests utilizing live agents and subsystem assessments/simulations/computer modeling.
>
> Blank 2. Identify the type and scope of demonstration required to provide confidence that the requirement elements have been met. An example might include a demonstration of a ground simulation CB threat with aircrew and maintenance performing all necessary tasks and procedures to decontaminate the aircraft and the required post decontamination functions in MOPP Level 0 gear. Demonstration should include the functionality of any aircraft mounted protection to assert full compliance with the CB threat. CB test results should be used to supplement the demonstration data.

VERIFICATION LESSONS LEARNED (4.1.8.2.6.3)

F-22 is the first aircraft to require a CB compliant aircraft to include decontamination. The affectivity has not been demonstrated at this time. On previous systems, the CB requirement has not been levied, and therefore decontamination was employed as an after thought. Upfront designs can prevent/minimize contamination or enhance the decontamination process. CB verification is often deferred until late in the EMD program, as initial aircraft do not incorporate the CB compliant components.

3.1.8.2.7 Nuclear weapons survivability

The air vehicle shall not experience loss or degradation of mission or safety function due to the nuclear weapon effects resultant from the nuclear weapon delivery.

REQUIREMENT RATIONALE (3.1.8.2.7)

An air vehicle delivering a nuclear weapon could be damaged from the thermal effects of a nuclear burst. External coatings, the canopy, and aircrew are sensitive to thermal effects from a nuclear burst. Invoking this requirement acknowledges understanding of the design impacts and resulting costs. For example, this can be a driver in the design point performance.

REQUIREMENT GUIDANCE (3.1.8.2.7)

For an air vehicle conducting nuclear weapons delivery, typically nuclear thermal effects dominates all other weapon effects. The air vehicle design considerations for nuclear thermal effects are external coatings, canopy, crew station, and aircrew protection. Coatings applied to composite materials are more likely to be damaged by a thermal pulse than coatings applied to metals. Composite materials typically retain more of the thermal energy at the material front face, hence increased temperature on the coating. Small changes in coating formulations may greatly alter thermal hardness. Considerable external coating damage may occur on low observable (LO) air vehicles during a nuclear weapon delivery. A thermal pulse test can demonstrate this design requirement. Recommend using two thermal exposures (several minutes apart).

Aircrew can experience flash blindness at very large distances from a nuclear weapon, if they are looking in the direction of the burst. At night, the flash blindness distance increases significantly due to increased pupil size. During nuclear weapon delivery, the air vehicle is flying away from the burst point.

The issue of hardening an air vehicle to all possible nuclear effects (transient radiation effects on electronics (TREE), electro-magnetic pulse (EMP), overpressure, gust, thermal, crew radiation, dust and fallout) will be a function of the threat (current and projected), costs (including development, production, support, and potential retrofit) and risk. New air vehicles will likely have an inventory life of decades with an associated increasing uncertainty in the threat. A decision to not require nuclear effects hardening in development can not be easily, or completely, redressed by a modification program later in the air vehicle's useful life. To require retrofit hardening after the initial design is expensive and may be prohibitive.

REQUIREMENT LESSONS LEARNED (3.1.8.2.7)

Nuclear EMP hardening has been integrated into the Electromagnetic Interference / Compatibility (EMI/C) electromagnetic environment design activities. For air vehicles, additional EMP design requirements are balanced based on cost-benefits and risks. Retrofitting EMP hardening as a modification is costly and will not likely achieve the benefits potentially available if designed into the air vehicle from the beginning. The need to provide additional EMP hardening characteristics, for air vehicles intended to remain in the inventory for decades, must be carefully considered and weighed against the consequences of not providing such characteristics.

Nuclear overpressure, gust, and thermal hardening have been required for high value air vehicles that had a base escape requirement. Nuclear hardening effectively decreases the needed escape distance and reaction time. For air vehicles, overpressure, gust, thermal design requirements are dependent on the threat postulated. Careful consideration, including cost-benefit and risk analyses, are necessary since such characteristics can be design drivers in air vehicle development but are exceedingly more difficult and expensive to retrofit into an existing air vehicle.

TREE hardening has been required for high value, high altitude air vehicles. TREE includes these weapon effects: neutron fluence, total dose, and gamma dose rate. At lower altitudes (less than ~30,000 ft), TREE damage occurs well inside the damage radius of other nuclear weapons effects (overpressure, gust, thermal).

TREE hardening requires detail circuits analysis and piece-part data. Only a small fraction of available piece parts are designed as radiation hardened parts. If TREE hardening requirements are near the inherent hardness of the piece parts, then little additional military capability has been achieved – why spend the effort? If TREE hardening requirements are beyond the inherent hardness of the piece parts, significant piece-part control during assembly and throughout the life cycle is required. Piece parts that are inherently harder than the typical part is dependent upon the manufactures processing. Controlling the manufacturing process for each inherently harder piece part is counter to the way that DoD manages piece parts. For air vehicles, TREE design requirements are not recommended unless the nuclear threat is significant.

4.1.8.2.7 Nuclear weapons survivability verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
The air vehicle shall not experience loss or degradation of mission or safety function due to thermal energy release during nuclear weapon delivery.	Pass/Fail	A	A	A		A

VERIFICATION DISCUSSION (4.1.8.2.7)

The verification of the air vehicle's ability to withstand the thermal effects resultant from a nuclear weapon delivery will focus on ensuring that the design utilizes materials that prevent injury to the aircrew and allow for continuation of the mission after exposure. Subsystem and coupon test results should be included in the full system analysis.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the design concept indicates that nuclear weapon survivability requirements are identified and allocated to air vehicle subsystem requirements. Analyses indicate that the control of system hardness has been factored into the systems engineering process.

PDR: Analysis of the preliminary design documentation indicates that the air vehicle is addressing the nuclear weapons survivability requirements. Analysis of simulation data and subsystem trades/ tests indicate the adequacy of the design. Analyses and inspections of the preliminary design and lower-tier specifications indicate applicable lower-tier requirements have been derived. Analysis of the preliminary design indicates the air vehicle achieves required nuclear hardness of the air vehicle and protection of the aircrew. Air vehicle analysis is typically supported by lower-level material testing (i.e., coupon testing) and subsystem survivability analysis.

CDR: Analyses of detailed design and updated lower-level test/simulation/demonstration data confirm the air vehicle performance withstands the nuclear weapon and allow for mission completion. Analysis of material and coatings, using a thermal source with a representative spectrum and airflow, demonstrate the air vehicle hardness.

FFR: No unique verification action occurs at this milestone.

SVR: Analysis of lower-level test/demonstration data confirms survivability of the air vehicle.

Sample Final Verification Criteria

The nuclear survivability requirement shall be satisfied when __(1)__ analyses confirm that the air vehicle will not experience loss or degradation of mission or safety function due to the nuclear weapon effects resultant from the nuclear weapon delivery.

> Blank 1. Identify the type and scope of analysis required to confirm that the requirement elements have been met. Analysis may include test results of coupons exposure to a thermal energy impact and subsystem assessments/ computer modeling, results from high-energy thermal pulse to localized portions of the air vehicle; functional evaluation of air vehicle mounted protection, and sub-scale test results.

VERIFICATION LESSONS LEARNED (4.1.8.2.7)

To Be Prepared

3.1.9 Mission lethality

3.1.9.1 Target detection, track, identification, and designation

The air vehicle shall be capable of detecting, tracking, identifying and designating targets as defined in table 3.1.9.1-I, Target description, with the capability as defined in table 3.1.9.1-II. The air vehicle shall be capable of utilizing detection, track, and identification information from the following off-board sources: __(1)__. The air vehicle shall be capable of prioritizing targets with aircrew override and reprioritization.

TABLE 3.1.9.1-I. Target description.

Target #	Target Type	Target Activity	Target Signature	Target Countermeasures

TABLE 3.1.9.1-II. Air vehicle targeting capabilities.

Target #	Capability	FOR	FOV	Range	Currency	Conditions
	P_{Detect} $P_{FalseAlarm}$ P_{Track} $T_{Reacquire}$ P_{ID} $P_{FalseID}$ P_{Acq}					

REQUIREMENT RATIONALE (3.1.9.1)

This requirement is applicable to air-to-air, air-to-ground, and air-to-sea target detection, tracking and identification capabilities.

This requirement establishes the air vehicle's capability to detect, track, identify, and acquire (i.e., designate) targets. It also establishes both the field of view and field of regard that the air vehicle must be capable of examining, as well the maximum allowed time between updates of target information. Such target acquisition requirements are critical for being able to employ weapons and are applicable for the detection of significant geographic "waypoints" to update air vehicle position information autonomously. Further this requirement provides for obtaining the target information from off-board sources (e.g., E-2C, AWACS, UAV, Observation Helicopter, etc.) and correlating that information with on-board sensor information.

REQUIREMENT GUIDANCE (3.1.9.1)

While this requirement has been written in a fashion to allow specification of capabilities against airborne, ground-based, and sea based targets in a single table, it may be prudent (in the program-specific specification) to replicate this requirement to address the acquisition of airborne, surface, and undersea sea targets in separate requirements.

Blank 1. List the sources of off-board target acquisition information (e.g., intraflight, AWACS/E-2C, etc.). Provide the location of a paragraph in the interface section that identifies the specifics of the information and quality of information to be passed to the air vehicle.

Guidance for completing table 3.1.9.1-I follows:

Target #: A unique identifier to link an air vehicle detection, identification, and track capability row in table 3.1.9.1-II to the target description contained in a row of this table.

Target Type: A description of the target type. It can be as simple as “Tank” or could identify a specific vehicle, such as “F-14,” “MIG-29,” “M-60A3,” “Arleigh Burke class destroyer,” “submarine,” etc.

Target Activity: A description of what the target is doing. This could be “parked on a taxi-way,” “moving at 25 kph in a tank company in road march formation,” “cruising at Mach 0.8 at 20,000 feet,” “cruising at 20 kts in sea state 3,” etc. Add any information useful for describing the conditions for which detection, acquisition, and identification capabilities are required.

Target Signature: Typical signatures include RF, RCS, IR, visual, and acoustic. There are three basic choices for filling in the target signature information. One option is to define the specific signature at various azimuths and elevations for each target the air vehicle must operate against. This will necessitate defining the target acquisition information versus each such target. Another option is to use generic, reference signatures (e.g., 10 square meter target at frequency XXX, or 1 square foot presented area, etc.) for each class of target, where the classes may be differentiated only by target background or, for special cases, deemed not appropriate for “extrapolation” from a generic reference signature. Again, the target acquisition information should be defined for each target. Lastly, a single set of generic, reference signatures could be used. Where practicable, signature information should be entered for each type of signature thereby enabling the developer to define the best “suite” of sensors needed to provide the needed acquisition capabilities. If there are other signature types of interest/utility then add those to the table. For specific targets (e.g., MIG-21), a document may exist that defines the specific signature characteristics of that target that could be referenced in lieu of filling-in the table with specific numbers. An example of some signature characteristics that may be entered are

a. Radio Frequency: Enter the RF signal emissions from the threat to enable detection by devices such as radar warning receivers. RF emissions should be characterized by both power and frequency.

b. Radar Cross Section: Enter the radar cross section by frequency.

c. Infrared: Enter the Infrared signature by frequency/frequency band.

d. Visual Signature: Enter the visual signature, nominally a presented area.

e. Acoustic Signature: Enter the acoustic signature.

Target Countermeasures: Define the countermeasures that potential targets use to degrade acquisition capability. This can take the form of jamming capabilities, camouflage, and so forth.

For specific targets (e.g., MIG-21), a document may exist that defines the specific counter-measures capability of that target that could be referenced in lieu of specific details.

Guidance for completing table 3.1.9.1-II follows:

Target #: A unique identifier to link an air vehicle detection, identification, and track capability row in this table to the target description contained in a row of table 3.1.9.1-I, Target description.

Capability: There are nominally three options for defining various acquisition capabilities. One option is to specify the value of the parameter at a given range. Another option is to utilize the field-of-view and range information specified in the table and enter a percentage for the parameter (e.g., Detect 99 percent of the targets meeting one or more of the target signature values within a volume defined by the field-of-view and range). The third option would be to describe the value of the parameter as a function of range. These capabilities should describe both the autonomous capabilities as well as the cooperative capabilities. The probability should be based on previous studies/experience, and analyses. Tradeoffs are likely (e.g., P_{ID} vs FOR) when determining final specification values.

a. P_{Detect}: Capability to detect a single target or detecting some percentage of the targets within a volume defined by the FOV/range or FOR/range. Examples:

(1) Detect 99 percent of the targets meeting one or more of the target signature values within the volume defined by the FOR

(2) Probability of detecting a single target within the FOV at a specific range (e.g., 0.XX at YY NM)

(3) Probability of detecting a single target within the FOV as a function of range (enter either a probability of detection versus range table or curve)

b. $P_{FalseAlarm}$: Ability to avoid false detections

c. P_{Track}: Capability to track a single target.

d. $T_{Reacquire}$: Time to reacquire track after loss of track

e. P_{ID}: Probability of identifying a single target. This may need to be specified for friendly, neutral, and hostile.

f. $P_{FalseID}$: Ability to avoid incorrect identification

g. P_{Acq}: Probability of acquiring (or designating) a target for attack.

Field of Regard (FOR): The maximum azimuth and elevation limits that the air vehicle must be capable of examining. Tradeoffs are likely (e.g., range vs FOR) when determining final specification values.

Field of View (FOV): The instantaneous (or sweep) azimuth and elevation limits that the air vehicle must be capable of examining. This should be based on previous studies/experience, and analyses. Tradeoffs are likely (e.g., range vs FOV) when determining final specification values.

Range: The range at which the air vehicle must be capable of detecting, tracking, identifying, and designating targets. This should be based on previous studies/experience, and analyses. Tradeoffs are likely (e.g., range vs FOR) when determining final specification values.

Currency: The “refresh” rate of target information within the FOR and FOV. This parameter is based on targeting and weapon support requirements for both single weapon and multiple weapon attacks.

Conditions: Specify the conditions of measurement for the requirement and other factors that bear on the achievement of the requirement. These conditions should be in concert with those requirements defined in 3.2 Environment sections of this document. Such factors include

a. Maneuvers

b. Weather

c. Operational environment (e.g., pulse density, smoke and other obscurants)

d. Terrain and sky (target background e.g., sea state)

REQUIREMENT LESSONS LEARNED (3.1.9.1)

Target prioritization is handled via whatever algorithms are determined appropriate for the air vehicle in concert with predetermined "rules" that can be used for filtering/prioritizing information relative to specific missions and situations. Such prioritization is critical in enabling the "best" employment of weapons to meet both mission objects and to promote air vehicle survivability.

4.1.9.1 Target detection, track, identification, and designation verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Target detection	P_{Detect}	A	A,S	A,S		S,T
	$P_{FalseAlarm}$	A	A,S	A,S		S,T
	FOV	A	A,S	A,S		S,T
	FOR	A	A,S	A,S		S,T
	Currency	A	A,S	A,S		S,T
Target track	P_{Track}	A	A,S	A,S		S,T
	$T_{Reacquire}$	A	A,S	A,S		S,T
	FOV	A	A,S	A,S		S,T
	FOR	A	A,S	A,S		S,T
	Currency	A	A,S	A,S		S,T
Target identification	P_{ID}	A	A,S	A,S		S,T
	$P_{FalseID}$	A	A,S	A,S		S,T
	FOV	A	A,S	A,S		S,T
	FOR	A	A,S	A,S		S,T
	Currency	A	A,S	A,S		S,T
Target designation	P_{Acq}	A	A,S	A,S		S,T
	FOV	A	A,S	A,S		S,T
	FOR	A	A,S	A,S		S,T
	Currency	A	A,S	A,S		S,T
Use of offboard targeting data	Yes/No	A	A,S	A,S		S,T

VERIFICATION DISCUSSION (4.1.9.1)

This is a varied and complex requirement with many qualifying conditions that are themselves verifiable requirements. Verification activities will rely heavily on analysis and simulation with final verification accomplished through a combination of high fidelity simulation (both man and hardware in-the-loop) and modeling, and flight test.

Preliminary and interim verifications can take the form of analysis, and simulation using the expected, or demonstrated performance of the weapon system sensors and high fidelity target modeling. This requirement is critical to determining the air vehicle sensor mix and many of the sensor performance requirements. In addition, computer resource sizing, display characteristics, and data presentation can be heavily influenced by this requirement. Analyses and simulations must consider and include these key derivative requirements.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analysis of the preliminary design concept indicates target detection, track, identification, and designation verification requirements, including use of off-board sources as required, have been decomposed to lower-tier requirements. Analysis indicates that meeting these lower-tier requirements provides the required performance.

PDR: Analysis of predictions based on preliminary designs indicate the target detection, track, identification, and designation capabilities, including off-board sources, meets the requirement as defined in table 3.1.9.1-II. Test results for GFE and existing commercial items should be used whenever possible. If test data is not available, simulation results or performance requirements should be used. Target signature and countermeasure capabilities should be simulated using accepted service models, data and simulations.

CDR: Analysis of predictions using detailed designs confirms the target detection, track, identification, and designation capabilities, including off-board sources, meets the requirement as defined in table 3.1.9.1-II. Additional test results for GFE and existing commercial items should be available and used. Target signature and countermeasure capabilities should be simulated using validated service models, data, and simulations. Increased availability of test results provides additional fidelity and confidence. Higher fidelity simulations are used, and man-in-the-loop, hardware-in-the-loop simulations are being developed in preparation for SVR activities.

FFR: No unique verification action occurs at this milestone.

SVR: A combination of high fidelity simulation and flight test confirms the target detection, track, identification, and designation requirement has been met. For the conditions listed in this paragraph that cannot be recreated on a test range, modeling and simulation should be used to augment the testing. Simulation efforts use man, hardware, and operational flight program in-the-loop. Results of flight test confirm the ability to use off-board targeting data.

Sample Final Verification Criteria

The target detection, track, identification, designation, and off-board sources requirement shall be satisfied when __(1)__ analyses, __(2)__ simulations, and __(3)__ tests confirm specified performance is achieved.

Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement has been satisfied. Include the analysis methods for determining the target signature for the appropriate emission spectrums as well as any analysis methods used to predict system performance against the target.

Blank 2. Identify the type and scope of simulation(s) required to provide confidence that the requirement has been satisfied. Include any simulation methods for determining the target signature in the appropriate emission spectrums as well as any simulations used to predict system performance against the target.

Blank 3. Identify the type and scope of flight tests required to provide confidence that the requirement has been satisfied.

(Note: One method for completing blanks 1, 2, and 3 is to use a table such as the following to specify the verification methods, types, and scope.)

Target #.	Requirement	Measurand	Analysis	Simulation	Flight Test
Target 1	Detection	P_{Detect}			
		$P_{FalseAlarm}$			
		FOV			
		FOR			
		Currency			
	Tracking	P_{Track}			
		$T_{Reacquire}$			
		FOV			
		FOR			
		Currency			
		Support			
	Identification	P_{ID}			
		$P_{FalseID}$			
		FOV			
		FOR			
		Currency			
	Acquisition	P_{Acq}			
		FOV			
		FOR			
		Currency			
	Offboard Sources				
Target 2					
Target 3					
…					
Target x					

VERIFICATION LESSONS LEARNED (4.1.9.1)

To Be Prepared

3.1.9.1.1 Multiple target track and weapon delivery support

The air vehicle shall be capable of discretely tracking the target sets listed in table 3.1.9.1.1-I separated in space by a distance as shown from the identified ranges. The air vehicle shall support __(1)__.

TABLE 3.1.9.1.1-I. Multiple target track.

Target Set ID	Total Number of Targets in Target Set	Number of each Target Type	Range to Closest Target	Min. Separation Distance			Conditions
				X	Y	Z	

REQUIREMENT RATIONALE (3.1.9.1.1)

This requirement is applicable to air-to-air, air-to-ground, and air-to-sea target tracking capabilities.

This requirement establishes the air vehicle's capability to simultaneously track multiple targets.

REQUIREMENT GUIDANCE (3.1.9.1.1)

While this requirement has been written in a fashion to allow specification of capabilities against airborne, ground-based, and sea based targets in a single table, it may be prudent (in the program-specific specification) to replicate this requirement to address the acquisition of airborne, surface, and undersea sea targets in separate requirements.

Blank 1. List the support requirements associated with this requirement. Examples include

a. The air vehicle shall support pre-launch, launch, delivery, and guidance of the air-to-air missiles and the air-to-surface ordnance listed in table 3.4.1.1-I, Stores list.

b. The air vehicle shall support route planning and threat avoidance.

c. Provide designation for other attack assets.

d. Provide weapon guidance for weapon launch from another vehicle.

e. Provide targeting information to other attack assets.

Guidance for completing table 3.1.9.1.1-I follows:

<u>Target Set ID</u>: A unique number to identify multiple target sets contained in a row of this table.

<u>Total Number of Targets</u>: List the number of targets that must be tracked simultaneously.

Number of each Target Type: List the number of each type of target.

Range to Closest Target: The range to the closest target of the target set.

Min. Separation Range: The minimum separation distance between two or more targets in the target set. Provide the minimum separation distances in three dimensions.

Conditions: Specify any conditions which further define this requirement. Target signature criteria and specific target activity (including countermeasures) should be included here if necessary. Other factors that may be listed here include, but are not limited to maneuvers, weather, operational environment (e.g., pulse density, smoke and other obscurants), terrain and sky (target background e.g., sea state).

REQUIREMENT LESSONS LEARNED (3.1.9.1.1)

To Be Prepared

4.1.9.1.1 Multiple target track and weapon delivery support verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Target track	Discretely tracks targets within target sets	A	A,S	A,S		A,S, T
Target support	(1)	A	A,S	A,S		A,S, T

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.1.9.1.1)

This is a complex requirement with a potential for many qualifying conditions. Verification activities will rely heavily on analysis and simulation with final verification accomplished through a combination of high fidelity simulation (both man and hardware in-the-loop) and modeling, and flight test.

Preliminary and interim verifications can take the form of analysis, and simulation using the expected, or demonstrated performance of the weapon system sensors and high fidelity target modeling. This requirement is critical to determining the air vehicle sensor mix and many of the sensor performance requirements. In addition, computer resource sizing, display characteristics, and data presentation can be heavily influenced by this requirement. Analyses and simulations must consider and include these key derivative requirements.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to each of the requirement elements specified in the verification table.)

SRR/SFR: Analysis indicates that the requirements are consistent with the scenarios in the Mission Profile Performance specified elsewhere in this document.

PDR: Analysis of predictions based on preliminary designs indicate success in meeting the multiple target track capabilities as defined in table 3.1.9.1.1-I. Analysis of test results for GFE and existing commercial items should be used whenever possible. If test data is not available, simulation results or performance requirements should be used. Target signature and countermeasure capabilities inherent to the identified targets should be simulated using accepted service models, data and simulations.

CDR: Analysis of predictions using detailed designs indicate success in meeting the capabilities as defined in table 3.1.9.1.1-I. Additional test results for GFE and existing commercial items should be available and used in analysis. Target signature and countermeasure capabilities should be simulated using validated service models, data, and simulations. Increased availability of test results provides additional fidelity and confidence. Higher fidelity simulations are used, and man-in-the-loop, hardware-in-the-loop simulations are being developed in preparation for SVR activities.

FFR: No unique verification action occurs at this milestone.

SVR: A combination of analysis, high fidelity simulation and flight test should be used to verify this requirement. Some conditions listed in 3.1.9.1.1 Multiple target track and weapon delivery support cannot be recreated on the test range. For those conditions, modeling and simulation should be used to augment the testing. Simulation efforts use man, hardware, and operational flight program in-the-loop. The ability to use off-board targeting data should be verified during flight test.

Sample Final Verification Criteria (4.1.9.1.1)

The multiple target track and weapon delivery support requirement shall be satisfied when __(1)__ analyses, __(2)__ simulations, and __(3)__ tests confirm specified performance is achieved.

Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement has been satisfied. Include the analysis methods for determining the target signature for the appropriate emission spectrums as well as the analysis methods used to predict system performance against the target.

Blank 2. Identify the type and scope of simulation(s) required to provide confidence that the requirement has been satisfied. Include the simulation methods for determining the target signature in the appropriate emission spectrums as well as the simulations used to predict system performance against the target.

Blank 3. Identify the type and scope of flight tests required to provide confidence that the requirement has been satisfied.

Note: One method for completing blanks 1, 2, and 3 is to use a table such as the one below to specify the verification methods, types, and scope. The target set ID is the link to the particular target set in this requirement.

Target Set ID	Analysis Method	Simulation	Flight Test

VERIFICATION LESSONS LEARNED (4.1.9.1.1)

To Be Prepared

3.1.9.2 Integrated earth/space reference accuracy

The air vehicle shall provide integrated earth/space reference accuracy for position (both aided and unaided), altitude, velocity, acceleration, pitch, roll, and heading that satisfy the air vehicle mission requirements specified herein and, minimally, the requirements of table 3.1.9.2-I. The air vehicle shall provide the GATM-related integrity monitoring and protection threshold performance (needed primarily for civil operation) as identified in table 3.1.9.2-II

TABLE 3.1.9.2-I. Integrated earth/space reference accuracy requirements.

Parameter	Autonomous Free Inertial Performance[1]	GPS Aided Inertial Performance	__(17)__ -Aided Inertial Performance
Position (CEP)	__(1)__	__(8)__	__(18)__
Position (CEP) after Aiding Interrupted for ___ Minutes	Not Applicable	__(9)__	__(19)__
Altitude (rms)	__(2)__	__(10)__	__(20)__
Velocity North, East (rms)	__(3)__	__(11)__	__(21)__
Velocity Up (rms)	__(4)__	__(12)__	__(22)__
Acceleration North, East, Up (rms)	__(5)__	__(13)__	__(23)__
Pitch, Roll (rms)	__(6)__	__(14)__	__(24)__
True Heading (rms)	__(7)__	__(15)__	__(25)__
Time (rms)	Not Applicable	__(16)__	__(26)__

[1]Gyro Compass Alignment and Baro Input

TABLE 3.1.9.2-II. Integrity monitoring and protection threshold performance requirements.

Phase of Flight	Allowable Time to Alarm (Sec)	Protection Threshold (PT) 95% (NM) (Containment Threshold equals 2 x PT 99.99999%)	Maximum Allowable False Alarm Rate (False Alarms/Hr)	Minimum Detection Probability	Continuity of Service Probability
En Route	__(27)__	__(33)__	__(39)__	__(45)__	__(51)__
Terminal	__(28)__	__(34)__	__(40)__	__(46)__	__(52)__
Non-precision Approach	__(29)__	__(35)__	__(41)__	__(47)__	__(53)__
Cat I Landing	__(30)__	__(36)__	__(42)__	__(48)__	__(54)__
Cat II Landing	__(31)__	__(37)__	__(43)__	__(49)__	__(55)__
Cat III Landing	__(32)__	__(38)__	__(44)__	__(50)__	__(56)__

REQUIREMENT RATIONALE (3.1.9.2)

The air vehicle performance requirements for integrated reference are derived from mission scenarios specified elsewhere within the air vehicle requirements or from the requirement of the air vehicle to operate in the civilian controlled airspace. The definition of the values of the performance parameters listed in the requirement will be accomplished during air vehicle development and air vehicle compliance with the requirement will be verified by measurement of said parameters via analysis, simulation and test.

REQUIREMENT GUIDANCE (3.1.9.2)

Both tables 3.1.9.2-I and 3.1.9.2-II must be completed considering any conflicts with other requirements within this document (e.g., mission scenarios, weapons accuracy, etc.). table 3.1.9.2-I documents the integrated reference accuracy requirements necessary to support the military mission. Table 3.1.9.2-II documents the integrated reference requirements need to support safe operation in civil airspace.

Guidance for completing table 3.1.9.2-I follows:

<u>Autonomous Free Inertial Performance</u>: List the air vehicle autonomous free inertial performance requirements for each applicable reference parameter in blanks 1-7. With the advent of faster throughput computers and cheap memory it is now possible to maintain multiple navigation solutions simultaneously. A continuously available autonomous free inertial solution provides several potential benefits. It provides a backup solution if the aided solution(s) suffers from a filter divergence problem or system failure. It provides lower noise output to support flight control or motion compensation if needed. It also provides a means to track inertial health via a means independent of GPS or other aiding sensors. The table below provides a sample list of

autonomous free inertial performance requirements as identified for the embedded GPS/INS (EGI).

EGI inertial only performance. - (Example table)

Parameter	Performance[1]	Metric Approximation
Position (CEP)	1 nm/hr (1 hour)	~1.9 Km/hr (1 hour)
Position (CEP)	0.8 nm/hr (2 hour)	~1.5 Km/hr (2 hour)
Altitude (rms)	50 ft	~15 m
Velocity North, East (rms)	3.0 ft/sec	~0.9 m/sec
Velocity UP (rms)	2.0 ft/sec	~0.6 m/sec
Acceleration N, E, Up (rms)	0.064 ft/sec/sec	~0.02 m/sec/sec
Pitch, Roll (rms)	0.05 deg	
True Heading (rms)	0.1 deg	

[1]GC Alignment with Baro

<u>GPS Aided Inertial Performance</u>: List the air vehicle autonomous GPS aided inertial performance requirements for each applicable reference parameter in blanks 8-16. A specified position performance after an operational realistic period of outage (e.g., an interference induced outage) should be included to ensure that other air vehicle sensors and/or weapons can be initialized properly. An alternate approach is to specify a position performance requirement under operationally realistic jamming conditions (Such a requirement is normally classified). The table below provides a sample list of GPS aided inertial performance requirements as identified for the embedded GPS/INS (EGI).

EGI GPS aided INS performance. - (Example table)

Parameter	Performance
Position (CEP)	<10 meters CEP
Position (CEP) after 20 minute GPS outage	<120 meters CEP
Altitude (rms)	12.5 meters
Velocity North, East, and Up (rms)	0.03 m/sec
Acceleration N, E, Up (rms)	0.064 ft/sec/sec
Pitch, Roll (rms)	0.05 deg
True Heading (rms)	0.1 deg
Time (rms)	100 nsec

Aided Inertial Performance: Air vehicle required reference parameter performance for an inertial aided with a different sensor (e.g., terrain correlation) or a different combination of sensors should be specified in this column. First the different sensor or sensor combination should be listed in blank 17. Next list the air vehicle aided inertial performance requirements for each applicable reference parameter in blanks 18-26.

In the new GATM environment, navigation standards will be defined by specifying thresholds of required performance versus a requirement to install specific pieces of equipment, as is the case today. These thresholds of performance (also called required navigation performance (RNP)) require an air vehicle to be within a specific number of NM of its cleared position (cross track and along track) during the duration of the flight (This accuracy includes positioning error, flight technical error (FTE), path definition error, and display error). Differing levels of accuracy are required in different airspace and regions, and are implemented under different timelines. Worldwide progression in the civil aviation community, however, is for the threshold of required performance to reduce to 10NM, 4NM, 1NM, and eventually less than 1NM. Continental Europe also requires basic area navigation (BRNAV) equivalent to a required of performance threshold of 5NM and will progress to precision area navigation (PRNAV) equivalent to a required performance threshold of 1NM. Many current inertial navigation systems capable of flying in remote and oceanic airspace (in the absence of ground based navigation aids for position updates) are certified by civil authorities to a drift rate of 2 NM per hour. This would impose a 2-hour flight duration under a required performance threshold of 4 NM if no updates are available. In order to operate effectively in this airspace, and in all airspace as ground based navigation aids are decommissioned, air vehicle navigation systems will require a satellite navigation capability such as the Global Positioning System (GPS).

Guidance for completing table 3.1.9.2-II follows:

Allowable Time to Alarm (Sec): List the air vehicle allowable time to alarm for each phase of flight in blanks 27-32. Sample allowable times to alarm, protection thresholds, false alarm limits, and minimum detection probabilities for different phases of flight from RTCA DO-208 “Minimum Operational Performance Standard for Airborne Supplemental Navigation Equipment Using Global Positioning System (GPS)” are provided in the following table:

Phase of Flight	Allowable time to Alarm	Protection Threshold	Maximum Allowable False Alarm Rate	Minimum Detection Probability
En Route	30 seconds	2.0 nm	.002/Hr	.999
Terminal	10 seconds	1.0 nm	.002/Hr	.999
Nonprecision Approach	10 seconds	0.3 nm	.002/Hr	.999

For GPS/GPS augmentation systems to be used for precision approach they must comply with applicable RTCA/FAA requirements which are now under development. The current radio navigation aid systems (VHF omni-directional range (VOR), instrument landing system (ILS), distance-measuring equipment (DME), tactical air navigation (TACAN), etc.) are required for at least the near-term (far-term plan is to decommission ground based navigation aids).

Protection Threshold (NM): List in blanks 33-38 the air vehicle protection threshold for each phase of flight.

Maximum Allowable False Alarm Rate (False Alarms/Hr): List in blanks 39-44 the air vehicle maximum allowable false alarm rate for each phase of flight.

Minimum Detection Probability: List in blanks 45-50 the air vehicle minimum detection probability for each phase of flight. The requirements for GPS precise positioning system (PPS) integrity monitoring have not been set at this time. However, it is expected that the requirements will be similar to standard positioning system (SPS) requirements. FAA approved SPS Supplemental Means navigation systems must have a GPS integrity monitoring system confidence of .99999999. To achieve this confidence, it is assumed that the Control and Space segment has a confidence of .99999. The remaining required confidence must be provided by integrity monitoring on the air vehicle. Therefore the integrity monitoring on air vehicle must have a Minimum Detection Probability of 0.999. An undetected event failure is when the integrity system fails to provide an alarm within the allowable time to alarm after a radial position error exceeds the specified protection alarm limit (normally the containment threshold). RTCA DO-236 requires the probability that the total system error of each air vehicle operating in RNP airspace exceeds the specified cross track containment limit without annunciation shall be less than 10^{-5} per flight hour. The RTCA DO-236 requirement is a top-level air vehicle requirement independent of the sensor technology used to achieve the requirement.

Continuity of Service Probability: List the probability of air vehicle minimum continuity of service for each phase of flight in blanks 51-56. The continuity of service probability is the probability that the service will be available for the duration of the phase of operation, presuming that the service was available at the beginning of that phase of operation. RTCA DO-208 does not list any sample values for this parameter; however, RTCA DO-236 states that the probability of annunciated loss of RNP area navigation (RNAV) capability (for a given RNP RNAV type) shall be less than 10^{-4} per flight hour. Continuity of service is a not major concern when GPS is used as only a supplemental means. However, the ultimate plan is to certify GPS as the primary and/or sole means. Continuity of service will also be a key requirement for precision approaches.

REQUIREMENT LESSONS LEARNED (3.1.9.2)

It will be important to determine which air vehicle performance requirements drive the integrated reference system performance requirements. For example, in the case of the F-15A, the inertial reference system was included on the air vehicle to provide Doppler reference for the pulse Doppler radar. The velocity stabilization requirement resulted in a derived requirement for an inertial reference system of 1 NM/hr CEP. Point to point navigation was not the driving requirement. Each air vehicle may have different performance drivers. These must be understood to assure consistency in the requirements allocation process.

Some inertial systems, once they are placed in the navigation mode, have the capability to sense that they are not moving and to reenter the alignment mode. This feature allows the INS alignment filter to better characterize the INS instrument errors and thereby significantly improve overall performance. However, some air vehicle navigation Kalman filters initialize when the INS is placed in the Navigation mode. This can result in filter stability problems, since both filters may try to measurement identical INS instrument errors at the same time. To ensure filter stability is maintained simultaneous operation of these filters should be precluded.

4.1.9.2 Integrated earth/space reference accuracy verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Autonomous free inertial performance	(1,2,3,4,5,6, & 7)	A,I	A,I, S	A,I, S	A,I, D	A,D, T
GPS aided inertial performance	(8,9,10,11,12,13,14,15, & 16)	A,I	A,I, S	A,I, S	A,I, D	A,D, T
__17__ aided inertial performance	(18,19,20,21,22,23,24,25 & 26)	A,I	A,I, S	A,I, S	A,I, D	A,D, T
Allowable time to alarm (sec)	(27,28,29,30,31, & 32)	A,I	A,I, S	A,I, S	A,I, D	A,D, T
Protection threshold (PT) 95% (NM) (containment threshold equals 2 x PT 99.99999%)	(33,34,35,36,37 & 38)	A,I	A,I, S	A,I, S	A,I, D	A,D, T
Maximum allowable false alarm rate (false alarms/hr)	(39,40,41,42,43 & 44)	A,I	A,I, S	A,I, S	A,I, D	A,D, S,T
Minimum detection probability	(45,46,47,48,49 & 50)	A,I	A,I, S	A,I, S	A,I, D	A,D, S,T
Continuity of service probability	(51,52,53,54,55 & 56)	A,I	A,I, S	A,I, S	A,I, D	A,D, S,T

*Numbers in parentheses in the Measurand column refer to numbered blanks in the requirement.

VERIFICATION DISCUSSION (4.1.9.2)

The air vehicle integrated reference accuracy requirements must be verified by a combination of analysis, inspection, simulation and test. For example, when a Kalman filter is used in an integrated reference system, a representative subset of operational flight profiles must be chosen via analysis to demonstrate direct compliance to performance requirements as well as validate integrated reference system simulations. Once validated, the integrated reference system simulations can be used to predict air vehicle integrated reference performance under other/new operational flight profiles. Typically, verification of air vehicle reference capabilities is done incrementally. The integrated reference system performance requirements are derived via analysis from mission scenarios and mission performance values specified elsewhere within the air vehicle specification. (Often during “state-of-the-art” integrated reference system developments these performance requirements may iterate multiple times as part of the development and test cycle). During the preliminary design phase and the critical design phase analysis and simulation results, using component error budgets and historical performance data, are used to predict performance. Simulations may also be used to extrapolate performance measured in the laboratory (e.g., drift rates) to mission performance (e.g., CEP). Flight critical and flight safety related integrated reference system parameters must be verified by a combination of analysis, simulation and test to be well within margins (e. g. accuracy, timeliness, stability, integrity) that allow for safe operation of the air vehicle. Flight tests are an essential element of verification, but due to their cost it is not practical to verify all capabilities for all mission profiles. Frequently, the main purpose of flight test is to verify the integrity of integrated reference simulations. Through out the development and test cycle program documentation must be inspected to confirm that the design information generated has been fully incorporated into the training, support and prime mission specifications

The GATM related integrity monitoring and protection threshold performance requirements must be verified by a combination of analysis, inspection, simulation and test. The integrity monitoring and protection threshold performance requirements for the integrated reference system are derived from the requirement of the air vehicle to operate in the civilian controlled airspace. The purpose of GATM verification is to provide formal validation that air vehicle performance either meets civil standards or provides an equivalent level of safety, in order to obtain access to restricted airspace. A combination of navigation performance analysis, simulation, inspection, and flight test must be used to substantiate compliance. In choosing a method(s), consider all system elements that can contribute to satisfying the GATM integrity and protection threshold requirements. The following list provides some (but not all) of the items which are typically considered:

a. System operating configurations (e.g., architecture, sensor mix, manual/coupled system, configuration changes due to switching, dispatch configurations, sensor source redundancy);

b. Nonfaulted performance;

c. Dependencies on system modes, features and operation;

d. Display resolution;

e. Data and computational latencies and resolutions;

f. Sensor error characteristics;

g. Effects when reference facility magnetic variation differs from that for procedure;

h. System response time;

i. Establishment of minimum equipment requirements for dispatch for RNP RNAV operations, identification of appropriate indications and annunciation available to the flight crew for detected loss of containment integrity;

j. Identification of critical faults (e.g., loss of component or subsystem) leading to loss of RNP RNAV capability;

k. Assessment of effect of loss of RNP RNAV capability including identification of mitigation techniques or procedures; and

l. Identification of appropriate indications and annunciations available to the flight crew for loss of RNP RNAV capability.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analysis and inspection of the air vehicle design concept indicates that the functional and performance requirements characterize a design approach which satisfies air vehicle mission needs. Analysis indicates requirements have been derived from the ORD and are properly allocated to air vehicle subsystem requirements. Analysis verifies linkage of air vehicle integrated reference accuracy requirements to supporting trades and mission effectiveness results. (Ideally, prior to SRR and SFR, the integrated reference system performance requirements are derived via analysis from mission scenarios and performance values specified within the air vehicle specification (During “state-of-the-art” integrated reference system developments, these performance requirements may iterate as part of the development and test cycle).)

PDR: Inspections and analyses of the preliminary air vehicle design and lower-tier specifications indicate the derivation of appropriate lower-tier requirements. Analysis indicates an ability to attain performance under specified characteristics and conditions for both air vehicle navigation and mission execution. (During the preliminary design phase analysis and simulation results, component error budgets and historical performance data are used to predict performance. Simulations may also be used to extrapolate performance measured in the laboratory (e.g., drift rates) to mission performance (e.g., CEP).)

CDR: Inspections of air vehicle design and updated analysis of lower-level test/demonstration data confirm the ability to achieve the required performance under specified characteristics and conditions for air vehicle navigation and mission execution as well as safe operation in civilian airspace. Analysis verifies that lower subtier reference requirements in aggregate, and the regeneration of the top-level air vehicle integrated reference accuracy, meet specified requirements. (During critical design phase analysis and simulation, results should be updated using the latest component error budgets and historical performance data to predict performance. Simulations may also be used to extrapolate performance measured in the laboratory (e.g., drift rates) to mission performance (e.g., CEP).)

FFR: Analyses, inspection of design, and demonstrations of reference accuracy performance confirm flight critical functions are available for conduct of first flight and verify that flight critical and flight safety related air vehicle reference parameters are well within margins (e. g., accuracy, timeliness, stability, integrity) that allow for safe operation of the air vehicle.

SVR: Demonstrations, tests, and analysis of lower-level test and demonstration data, confirm the ability to achieve reference accuracy performance under specified characteristics and conditions for both air vehicle navigation and mission execution. Verification should confirm that major components (that in aggregate satisfy the air vehicle integrated reference accuracy requirements) meet their allocated functional, performance, interface, and acceptance requirements.

Sample Final Verification Criteria

The integrated earth/space reference accuracy requirements and the GATM related integrity monitoring and protection threshold performance accuracy requirements shall be satisfied when __(1)__ analyses, __(2)__ simulations __(3)__ inspections, and __(4)__ tests confirm achievement of the specified performance requirements

Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement elements have been met. During the preliminary design phase and the critical design phase analysis and simulation, component error budgets and historical performance data are used to predict performance. Prior to FRR flight critical and flight safety related integrated reference system parameters must be verified by a combination of analysis, simulation and test to be well within margins (e. g. accuracy, timeliness, stability, integrity) that allow for safe operation of the air vehicle.

Blank 2. Identify the type and scope of simulations required to provide confidence that the requirement elements have been met. During the preliminary design phase and critical design phase analysis and simulation, component error budgets and historical performance data, are used to predict performance. Simulations may also be used to extrapolate performance measured in the laboratory (e.g., drift rates) to mission performance (e.g., CEP). Prior to FRR flight critical and flight safety related integrated reference system parameters must be verified by a combination of analysis, simulation and test to be well within margins (e.g., accuracy, timeliness, stability, integrity) that allow for safe operation of the air vehicle. Frequently, due to cost, the main purpose of flight test is to verify the integrity of integrated reference simulations.

Blank 3. Identify the type and scope of inspections required to provide confidence that the requirement elements have been met.

Blank 4. Identify the type and scope of tests required to provide confidence that the requirement elements have been met. Prior to FFR flight critical and flight safety related integrated reference system parameters must be verified by a combination of analysis, simulation and test to be well within margins (e.g., accuracy, timeliness, stability, integrity) that allow for safe operation of the air vehicle. Flight tests are an essential element of verification, but due to their cost it is not practical to verify all capabilities for all mission profiles. Frequently, the main purpose of flight test is to verify the integrity of integrated reference simulations.

VERIFICATION LESSONS LEARNED (4.1.9.2)

The air vehicle integrated reference accuracy requirements are normally specified in a statistical manner e.g., CEP, 1 sigma, 2 sigma, etc. To verify reference performance to a degree of statistical confidence a number of independent test runs are required. For example, normally a minimum of six independent test runs are performed before a statistically meaningful 50% circular error probable position drift value can be computed for the air vehicle.

3.1.9.3 Air-to-surface accuracy

The air vehicle shall be capable of air-to-surface delivery accuracy as identified in table 3.1.9.3-I, air-to-surface delivery accuracy requirements.

TABLE 3.1.9.3-I. Air-to-surface delivery accuracy requirements.

Weapon Type	Accuracy Req. (___)	Light Level	Weather	Pitch	Roll	Accel	Range	Altitude	Speed

REQUIREMENT RATIONALE (3.1.9.3)

Operational effectiveness requirements, such as probability of kill, or number of targets destroyed, are levied in the system specification. Many factors are involved in determining the operational effectiveness of a system, one of the most critical being the delivery accuracy of the system. Delivery accuracy is a product of the air vehicle avionics, software, displays, mechanization, data, racks, pilot, delivery conditions, and the weapons employed. Accuracy must be specified with as many applicable parameters as needed to ensure proper requirement definition and consistency with the effectiveness requirements levied in the system specification.

REQUIREMENT GUIDANCE (3.1.9.3)

If target state information is required to properly define accuracy requirements, add two new columns to table 3.1.9.3-I under the title "Target State" with two subtitles: "Vel. Of Target," and "Target Maneuver and Direction."

Guidance for completing table 3.1.9.3-I follows:

Weapon Type: List the appropriate weapon categories. Examples would be "Unguided, low drag, general purpose bomb," "Unguided, high drag, general purpose bomb," "Maverick," and "20mm Cannon." An entry of "Unguided low drag, general purpose bomb" and its related accuracy requirement would apply for all weapons included in Stores list table 3.4.1.1-I that fall into this category.

Accuracy Req. (___): List the accuracy requirement for each weapon type specified. Typically, accuracy requirements for air-to-surface munitions are specified as Circular Error Probable (CEP) in units of milliradians. For some precision guided munitions CEPs in units of meters or feet are more appropriate, but it is recommended that milliradians be used to specify all accuracy requirements for unguided munitions. The blank space between the parentheses provided in the header of this column could be used to identify the selected accuracy measurement units if a single measure is used throughout the table. The accuracy requirement entered should be a total accuracy requirement that includes all targeting, fire control, and weapon post release effects, and should include weapon guidance errors, pilot errors, and weapon errors. Therefore, the accuracy requirement entered should never be better than the weapon dispersion, or, in the case of guided munitions, the expected weapon accuracy.

Light Level: Describe the minimum light level under which the accuracy requirement must be met. Entries such as "Day" or "Night" are acceptable, unless a more precise measure of light level is required. Whatever measure is used, this entry should support the lethality requirements specified in the system specification.

Weather: Enter the worse case weather conditions for which the accuracy requirement must be met.

Pitch: Enter the pitch region for which the accuracy requirement must be met. An example of a valid entry would be -60 to +45 degrees.

Roll: Enter the maximum roll angle for which the accuracy requirement must be met. This entry should be filled in if the air vehicle must be capable of releasing weapons while maneuvering. An example of a valid entry would be "+ or - 45 degrees." If the air vehicle has no maneuvering attack requirement enter "NA" to signify "Not Applicable."

Accel: Enter the acceleration range for which the accuracy must be met. An example of a valid entry would be "0-4 Gs."

Range: Enter the ranges over which the accuracy requirement must be met. An example entry would be "30,000 - 50,000 feet"

Altitude: Enter the altitude range for which the accuracy requirement must be met. An example entry would be "1000 feet - 25000 feet."

Speed: Enter the range of speeds for which the accuracy requirement must be met. An example entry would be "450 knots - 540 knots." The pitch, roll, acceleration, altitude, and speed entries should be consistent with the profiles defined in 3.1.2 Mission profile(s) performance and 3.1.8 Survivability requirements.

If Target State columns are added to table 3.1.9.3-I, use the following guidance to fill in those columns.

Velocity of Target: Enter the target velocities for which the accuracy requirement must be met. An example entry would be 0-10 miles per hour.

Target Maneuver and Direction: Enter the target maneuver characteristics and direction for which the accuracy requirement must be met.

REQUIREMENT LESSONS LEARNED (3.1.9.3)

In the past, some systems suffered from poor definition of accuracy requirements. Accuracy requirements often were too vague, or in some cases, simply demanded performance “as good” as provided by other air vehicles. Such requirements are difficult, if not impossible to quantify because of the differences between air vehicles. As a result, test organizations frequently could not easily judge acceptable or unacceptable performance. Performance was sometimes accepted that did not satisfy the user, but because of vague requirement wording no means existed for the program offices to approach the contractor for corrective action without new tasking, negotiation, and money. Conversely, test organizations sometimes declared some test results unacceptable when, in fact, the achieved accuracy was optimum for the air vehicle design and prevailing test conditions.

Experience has also shown that accuracy requirements are often not defined to support a desired operational effectiveness. Such a disconnect can leave the user with an air vehicle that meets all specified performance requirements, but fails to provide the expected or desired operational effectiveness. Whenever possible, accuracy requirements should be a derivative requirement that supports the overall system lethality requirements.

4.1.9.3 Air-to-surface accuracy verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Delivery accuracy 1	CEP	A	A,S	A,S		A,S, T
Delivery accuracy 2	CEP	A	A,S	A,S		A,S, T
Delivery accuracy (…)	CEP	A	A,S	A,S		A,S, T

VERIFICATION DISCUSSION (4.1.9.3)

Air-to-surface delivery accuracy is a product of the air vehicle avionics, software, displays, mechanization, data, racks, pilot performance, delivery conditions, and the weapons employed. Accuracy must be specified with as many applicable parameters as needed to ensure proper requirement definition and consistency with the effectiveness requirements levied in the system specification.

Preliminary and interim verifications can take the form of analysis using the expected, or demonstrated performance of the weapon system sensors, equipment, and weapons. Final verification should only be accomplished after separation mitigation efforts have concluded, and must involve as many actual weapon drops as possible. The number of bombs dropped, in combination with modeling and/or simulations must ensure statistical confidence in the calculation of the accuracy measures. For final verification, augmenting models and simulations must use as much telemetry information as is feasible and reasonable.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis indicates that accuracy requirements have been decomposed to lower-tier requirements. Analysis indicates that meeting these lower-tier requirements will provide the required air-to-surface accuracy.

PDR: Analysis indicates that preliminary air vehicle design will provide the air-to-surface delivery accuracy defined in table 3.1.9.3. Simulation and analysis of results from lower-level GFE and existing commercial items tests should be used whenever possible. If test data is not available, simulation results or performance requirements should be used.

CDR: Analysis verifies that the air vehicle design will provide the specified air-to-surface delivery accuracy. Simulation and analysis of lower-level test results for GFE and existing commercial items should be used whenever possible. Increasing fidelity of lower-tier test results confirms that air-to-surface accuracy requirements will be met.

FFR: No unique verification action occurs at this milestone.

SVR: A combination of analysis, simulation, and test confirm that the air-to-surface accuracy requirement is met. Some conditions listed in this paragraph cannot be recreated on the test range, and drop testing conducted during those conditions will make scoring and telemetry infeasible. For those conditions, modeling and simulation confirm the air-to surface requirement is satisfied.

Sample Final Verification Criteria

__(1)__ analyses, __(2)__ modeling, and simulation methods using the maximum amount of subsystem test data, and/or __(3)__ flight test with representative or actual munitions confirms compliance with this requirement.

Blank 1. Identify the type and scope of analysis methodology. An example of a valid entry would be "error budget."

Blank 2. Identify the type and scope of the model(s) or simulation(s) that will be used to supplement drop testing.

Blank 3. Identify the minimum number of test drops required for final verification for each weapon. The minimum number of drops should be determined based upon a desired confidence in the resulting accuracy statistics and the predetermined methodology of evaluating test results.

VERIFICATION LESSONS LEARNED (4.1.9.3)

To Be Prepared

3.1.9.4 Weapons selection and release control

The air vehicle shall provide operator selectable control of weapon(s) release. The air vehicle shall have, through operator action, the capability to release weapons in combinations of __(1)__. The air vehicle shall have the ability to select the minimum time interval between weapon releases. The time interval selections available to the aircrew shall range from a value not less than __(2)__, to a value not greater than __(3)__ with selectable increments of __(4)__. The air vehicle shall be capable of translating the stores from a stowed position to launch position within __(5)__.

REQUIREMENT RATIONALE (3.1.9.4)

The ability to control weapon release sequence is crucial to achieving maximum effectiveness. The length and width of the weapon impact patterns (often referred to as a stick) will often be a large factor in maximizing strike effectiveness. Control of the “stick” is a product of time interval between weapon releases as well as the number of bombs ejected per release event.

REQUIREMENT GUIDANCE (3.1.9.4)

Blank 1. Enter the desired release combinations, including releasing individually or all at once. Examples of valid entries would be individually, all at once, 2 at a time, 6 at a time, etc.

Blank 2. Enter the minimum time interval between weapon releases. The time interval is typically stated in units of milliseconds and a valid entry could be 25 milliseconds.

Blank 3. Enter the maximum time interval between weapon releases. This value is typically stated in units of milliseconds, and a valid entry could be 150 milliseconds.

Blank 4. Enter the smallest allowable selectable time increments. Units are typically milliseconds. A valid entry could be 10 milliseconds.

Blank 5. Enter the maximum allowable time for internally stowed weapons to translate to position for release.

If a requirement exists to control the order of weapon release, alter the wording of the first sentence to include this capability. Suggested wording: “The air vehicle shall provide operator selectable control of weapon(s) release, including selection of the order of release.”

REQUIREMENT LESSONS LEARNED (3.1.9.4)

To Be Prepared

4.1.9.4 Weapons selection and release control verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Operator ability to release selected combinations	(1)	A	A	S		S,D, T
Release Interval Timing and Limits	(2), (3), (4)	A	A	S		D
Stow to launch position time	(5)	A	A	S		D,T

*Numbers in parentheses in the Measurand column refer to numbered blanks in the requirement.

VERIFICATION DISCUSSION (4.1.9.4)

Preliminary verifications can take the form of analysis using the expected or demonstrated performance of the weapon system equipment and weapons. Interim verification can use simulation with hardware-in-the-loop, and as much laboratory demonstration as possible. Final verification must be a combination of demonstration and actual weapon drops to ensure that system resources can fulfill the requirements while under operational loads. For rigorous and complex selection and release control requirements, more flight test is necessary.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analysis indicates that weapons selection and release control requirements have been decomposed to lower-tier requirements. Analysis indicates that meeting these lower-tier requirements will provide the required weapons selection and release control.

PDR: Analysis of the preliminary design indicates that the air vehicle will provide the weapons selection and release control defined in table 3.1.9.1. Analyses should use existing simulation and test results for GFE and existing commercial items whenever possible.

CDR: Simulations (i.e., hardware-in-the-loop, pilot-in-the-loop) of air vehicle design indicates that the weapons selection and release control specified in table 3.1.9.1 will be met.

FFR: No unique verification action occurs at this milestone.

SVR: A combination of hardware-in-the-loop simulation, demonstration, and flight test confirm that weapons selection and release control requirements are satisfied. Modeling and simulation used to augment the verification testing for conditions that cannot be recreated on the test range, confirms compliance with this requirement.

Sample Final Verification Criteria

The ability to release the specified weapon combinations shall be verified through __(1)__simulation, __(2)__ demonstration and __(3)__ flight test using the loadouts contained in 3.4.1.2 Weapon and store loadouts. Release interval timing and limits shall be verified through __(4)__ demonstration. The stow position to launch position time requirement shall be verified through __(5)__.

> Blank 1. Identify any specific type and scope of simulation method required. Examples would be “man-in-the-loop” or “hardware-in-the-loop.”
>
> Blank 2. Identify the type and scope of demonstration that should be conducted.
>
> Blank 3. Identify the type and scope of flight tests that should be conducted.
>
> Blank 4. Identify the type and scope of demonstration that should be conducted.
>
> Blank 5. Identify the appropriate verification method. Examples could be “demonstration” or “test.”

VERIFICATION LESSONS LEARNED (4.1.9.4)

To Be Prepared

3.1.9.5 Gun accuracy and control

The guns shall have the accuracy specified in table 3.1.9.5-I. The air vehicle shall have operator selection and control of the number and combinations of guns to be fired, the rate of fire, and burst length. The air vehicle shall have the capability to fire the guns individually, all at one time, and in combinations of __(1)__, through operator selection.

TABLE 3.1.9.5-I. Gun accuracy requirements.

Weapon Type	Accuracy Required	Light Level	Weather	Pitch	Roll	Acceleration	Altitude	Velocity

REQUIREMENT RATIONALE (3.1.9.5)

Gunnery accuracy is a product of the air vehicle avionics, software, displays, mechanization, data, pilot, and guns employed. In other words, gun accuracy is a total air vehicle requirement. Accuracy must be specified with as many applicable parameters as needed to ensure viable verification consistency with the effectiveness requirements levied in the system specification. Cockpit selection may not apply to gunships.

REQUIREMENT GUIDANCE (3.1.9.5)

Blank 1. Enter the selectable combinations required. Further, if guns of a variety of calibers are involved, alter the wording of this requirement to include all gun type combinations needed to meet the lethality requirements of the system specification.

Guidance for completing table 3.1.9.5-I follows:

Appropriate specification of air-to-air gunnery should be in circular error probable (CEP) for various rates of change in relative velocity and rates of change in angular rate of the target.

If target state information is required to properly define accuracy requirements, add two new columns to the table under the title "Target State" with two sub-titles: "Velocity of Target," and "Target Maneuver and Direction."

If target state columns are added to the table, use the following guidance to fill in those columns:

Velocity of Target: Enter the target velocities for which the accuracy requirement must be met. An example entry would be 0-10 miles per hour.

Target Maneuver and Direction: Enter the target maneuver characteristics and direction for which the accuracy requirement must be met.

REQUIREMENT LESSONS LEARNED (3.1.9.5)

To Be Prepared

4.1.9.5 Gun accuracy and control verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Accuracy requirement	CEP	A	A,S	A,S		S,D, T
Gun control	Gun combinations, burst length, rate of fire	A	A,S	A,S		S,D, T

VERIFICATION DISCUSSION (4.1.9.5)

Gun accuracy is a product of the air vehicle avionics, software, displays, mechanization, data, pilot performance, engagement conditions, and the gun system employed. Accuracy must be specified with as many applicable parameters as needed to ensure proper requirement definition and consistency with the effectiveness requirements levied in the system specification.

Preliminary and interim verifications can take the form of analysis and simulation using the expected or demonstrated performance of the weapon system sensors, equipment, and gun systems. Final verification should involve as many actual gun firings as possible. The gun firings, in combination with modeling and/or simulations, must ensure statistical confidence in the calculation of the accuracy measures. For final verification, augmenting models and simulations must use as much telemetry information as is feasible and reasonable.

Gun control requirements should be accomplished through a combination of simulation, demonstration and test.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analysis indicates that gun accuracy and control requirements have been decomposed to lower-tier requirements. Analysis indicates that meeting these lower-tier requirements will provide the required accuracy.

PDR: Analytical predictions indicate that preliminary air vehicle design will provide the gun accuracy and control defined in table 3.1.9.5-I. Simulation and analysis of lower-tier test results indicate that the required accuracy can be attained. If test data were not available, simulation results or performance requirements should have been used.

CDR: Analytical predictions indicate that air vehicle design will provide the gun accuracy and control defined in table 3.1.9.5-I. Analyses and simulations use increased availability of lower-level test results to provide additional fidelity and confidence that the requirement can be met.

FFR: No specific verification action occurs at this milestone.

SVR: A combination of simulation, demonstration, and test verifies that the gun accuracy portion of the requirement is met. If required conditions of 3.1.9.5 can not be recreated on the test range, modeling and simulation is used to augment the verification demonstrations and testing. Whenever possible, man and hardware-in-the-loop simulation methods have been used to the maximum extent for the operational flight program (OFP). Testing confirms that the gun control requirement is met.

Sample Final Verification Criteria

Analysis and simulation methods using the maximum amount of subsystem test data, and/or flight test with a representative gun system, demonstration, and tests confirm air vehicle compliance with this requirement. Analysis methodology, the specific model or simulation, and the minimum number of test firings defined in the table below for each requirement listed in 3.1.9.5 verifies requirement compliance.

Requirement Element(s)	Analysis Method	Model and/or Simulation	Demonstration(s)	Number of Test Firings
Element 1	(1)	(2)	(3)	(4)
Element 2	(1)	(2)	(3)	(4)
Element …	(1)	(2)	(3)	(4)

Blank 1. Identify the scope and type of analysis methodology that will be used, if any. An example of a valid entry would be "error budget."

Blank 2. Identify the scope and type of model(s), or simulation(s) that will be used to supplement demonstrations and testing.

Blank 3. Identify the scope and type of demonstrations that will be used.

Blank 4. Identify the minimum number of test firings for final verification for each requirement. The minimum number of firings should be determined based upon a desired confidence level.

3.1.10 Reserve modes

The air vehicle shall be capable of providing wartime reserve modes as indicated in table 3.1.10-I.

TABLE 3.1.10-I. Reserve modes.

Function/Characteristic	Capability

REQUIREMENT RATIONALE (3.1.10)

Wartime reserve modes are characteristics and operating procedures of sensor, communications, navigation aids, threat recognition, weapons, and countermeasures systems that will contribute to military effectiveness if unknown to or misunderstood by opposing commanders before they are used, but could be exploited or neutralized if known in advance. Wartime reserve modes are deliberately held in reserve for wartime or emergency use and seldom, if ever, applied or intercepted prior to such use.

When the air vehicle has the capability to provide a wartime mission that would not be used during peacetime, such as a unique communications/sensor modes or special weapons capability, each function or characteristic and related capabilities would be denoted and prioritized for installation.

REQUIREMENT GUIDANCE (3.1.10)

The intent of this requirement is to preplan and install, or provide for the essential provisions that will be required for the operation of one or more designated wartime reserve functions or characteristics.

Wartime reserve modes are determined via three primary sources:

a. They can be directed, for example, in the Operational Requirements Document or program direction.

b. They may be interface driven (either directed or derived).

c. They may be the result of translating operational (or other) requirements into air vehicle specific capabilities. That is, during concept exploration and program definition phases, capabilities are identified that are consistent with and support achievement of warfighter requirements but should be held in reserve for wartime use to prevent exploitation by an adversary.

Guidance for completing table 3.1.10-I follows:

Function/Characteristic: Identify the function or characteristic for which a wartime reserve mode capability is required.

When a function is identified, be as explicit as possible to provide limiting guidance to the extent required. When a characteristic is identified, specificity is also important. One dilemma with characteristics is they tend to be associated with specific solutions. This may be unavoidable where characteristics are associated with specific parameters the warfighter has deemed important and with characteristics/capabilities associated with an interfacing item. Characteristics should be tied to a specific requirement in the air vehicle specification or, if appropriate, an attachment to it.

Capability: Describe the capability required. It will likely be necessary to describe capabilities for characteristics in more specific terms than is necessary for a function. For example, the capability for secure intra-flight communication could be expressed in terms of denial of reception of an emission, interpretation of the content, etc. To the extent practicable, provide functional descriptions and performance requirements and avoid the use of specific solutions.

REQUIREMENT LESSONS LEARNED (3.1.10)

To Be Prepared

4.1.10 Reserve modes verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Unique to program	Capability measurement parameter	TBD	TBD	TBD	TBD	TBD

VERIFICATION DISCUSSION (4.1.10)

The above table, as well as the incremental and final verification criteria, is dependent upon what the actual reserved modes are. Some modes can be tested or demonstrated at the air vehicle or subsystem level while, for security reasons, others may only be evaluated through analysis or simulation at the air vehicle or subsystem level. No further guidance can be given on this section.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Unique to program.

PDR: Unique to program.

CDR: Unique to program.

FFR: Unique to program.

SVR: Unique to program.

Sample Final Verification Criteria

Unique to program.

VERIFICATION LESSONS LEARNED (4.1.10)

To Be Prepared

3.1.11 Lower-tier mandated requirements

The air vehicle lower-tier mandated requirements shall be as specified in the following: __(1)__.

REQUIREMENT RATIONALE (3.1.11)

This paragraph accommodates those circumstances in which system technical characteristics have been deemed essential by operational requirements proponents and incorporated in the operational requirements documents. Requirements included in this section are typically derived from air vehicle specification requirements and included in lower-tier specifications, but instead, have been identified as crucial air vehicle characteristics. Sources of such requirements include the Operational Requirements Document (ORD), the Program Management Directive (PMD), and the Acquisition Decision Memorandum (ADM), to name a few. Including these requirements in the Air Vehicle specification is necessary to ensure that all lower-tier requirements can be traced to controlling requirements.

REQUIREMENT GUIDANCE (3.1.11)

This paragraph should not be utilized to invent new requirements but rather to accommodate directed solutions from a higher level authority.

This requirement is typically completed by the Government program office, sometimes in concert with potential contractors.

> Blank 1. Complete with lower-tier mandated requirements. Include any performance solutions mandated by the sources listed in the Rationale paragraph above, but do not

include interface requirements. Provide a paragraph number for each separate requirement.

REQUIREMENT LESSONS LEARNED (3.1.11)

To Be Prepared

4.1.11 Lower-tier mandated requirement verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Mandated requirement 1	Capability measurement parameter	TBD	TBD	TBD	TBD	TBD
Mandated requirement 2	Capability measurement parameter	TBD	TBD	TBD	TBD	TBD
Mandated requirement …	Capability measurement parameter	TBD	TBD	TBD	TBD	TBD

VERIFICATION DISCUSSION (4.1.11)

The above table, as well as the incremental and final verification criteria, are dependent upon what the actual mandated requirements are. In general, the final verification of these requirements should be by test or demonstration at a lower-tier level and should be evaluated at this level by review of verification documentation. No further guidance can be given on this section.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Unique to program.

PDR: Unique to program.

CDR: Unique to program.

FFR: Unique to program.

SVR: Unique to program.

Sample Final Verification Criteria

Unique to program.

VERIFICATION LESSONS LEARNED (4.1.11)

To Be Prepared

3.2 Environment

3.2.1 Electromagnetic environmental effects

The air vehicle shall assure specified performance within the external electromagnetic environment of __(1)__, electromagnetic compatibility among all internal subsystems and equipment in accordance with __(2)__, and freedom from electromagnetic hazards as described in __(3)__.

REQUIREMENT RATIONALE (3.2.1)

The electromagnetic environmental effects (E^3) area addresses a number of interfacing issues with environments both external to the air vehicle and within it. External to the air vehicle are electromagnetic effects such as lightning, electromagnetic pulse (EMP), and man-made radio-frequency (RF) transmissions. Internal to the air vehicle are electromagnetic effects such as electronic noise emissions, self-generated RF transmissions from antennas, and cross coupling of electrical currents. Air vehicles today are complex from a materials usage and electronics standpoint. Many materials being used are nonmetallic and have unique electromagnetic properties that require consideration. Electronics performing critical functions are common. Wide use of RF transmitters, sensitive receivers, other sensors, and additional electronics creates a potential for problems within the air vehicle and from external influences. Increasing use of commercial equipment in unique military operational environments poses special interface considerations. Each air vehicle must be compatible with itself, other systems, and external environments to ensure required performance and to prevent costly redesigns for resolution of problems. Refer to the Appendix of MIL-STD-464 for additional requirement rationale.

REQUIREMENT GUIDANCE (3.2.1)

The air vehicle and all associated subsystems and equipment, including ordnance, need to achieve mutual compatibility and compatibility with the external environment. Every effort needs to be made to meet these requirements during initial design rather than on an after-the-fact basis. Refer to the Appendix of MIL-STD-464 for additional requirement guidance.

The following requirements should be essential factors in satisfying the requirements of blanks 1 through 3: A5.1 of MIL-STD-464 – Margins; A5.9 of MIL-STD-464 - Life Cycle, E^3 Hardness; A5.10 of MIL-STD-464 - Electrical Bonding.

Blank 1. Complete in accordance with the following requirements as applicable: A5.3 of MIL-STD-464 - Inter-system Electromagnetic Compatibility; A5.4 of MIL-STD-464 – Lightning; A5.5 of MIL-STD-464 - Electromagnetic Pulse (EMP); A5.7 of MIL-STD-464 - Electrostatic Charge Control.

Blank 2. Complete in accordance with the following requirements as applicable: A5.2 of MIL-STD-464 - Intra-system Electromagnetic Compatibility; A5.6 of MIL-STD-464 - Subsystems and Equipment Electromagnetic Interference (EMI); A5.7 of MIL-STD-464 - Electrostatic Charge Control.

Blank 3. Complete in accordance with the following MIL-STD-464 requirements as applicable: A.7 of MIL-STD-464 - Electrostatic charge control; A5.8 of MIL-STD-464 - Electromagnetic radiation hazards; A5.11 of MIL-STD-464 - External grounds.

REQUIREMENT LESSONS LEARNED (3.2.1)

The early implementation of E^3 requirements have been instrumental in preventing problems on previous programs. Evolving air vehicle designs regarding changing materials and increasing criticality of electronics demand that effective electromagnetic effects controls be implemented. It is important that all external environments be treated in a single unified approach. Duplication of efforts in different disciplines has occurred in the past. For example, hardening to EMP and lightning-induced transients has been addressed independently rather than as a common threat with different protection measures being implemented for each. This situation is apparently due in part to organizational structures at contractor facilities, which place responsibility in different offices for each of the threats. Refer to the Appendix of MIL-STD-464 for additional requirement lessons learned.

4.2.1 Electromagnetic environmental effects verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Performance within the external electromagnetic environment	(1)	A	A,S	A,S	A,I, D,T	A,I, D,T
Electromagnetic compatibility among all internal subsystems and equipment	(2)	A	A,S	A,S	A,I, D,T	A,I, D,T
Freedom from electromagnetic hazards	(3)	A	A,S	A,S	A,I, D,T	A,I, D,T

*Numbers in parentheses in the Measurand column refer to identical numbers in requirement.

VERIFICATION DISCUSSION (4.2.1)

The three requirement blanks are best treated as an integrated whole. The wide use of military and commercial RF transmitters, sensitive receivers, other sensors, and electronic data processors creates a potential for interference problems within the air vehicle, as well as opportunity to cause hazards to personnel, fuels, and ordnance. Accordingly, verification should include analysis, testing, demonstration and inspections to show that the air vehicle is compatible with all environments and that potential hazards related to the electromagnetic effects are controlled. Verification methods must, to the greatest extent practicable, assess the full range of subsystem/equipment operation during exposure to the most demanding external electromagnetic environment anticipated during air vehicle missions. It is necessary to verify that the internally generated and external electromagnetic environments will not impair the mission of the air vehicle via disruption or damage to its subsystems or equipment.

The selection of test, analysis, demonstration or inspection or some combination to demonstrate a particular requirement is generally dependent on the degree of confidence in the results of the particular method, technical appropriateness, associated costs, and availability of assets. For example, subsystem and equipment-level testing must be accomplished, because analysis tools are not available which will produce credible results.

Analysis and testing often supplement each other. Prior to the availability of hardware, analysis will often be the primary tool being used to ensure that the design incorporates adequate provisions. Testing may then be oriented toward validating the accuracy and appropriateness of the models used. If model confidence is high, testing may then be limited. For example, design of an aircraft for protection against EMP or the indirect effects of lightning has to rely heavily on analysis.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Successful completion of this phase should include a definition of required events, establishment of tailored requirements for sub-elements of the air vehicle based on the overall design concept, and development of a documentation trail for verification (such as electromagnetic effects control procedures). The process of allocating requirements to lower-level elements of the air vehicle should be initiated and should address issues such as EMI requirements for subsystems, electrical bonding and grounding provisions throughout the vehicle, wiring harness design constraints, and potential shielding of volumes.

PDR: Analyses and simulations should be completed that address issues such as transfer functions relating external environments to induced currents on cables, electromagnetic coupling between various antennas on the vehicle, electromagnetic hardening trade-offs, presence and mitigation of any hazards, adequacy of subsystem design controls (such as EMI requirements, bonding, and grounding) and ability of air vehicle subsystems and equipment to function together, without unacceptable levels of internally generated disruption. Requirements allocated to lower-level elements of the air vehicle have been updated based upon the latest design information. Design risks and appropriate courses of action have been identified.

CDR: Refined simulations and analyses as listed for the PDR should be available. Limited testing (such as determinations of cable shield transfer functions, direct-effects lightning tests of structural coupons, and characterization of material properties) to reduce risk and validate analyses should be completed.

FFR: EMI qualification testing of equipment and subsystems should be complete. At the air vehicle level, a safety-of-flight intra-system electromagnetic compatibility evaluation must be completed and the air vehicle must be cleared for lightning and external RF environments, or appropriate flight restrictions should be imposed. Testing, analysis, demonstrations, and inspections to verify control of any potential electromagnetic hazards should be complete.

SVR: The overall verification process consisting of an accumulated audit trail of analyses, tests, demonstrations, and inspections that establish compliance with requirements for all subsystems and equipment installed must be completed.

Sample Final Verification Criteria

Operation within the electromagnetic environment shall be verified during EMD when __(1)__ indicate acceptable performance within the external electromagnetic environment; when __(2)__ indicate safety-critical functions are electromagnetically compatible within the system, including compatibility among all internal subsystems; and, when __(3)__ indicate freedom from electromagnetic hazards.

> Blanks 1 - 3. Specify test, analyses, simulations, demonstrations, or inspections, or a combination thereof, as appropriate for the requirement/requirement element in accordance with MIL-STD-464.

The selection of test, analysis, simulation, demonstration or inspection or some combination to verify a particular requirement or requirement element is generally dependent on the degree of confidence in the results of the particular method, technical appropriateness, associated costs, and availability of assets. For example, subsystem and equipment-level testing must be accomplished, because analysis tools are not available which will produce credible results.

VERIFICATION LESSONS LEARNED (4.2.1)

Without specific design and verification requirements, problems caused by the external electromagnetic environment are not discovered until the air vehicle becomes operational. By that time, the air vehicle can be well into production, and changes will be expensive. In the past, onboard RF subsystems of the air vehicle produced the controlling electromagnetic environment; however, with external transmitter power levels increasing, external transmitters can drive the overall system environment. The nonmetallic (composite) skins used on most aircraft provide relatively less shielding than metallic skins against electromagnetic fields at frequencies below approximately 100 MHz, and against lightning. These effects have become important due to the increased use of electrically- and electronically-controlled flight and engine systems. The use of nonmetallic materials for parts such as fuel tanks and aircraft wings also introduces the need for specific tests for lightning-induced sparking and arcing in these members; most aircraft lost to lightning have been lost as a result of fuel tank arcing and explosion.

The limits specified in MIL-STD-464 are empirically derived levels that cover most configurations and environments; however, they may not be sufficient to guarantee system compatibility. Tailoring needs to be considered for the peculiarities of the intended installation. When appropriate controls are implemented (such as hardening, EMI requirements on subsystems and equipment, and good grounding and bonding practices), there are relatively few intra-system EMC problems found.

It has been firmly established that sufficiently high electromagnetic fields can harm personnel, ignite fuel, and fire electrically initiated devices. Multiple emitters may be present. Even when overall field strength is below hazardous levels, resonance and reflections may create “hot spots." In addition, ignitions of ordnance and fuel vapors, injury to personnel, and damage to electronics have all occurred from static discharges. The physical arrangement of structural components and the design of electrical systems may have interrelated effects that may not be seen until tested in their final configuration.

Historically, failure to adequately verify system performance in an operational Electromagnetic Environment (EME) has resulted in costly delays during system development, mission aborts, and reduced system and equipment operational effectiveness. It is important that assets required for verification of E^3 requirements be identified early in the program to ensure their availability when needed.

3.2.2 Natural climate

The air vehicle shall achieve full operational performance during and after experiencing the worldwide surface and air natural climate environments of __(1)__.

REQUIREMENT RATIONALE (3.2.2)

Air vehicles have to be capable of operating in the natural environments associated with primary and secondary land based and sea based missions.

REQUIREMENT GUIDANCE (3.2.2)

Blank 1. The natural environment requirements should be specified using MIL-HDBK-310 as a guide, except that the air vehicle maximum operating altitude should be used in lieu of MIL-HDBK-310 maximum altitude of 80 km (262,000 ft). The natural climate proposed should consist of the conditions described below and the combinations mentioned in MIL-HDBK-310. (Each environmental condition should be evaluated to determine if the air vehicle must withstand the condition and/or be subjected to that condition throughout its service life.)

a. Temperature - See table below and figure 3.2.2-1

(1) Ground operation high temperature withstand. 120°F (MIL-HDBK-310, 1 percent extreme).

(2) Ground operation low temperature withstand. –60°F (MIL-HDBK-310, 20 percent extreme).

(3) Flight operation high temperature. (MIL-HDBK-310, 1 percent extreme).

(4) Low temperature flight operation. When subjected to ____ degrees C at any altitude above ____ feet MSL in an airborne condition, the vehicle shall retain the performance specified herein with out loss of aircraft life. (MIL-HDBK-310, 1 percent extreme).

(5) Temperature cycles. The air vehicle shall deliver the performance herein specified over the course of the intended service life when subjected to the temperature cycles resulting from the convolution of the natural environments with the mission profiles applicable to expected vehicle operating locations.

b. Humidity - See table below and figure 3.2.2-1

(1) Ground operation humidity. (1 percent extreme of figure 3.2.2-1.)

(2) Flight operation humidity. (MIL-HDBK-310, 1 percent extreme, but not to exceed the limits of figure 3.2.2-1, 1 percent extreme.)

c. Wind speed

d. Rainfall rate

(1) Ground operation rainfall rate. (MIL-HDBK-310, 0.5 percent extreme.)

(2) Flight operation rainfall rate. (MIL-HDBK-310, 0.5 percent extreme.)

e. Blowing snow

f. Snowload

g. Ice Accretion (Icing conditions. As defined by figures 3.2.2-2 and 3.2.2-3.)

h. Atmospheric pressure

i. Pressure altitudes from 1,300 feet below sea level to the operational ceiling of the vehicle.

j. Atmospheric density

k. Ozone concentration

l. Freeze-thaw cycles

m. Salt spray - Protection against sea salt fallout of at least 27 kilograms per hour per year shall be provided.

n. Salt fog - The air vehicle, when subjected to salt fog exposures of duration and frequency expected during the lifetime when operated and deployed as defined in 3.1, shall not incur degradation of the functional performance specified herein. Use MIL-HDBK-310 and MIL-STD-810 as guides.

o. Fungus - Fungus types for operation and stowage shall be in accordance with MIL-STD-810.

p. Solar radiation intensity. As defined by figure 3.2.2-4.

q. Sea state

r. Hail

s. Birdstrikes of less than XX lbs at an air vehicle velocity of YY

(The above Arabic numeral subparagraphs under the alphabetical paragraphs are values recommended for unlimited, worldwide usage.)

Relative joint frequency (for percent of time, multiply by 100) with which joint values of high temperature and high dewpoint equal or exceed given threshold values:

	Dt (°F)									
Tt (°F)	45.0	47.5	50.0	52.5	55.0	57.5	60.0	62.5	65.0	67.5
118	.00984	.00970	.00950	.00920	.00890	.00850	.00810	.00750	.00680	.00610
113	.089	.088	.087	.085	.081	.077	.072	.065	.059	.053
108	.267	.261	.253	.243	.230	.216	.198	.180	.157	.136
103	.160	.126	.100	.069	.035	.018	.0094	.0045	.00074	.000014
98	.212	.165	.128	.088	.047	.027	.014	.0069	.0014	.000027
93	.253	.192	.146	.101	.057	.033	.017	.0078	.0016	.000076
88	.288	.214	.162	.115	.069	.043	.022	.0092	.0016	.000076
83	.321	.239	.183	.131	.080	.048	.023	.0092	.0016	.000076

Note: Tt = Dry Temperature, Dt = Dew Point.

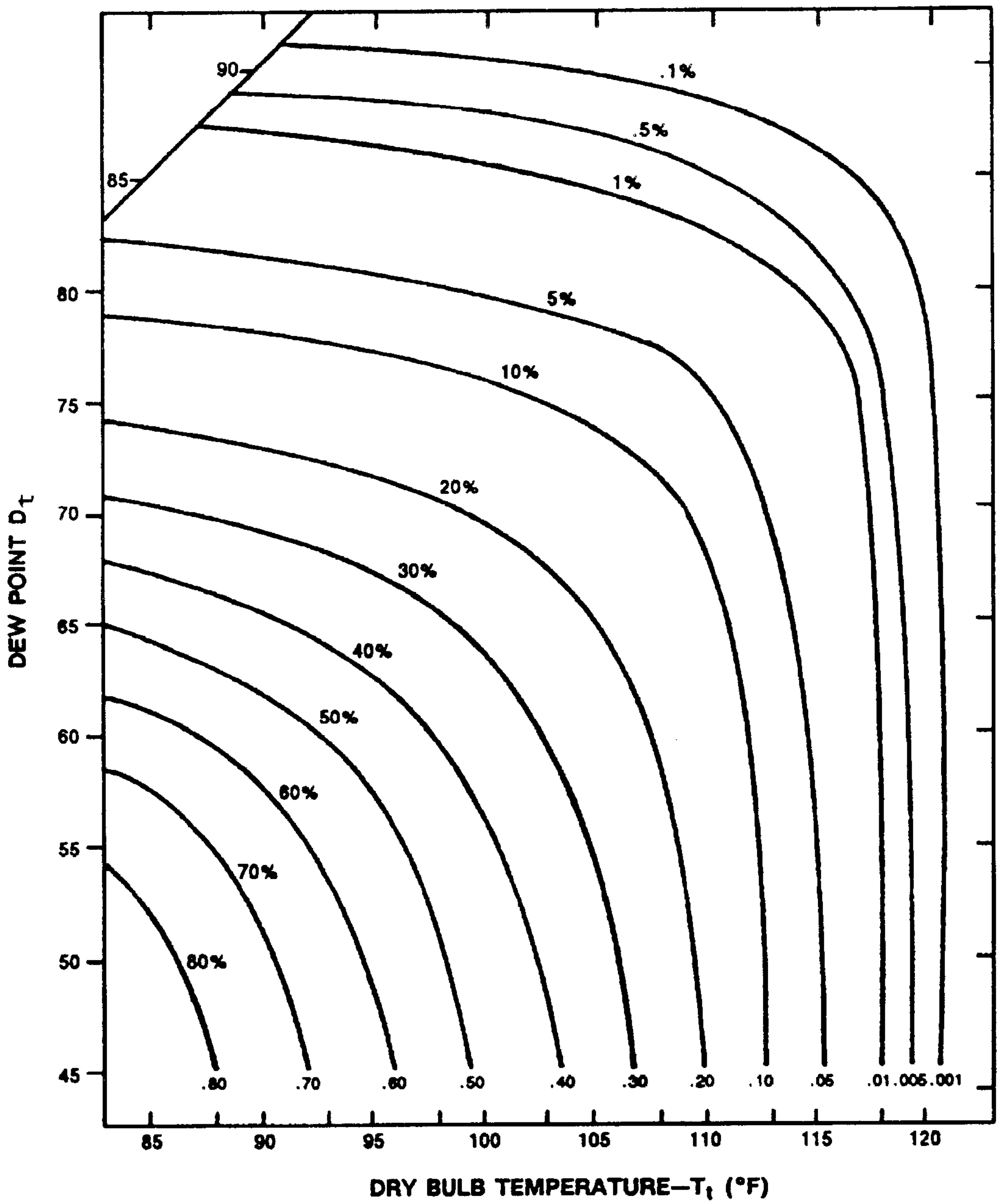


FIGURE 3.2.2-1. Joint values of high temperature and high humidity.

Joint values of high temperature (to 120° F) and high humidity which are equaled or exceeded 0.1, 0.5, 1, 5, 10, 20, 30, 40, 50, 60, 70, and 80 percent of the time (hr) of the most severe month in the world's severest joint high-temperature, high-humidity environment.

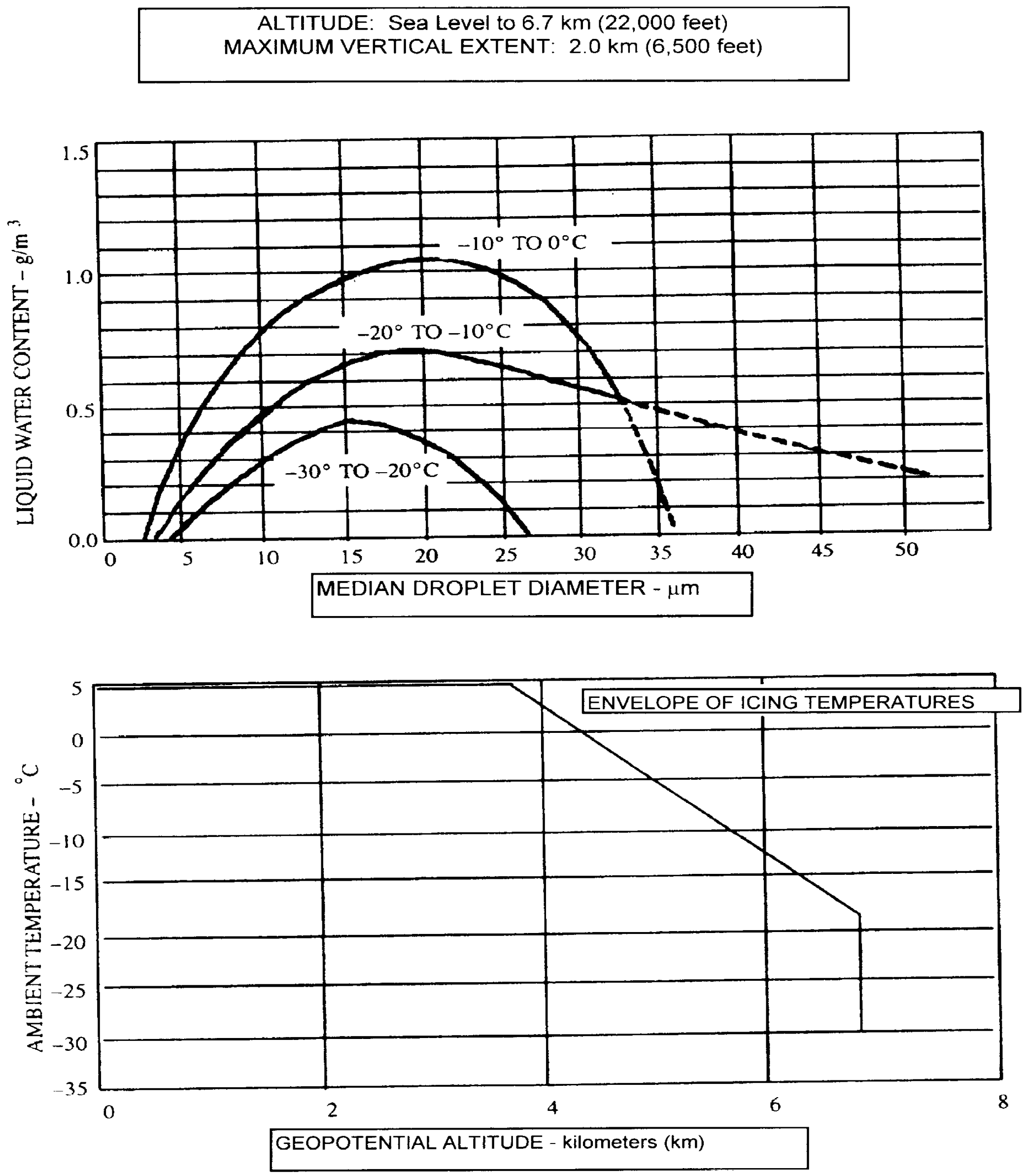


FIGURE 3.2.2-2. Continuous maximum icing conditions.

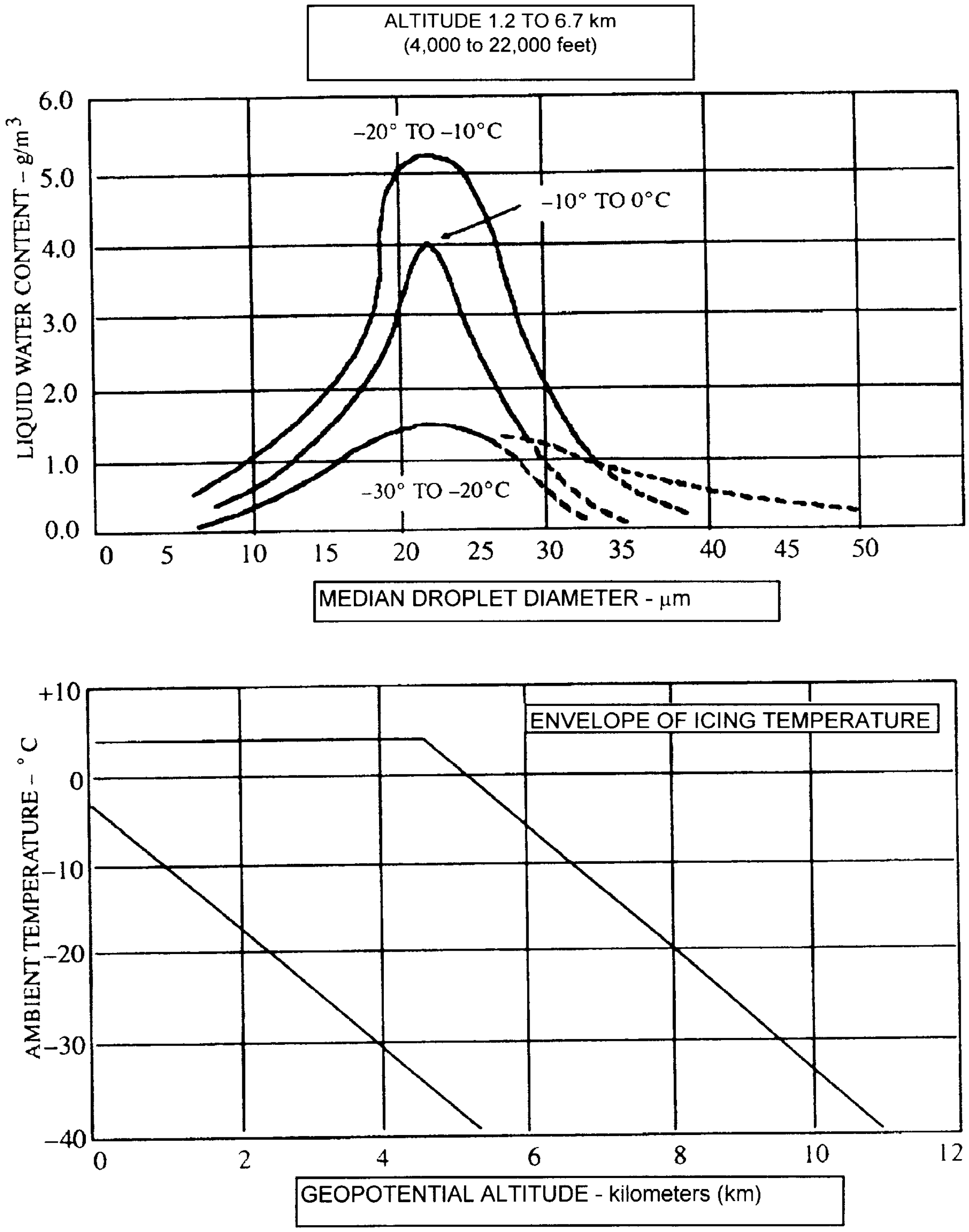


FIGURE 3.2.2-3. Intermittent maximum icing conditions.

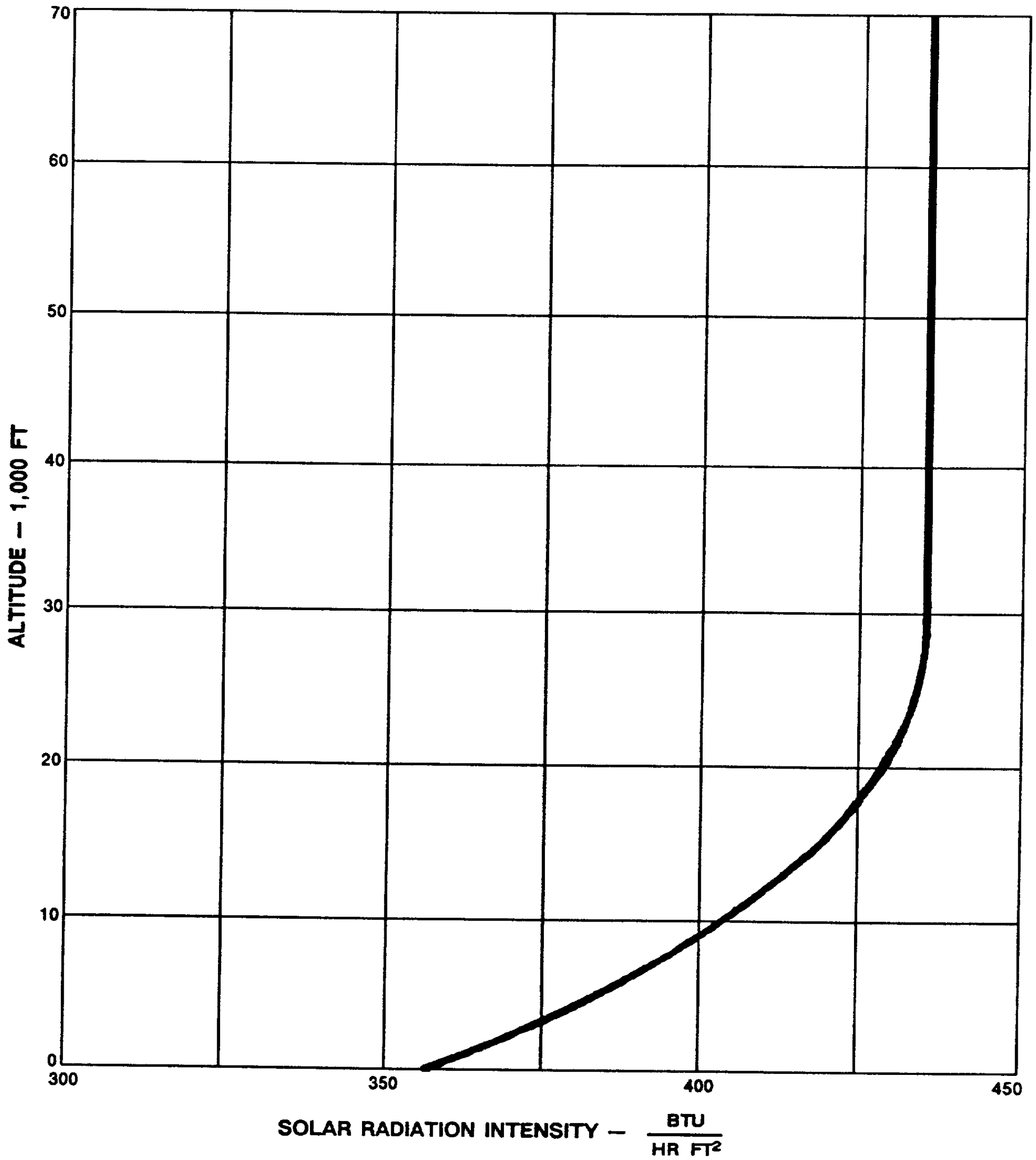


FIGURE 3.2.2-4. Solar radiation intensity versus altitude.

REQUIREMENT LESSONS LEARNED (3.2.2)

The worldwide surface and air temperature environments of MIL-HDBK-310 are not suitable for use in specifying the high temperature design environment for locations where the terrain level differs significantly from sea level. For those cases, use the temperatures shown in MIL-HDBK-310 for terrain elevations up to 15,000 feet.

4.2.2 Natural climate verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Requirement element(s) to be verified as part of other performance requirement verifications						
Full operational performance in worldwide surface and air natural climate environments	Performance characteristics specified in other air vehicle performance requirement paragraphs	A	A	A	A	A
Requirement element(s) to be verified as part of paragraph 3.2.2 performance requirement verification						
Performance in specified temperatures chosen from MIL-HDBK-310 and figure 3.2.2-1	Performance characteristics specified in 3.2.2	A	A,S	A,S	A,T	A,T
Performance in specified humidity chosen from MIL-HDBK-310	Performance characteristics specified in 3.2.2	A	A	A	A	A
Performance in specified wind chosen from MIL-HDBK-310	Performance characteristics specified in 3.2.2	A	A,S	A,S	A,S	T
Performance in specified rainfall chosen from MIL-HDBK-310	Performance characteristics specified in 3.2.2	A	A,S	A,S	A,S	T
Performance in specified blowing snow chosen from MIL-HDBK-310	Performance characteristics specified in 3.2.2	A	A,S	A,S	A,S	S,T
Performance in specified snow loading chosen from MIL-HDBK-310	Performance characteristics specified in 3.2.2	A	A	A	A,S	A,S
Performance in specified ice accretion chosen from MIL-HDBK-310 and figures 3.2.2-2 and 3.2.2-3	Performance characteristics specified in 3.2.2	A	A	A,S	A,S	A,S, T
Performance in specified atmospheric pressure chosen from MIL-HDBK-310	Performance characteristics specified in 3.2.2	A	A,S	A,S	A,S	T
Performance in specified atmospheric density chosen from MIL-HDBK-310	Performance characteristics specified in 3.2.2	A	A,S	A,S	A,S	T

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Performance in specified ozone concentrations chosen from MIL-HDBK-310	Performance characteristics specified in 3.2.2	A	A	A	A	A
Performance in specified freeze-thaw cycles chosen from MIL-HDBK-310	Performance characteristics specified in 3.2.2	A	A	A	A,T	A,T
Performance in specified salt spray	Performance characteristics specified in 3.2.2	A	A	A	A,T	A,T
Performance in specified salt fog chosen from MIL-HDBK-310 and MIL-STD-810	Performance characteristics specified in 3.2.2	A	A	A	A,T	A,T
Performance in specified fungus chosen from MIL-STD-810	Performance characteristics specified in 3.2.2	A	A	A	A	A
Performance in specified solar radiation as shown in figure 3.2.2-4	Performance characteristics specified in 3.2.2	A	A	A	A,T	A,T
Performance during specified sea state	Performance characteristics specified in 3.2.2	A	A,S	A,S	S,T	S,T
Performance in specified hail chosen from MIL-HDBK-310	Performance characteristics specified in 3.2.2	A	A	A,S	A,S	A,S, T
Performance after sustaining specified bird strike	Performance characteristics specified in 3.2.2	A	A	A,S	A,S	A,S, T

VERIFICATION DISCUSSION (4.2.2)

This requirement provides condition information that must be considered in developing all air vehicle performance requirements and verifications. In the event that natural climate conditions are defined or modified in other specific section 3 air vehicle performance requirements, the text of said specific requirements should take precedence over this requirement for that particular performance. Therefore, the verification approach defined below assumes that some of the air vehicle performance in specific natural climate environments should be verified via the specific performance requirements. However, there will be natural climate environmental requirements that are best verified via this requirements paragraph. For example, verification of air vehicle performance while exposed to a specific rainfall rate should be verified as a unique verification effort. Conversely, verification that the air vehicle achieves air-to-surface lethality requirements under certain environmental conditions should be addressed in the air-to-surface lethality verification.

<u>Requirement element(s) to be verified as part of other performance requirement verifications</u>

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements to be verified as part of other performance requirement verifications.)

SRR/SFR: Natural climate conditions, requirements are defined and analyzed for the specified operations, missions, and service life usage profile. Analysis should define the life cycle model, which reflects natural climates, including any combinations expected to occur.

PDR: Analysis indicates all natural climateal conditions and data are finalized, and that the initial design requirements incorporate natural climate considerations.

CDR: Design requirements incorporate natural climate considerations.

FFR: Natural climate conditions have been appropriately (consistent application technique) applied to the air vehicle verifications.

SVR: Natural climate conditions have been appropriately (consistent application technique) applied to the air vehicle verifications.

Sample Final Verification Criteria

Analysis of verification criteria for each air vehicle performance requirement specified herein confirms that the natural climate requirements have been applied in defining the specific environmental requirements, conditions for each air vehicle performance requirement.

<u>Requirement element(s) to be verified as part of 3.2.2 performance requirement verification</u>

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements to be verified as part of other performance requirement verifications.)

SRR/SFR: Natural climate conditions, requirements are defined and analyzed for the specified operations, missions, and service life usage profile. Analysis should define the life cycle model, which reflects natural climates, including any combinations expected to occur.

PDR: Natural environmental conditions, data are finalized. Initial design requirements incorporate natural environment considerations to include air vehicle performance when exposed to the specific environmental conditions specified in section 3.2.2 Natural climate. Initial models and simulations include the environmental conditions specified in section 3.2.2 Natural climate.

CDR: Design requirements incorporate natural environment considerations to include air vehicle performance when exposed to the specific environmental conditions specified. Models and simulations include the environmental conditions specified. Utilize models to simulate performance of air vehicle when exposed to environmental conditions specified. Review results from lower-level demonstrations, tests to confirm that the performance of air vehicle subsystems in the natural environments specified will not degrade the air vehicle performance.

FFR: Data available at CDR is available for analysis and review, and that the air vehicle test plan is complete to include verification of the air vehicle's performance when exposed to applicable natural environments.

SVR: Analyses, simulation and air vehicle and subsystem test results verify specified air vehicle performance when exposed to the applicable natural environments.

Sample Final Verification Criteria

Note: Currently, the JSSG section 3.2.2 Natural climate does not include detailed guidance on creating unique air vehicle environmental performance requirements. Creation of a sample final verification criteria statement for the environmental requirements to be verified via this paragraph requires the presence of a more definitive requirements statement. To assist the document user in understanding the sample final verification criteria, a more definitive sample requirement under section 3.2.2 Natural climate is provided as an example:

Ground operation low temperature withstand (sample requirement).

After __(1)__ hours of exposure to minus __(2)__subsequent to reaching air vehicle temperature in equilibrium with ambient, the air vehicle shall be capable of starting and, within __(3)__ minutes, be capable of launch (takeoff), with full mission capability, without use of external utilities or support equipment.

> Blank 1. Identify the duration of the cold soak time period.
>
> Blank 2. Identify the temperature for the cold soak.
>
> Blank 3. Identify the time period that may elapse before the air vehicle is capable of launch.

A sample final verification statement corresponding to the above sample follows:

The requirement for ground operation, low temperature withstand shall be verified by test. A production configuration air vehicle shall be subjected to at least __(1)__ hours of cold soak after the core temperature reaches __(2)__ in a suitable environmental chamber. Subsequent to the cold soak period, the air vehicle start shall be initiated and time to achieve fully operational condition determined. The chamber shall maintain the ambient __(3)__ condition throughout the start process. The test article shall be instrumented as required to measure and record the core temperature and elapsed time. Acceptance that the air vehicle meets the specified performance shall be determined by measuring elapsed time between initiation of the start process and ready to launch condition of less than __(4)__ minutes.

> Blank 1. Specify the time period required to satisfy the verification of this element.
>
> Blank 2. Indicate the core temperature to be obtained during test.
>
> Blank 3. Specify ambient conditions for the post cold soak start.
>
> Blank 4. Specify the maximum time period allowed.

VERIFICATION LESSONS LEARNED (4.2.2)

The worldwide surface and air temperature air environments of MIL-HDBK-310 are not suitable for use in specifying the high temperature design environment for locations where the terrain level differs significantly from sea level. For those cases, the temperatures, shown in MIL-HDBK-310 for terrain elevations up to 15,000 feet should be used for verification.

Observations of wind speed are one of the least standardized of all meteorological elements. The exposure and height above the ground of wind-measuring equipment is not well standardized. Because wind speeds near the ground can vary significantly with height and exposure, specifying this variability is an important problem. Another problem, the interval over which wind speeds are averaged, varies from country to country. The current standard averaging period in the United States, one minute, is considered representative of the values referred to as the “average or steady wind.” Gusts associated with steady wind speeds must also be considered.

The effects of blowing snow are primarily dependent on mass flux and the shape, size, and hardness of the snow particles. Mass flux is defined as the mass of snow moving horizontally (or parallel to the ground) across a unit area per unit time; e.g., grams per square meter per second. The highest mass fluxes occur near the ground and decrease significantly with increasing height. However, substantial fluxes occur up to about 10 meters. This is the primary reason design values should be based on the height of the air vehicle.

Snow that accumulates on the air vehicle will impose a structural load on the supporting surfaces of the air vehicle. The magnitude of the load depends not only on snowfall accumulations and densities but also on the configuration of the receiving surface and on whether or not snow is typically allowed to accumulate. Measurements of snow loads on air vehicles are not normally available; therefore, the snow load values must be estimated based on ground surface snow accumulations. Such estimates are difficult to make and are subject to large errors; however, snow loads on the air vehicle will usually be much less than on the ground. The air vehicle is most closely defined as “temporary equipment” in MIL-HDBK-310 and can be clear of snow between storms. The load for this type of equipment is based on snowfalls resulting from storms that last longer than 24 hours. Snow loads recommended for use in design of the air vehicle, using MIL-HDBK-310 as guidance, would be expected to occur one year in ten at the worst nonmountainous areas in the world. They are based on data obtained for stations located in the United States and Canada. The values presented are based on ground snow loads from nonmountainous areas converted to loads on horizontal and exposed surfaces of the equipment over which the wind flow is unimpeded and unobstructed. This is the basis of using the guidance standards stated in the discussion paragraph above for snow loads.

Ice accretion can be a major destructive force to the air vehicle. Modeling and simulation plans should include consideration of the three basic kinds of ice formed by accretion in the atmosphere: glaze, hard rime, and soft rime. Also, strong winds are frequently associated with icing, occurring during its formation or after it has formed but before melting. For modeling air vehicle ground operations, the forces of such winds should be added to forces due to ice accretions part of the stress loads in verifying the air vehicle performance.

The lowest density to which the air vehicle may be subjected is a function primarily of altitude. As discussed in MIL-HDBK-310 the highest altitude contemplated for military operations is 15,000 feet. This figure is used to determine low-density extremes for this and lower elevations in MIL-HDBK-310. Low air density greatly affects aircraft aerodynamic and engine performance. The density of the air near the ground is especially important in aircraft design since the lower the density, the longer the takeoff roll required by fixed-wing air vehicles and the less weight a rotary-wing air vehicle can lift. Concurrent temperature also has an important secondary effect and is necessary for a thorough analysis of engine performance.

In unpolluted atmospheres, ozone generally attains highest concentrations between 12 and 18 km altitude at about 60 to 70 degrees latitude. At most altitudes, maximum concentrations occur during spring, and minimum concentrations occur in the winter. At low elevations, there is often a well-defined daily cycle with the highest values occurring during mid-day to late afternoon.

Ozone is constantly being created and destroyed in the atmosphere, and it moves from one place to another by force of gravity and various circulation mechanisms.

A freeze-thaw cycle occurs at a specific site on any day the temperature crosses the freezing mark. It is possible for more than one freeze-thaw cycle to occur at any site during a 24-hour period; however, because of the normal control of the daily temperature cycle by the solar cycle, this is not a common occurrence. Therefore, freeze-thaw cycles are described by the number of days in which they occur. Freeze-thaw is an important consideration in the design of the air vehicle due to the alternate expansion and contraction effects on the air vehicle materials.

Estimating the point probabilities of hail sizes aloft requires considerable inference based on limited objective data. The estimated probabilities of encountering hail at all altitudes were found to be quite low and should not be of concern for vertically rising air vehicles unless life is endangered. However, the probability of encountering hail while horizontally traversing the atmosphere (for distances greater than 200 miles) in the worst areas for hail occurrences is considerably greater. These frequencies are estimated by using a statistical model that relates spatial and lineal probabilities of a climatic event to its single-point probability.

3.2.3 Induced environment

The air vehicle shall meet its performance requirements while operating in the induced (nonthreat) environments of __(1)__.

REQUIREMENT RATIONALE (3.2.3)

The intent of this requirement is to assure that the air vehicle, subsystems and equipment are compatible with induced environmental conditions.

REQUIREMENT GUIDANCE (3.2.3)

Blank 1. The nonthreat induced environment requirements listed in blank 1 should be specified using the following listing and MIL-STD-810 as guides. For the threat-induced environment, see 3.1.8 Survivability.

a. Loading effects consist of the following and natural combinations thereof, such as:

(1) shock;

(2) vibration (e.g., self induced, engine, gun induced);

(3) catapult launches;

(4) arrested landings;

(5) aerodynamic and aeroacoustic loadings;

(6) heating and cooling to include thermal interface effects and thermal zoning;

(7) usage generated, such as climatic shock, taxiing, flight, and landing;

(8) maintenance generated, such as handling;

(9) man made, such as transportation;

(10) power cycling, power interruptions;

(11) noise (e.g., engine induced);

(12) foreign object damage (FOD); and

(13) other induced environments that are mission or performance related, to include interface effects of stores loading.

b. Corrosion effects consist of the following and natural combinations thereof:

(1) acidic moisture films, shipboard (e.g., sulfur and nitrogen oxide containing gases from ship stacks);

(2) acidic and corrosive atmosphere, air vehicle exhaust (for example, air vehicle exhaust combined with 3.5 percent sodium chloride sea spray to form highly acidic moisture films of pH 2.4 - 4.0;

(3) chemicals; and

(4) contaminants (e.g., relative humidity of 70 percent to 100 percent conditions exist simultaneously with sand and dust particle concentrations ranging from 1.32 x 10-4 to 4.0 x 10-6 pounds (lbs) per ft^3.

c. Fuel spray

The induced environments should be characterized for both steady-state and transient conditions for each critical point in the life cycle environmental profile and flight envelope. Particular attention should be directed at transient conditions, power cycling, vibration, and thermal stresses that occur on start-up, dwell, cycling, and shutdown.

REQUIREMENT LESSONS LEARNED (3.2.3)

Experience in recovery from spins, hard landings, and arrested landings in one type aircraft shows the tested acceleration and shock limits (MIL-STD-810) were exceeded. After one incident, a method of postflight inspection had to be instituted to ensure there was no damage to the mechanical equipment (rotating, values). The limits of MIL-STD-810 may have to be adjusted to meet the air vehicle requirements. Gunfire (pod) environment (especially vibration) may have to be adjusted upward to meet the air vehicle requirement since this environment is generally higher.

4.2.3 Induced environment verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Requirement element(s) to be verified as part of other performance requirement verifications						
Operational performance in induced environments	Performance characteristics specified in other air vehicle performance requirement paragraphs	A	A	A	A	A
Requirement element(s) to be verified as part of paragraph 3.2.2 performance requirement verification						
Performance in shock environments specified in 3.2.3	Performance characteristics specified in 3.2.3	A	A	A	A,T	A,T
Performance in vibration environments specified in 3.2.3	Performance characteristics specified in 3.2.3	A	A	A	A,T	A,T

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Performance in catapult launch environments specified in 3.2.3	Performance characteristics specified in 3.2.3	A	A	A	A	T
Performance in arrested landing environments specified in 3.2.3	Performance characteristics specified in 3.2.3	A	A	A	A	T
Performance in transportation environments specified in 3.2.3	Performance characteristics specified in 3.2.3	A	A	A	A	T
Performance in aerodynamic and acoustic loading environments specified in 3.2.3	Performance characteristics specified in 3.2.3	A	A	A	A	A,T
Performance in thermal environments specified in 3.2.3	Performance characteristics specified in 3.2.3	A	A	A	A,T	A,T
Performance in climatic shock environments specified in 3.2.3	Performance characteristics specified in 3.2.3	A	A	A	A,T	A,T
Performance in maintenance handling environments specified in 3.2.3	Performance characteristics specified in 3.2.3	A	A	A	A	T
Performance in power cycling, interruptions environments specified in 3.2.3	Performance characteristics specified in 3.2.3	A	A	A	A	A,T
Performance in induced noise environments specified in 3.2.3	Performance characteristics specified in 3.2.3	A	A	A	A,T	A,T
Performance in foreign object damage environments specified in 3.2.3	Performance characteristics specified in 3.2.3	A	A	A	A	A
Performance in stores interface environments specified in 3.2.3	Performance characteristics specified in 3.2.3	A	A	A	A,T	A,T
Performance in corrosion environments specified in 3.2.3	Performance characteristics specified in 3.2.3	A	A	A	A,T	A,T
Performance in fuel spray environments specified in 3.2.3	Performance characteristics specified in 3.2.3	A	A	A	A,T	A,T

VERIFICATION DISCUSSION (4.2.3)

This requirement provides condition information that must be considered in developing all air vehicle performance requirements and verifications. In the event that induced environmental requirements are defined or modified in other specific air vehicle performance requirements, the text of said specific requirements should take precedence over this requirement for that particular performance. Therefore, the verification approach defined below assumes that some of the air vehicle performance in specific induced environments will be verified via the specific performance requirements. However, there will be induced environmental requirements that are best verified via this requirements paragraph. For example, verification of air vehicle performance while exposed to a specific fuel spray should be verified as a unique verification effort. Conversely, verification that the air vehicle achieves service life requirements under certain induced environmental conditions should be addressed in the service life verification.

Requirement element(s) to be verified as part of other performance requirement verifications.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements to be verified as part of other performance requirement verifications.)

SRR/SFR: Induced environmental conditions/requirements are defined and analyzed for the specified operations, missions, and service life usage profile. Analysis should define the life cycle model, which reflects induced environments, including any combinations expected to occur.

PDR: Induced environmental conditions/data are finalized. Initial design requirements incorporate induced environment considerations.

CDR: Design requirements incorporate induced environmental considerations.

FFR: Induced environmental conditions have been appropriately (consistent application technique) applied to the air vehicle verifications.

SVR: Induced environmental conditions have been appropriately (consistent application technique) applied to the air vehicle verifications.

Sample Final Verification Criteria

Analysis of verification criteria for each air vehicle performance requirement specified herein confirms that the induced environment requirements have been applied in defining the specific environmental requirements/conditions for each air vehicle performance requirement.

Requirement element(s) to be verified as part of 3.2.2 performance requirement verification.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements to be verified as part of requirement verification.)

SRR/SFR: Induced environmental conditions/requirements are defined and analyzed for the specified operations, missions, and service life usage profile. Analysis should define the life cycle model, which reflects induced environments, including any combinations expected to occur.

PDR: Induced environmental conditions/data are finalized. Initial design requirements incorporate induced environment considerations to include air vehicle performance when exposed to the specific environmental conditions specified in section 3.2.3 Induced environment. Initial models include the environmental conditions specified in section 3.2.3 Induced environment.

CDR: Design requirements incorporate induced environment considerations to include air vehicle performance when exposed to the specific environmental conditions specified. Models include the environmental conditions specified. Utilize models to simulate performance of air vehicle when exposed to environmental conditions specified. Review results from lower-level demonstrations/tests to confirm that the performance of air vehicle subsystems in the induced environments specified will not degrade the air vehicle performance.

FFR: Data available at CDR is available for analysis and review, and that the air vehicle test plan is complete to include verification of the air vehicle's performance when exposed applicable induced environments. Test results confirm air vehicle performance in the induced environments expected to be encountered during the flight test program will not degrade safety of flight. Lower-level-test results confirm air vehicle performance in the induced environments specified.

SVR: Analyses and air vehicle and subsystem test results verify specified air vehicle performance when exposed to the applicable induced environments.

Sample Final Verification Criteria

Note 1: Test methodologies and induced environmental parameters for many of the above requirements are addressed in MIL-STD-810. Therefore, the specification preparers should refer to MIL-STD-810 when determining the induced environmental levels and the methods for verifying compliance with induced environmental requirements.

Note 2: Currently, the JSSG section 3.2.3 Induced environment does not include detailed guidance on creating unique air vehicle induced environmental performance requirements. Creation of a sample final verification criteria statement for the induced environmental requirements to be verified via this paragraph requires the presence of a more definitive requirements statement. To assist the document user in understanding the sample final verification criteria, a more definitive sample requirement under section 3.2.3 Induced environment is provided as an example:

Performance in fuel spray (Sample requirement).

Air vehicle performance, during and after exposure to __(1)__ fuel spray, shall not be degraded.

> Blank 1. Indicate the maximum anticipated spillage. Current spillage criterion for probe nozzles/couplings (component qualification) is 100 cc (MIL-C-81975) and for boom nozzle/receptacles is 75 cc.

A sample final verification criteria corresponding to the above sample follows:

Fuel spray requirement shall be verified by__(1)__. A production configuration air vehicle shall be subjected to at least __(2)__ fuel spray for a duration of __(3)__. Air vehicle engine operations shall be monitored to confirm no degradation in engine performance.

Blank 1. Specify analysis, lab tests, ground tests, and/or flight tests, including scope, confidence level and/or fidelity.

Blank 2. Specify the maximum anticipated spillage.

Blank 3. Specify the duration of the fuel spray.

VERIFICATION LESSONS LEARNED (4.2.3)

To Be Prepared

3.2.4 Performance limiting environmental conditions

The air vehicle shall withstand the environmental conditions listed in table 3.2.4-I, occurring at any point in the air vehicle service life, with performance degradation not greater than specified herein.

TABLE 3.2.4-I. Performance-limiting environmental conditions.

Environment Condition	Frequency	Duration	Performance Limitation	Remarks

REQUIREMENT RATIONALE (3.2.4)

This requirement establishes the environmental conditions, which the air vehicle may encounter in its operational life and is expected to withstand such environment with limited performance. This requirement can be utilized for limiting performance in both natural and induced environments.

REQUIREMENT GUIDANCE (3.2.4)

This paragraph should be utilized to specify environmental conditions in which degraded air vehicle performance is acceptable. However, other 3.x performance requirements may include limiting environmental conditions as well. In those cases, it is not necessary to repeat the performance limitation in this paragraph. This paragraph should be utilized only in cases in which the performance limitation cannot be defined in a specific 3.x paragraph.

Guidance for completing table 3.2.4-I follows:

Environment Condition: Identify environmental conditions under which the air vehicle may reasonably be expected to degrade the system’s ability to meet requirements. Care should be taken to ensure that limited capabilities are only for the duration of the exposure to the environmental condition.

Frequency: Identify the frequency (e.g., occurrences per year) that the limiting environmental condition will be expected to occur.

Duration: Identify the duration that the air vehicle will be exposed to the limiting environmental conditions, e.g., 30 minutes of a specific temperature extreme or flight in extreme weather conditions.

Performance Limitation: Identify the performance requirement relaxation that will be permitted when the air vehicle is exposed to the limiting environmental condition, e.g., bird strike with a bird of weight XX at a velocity of YY may require the air vehicle simply to return to base.

Remarks: Identify additional information that will impact the relaxed requirement or the limiting environmental condition.

REQUIREMENT LESSONS LEARNED (3.2.4)

To Be Prepared

4.2.4 Performance limiting environmental conditions verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Limiting environmental condition	Performance limitation specified in table 3.2.4-I	A	A	A	A	A,T, D

VERIFICATION DISCUSSION (4.2.4)

This paragraph should be utilized to verify environmental conditions in which degraded air vehicle performance is acceptable. However, other section 3 performance requirements may include limiting environmental conditions as well. In those cases, it is not necessary to verify that performance limitation in this paragraph. Verification of the degraded performance as specified in other section 3 requirements should be verified in that section 3 paragraph. The verification in this paragraph should only address performance limitations specified in requirement 3.2.4 Performance limiting environmental conditions.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Limiting environment conditions/requirements are defined and analyzed for the specified operations, missions, and service life usage profile. Analysis should define the life cycle model which reflects limiting environments, including any combinations expected to occur.

PDR: Limiting environmental conditions/data are finalized. Initial design requirements incorporate limiting environment considerations.

CDR: Design requirements incorporate limiting environment considerations.

FFR: Limiting environment conditions have been applied to the air vehicle and air vehicle subsystem element verifications.

SVR: Limiting environment conditions have been applied and air vehicle and air vehicle subsystem element verifications completed. Method of verification is dependent on the specific limiting conditions.

Sample Final Verification Criteria

__(1)__ shall be verified by __(2)__.

Blank 1. Identify the requirement which shall incur reduced level of performance while stressed with an adverse environment. For example, the air vehicle shall withstand bird strike to the canopy with a bird of weight XX at a velocity of YY, and retain flight critical functions.

Blank 2. Specify the verification method and scope/confidence level/fidelity. For example, analysis/simulations verify that canopy damage will not result in total loss of flight critical functions after incurring bird strike specified. Include in this blank the confidence level (and method for determining confidence level) that must exist prior to accepting the analysis/simulations. In development of this verification the specification developer should refer to the verification associated with the requirement prior to exception (e.g., natural climate birdstrike requirement).

VERIFICATION LESSONS LEARNED (4.2.4)

To Be Prepared

3.3 System characteristics

3.3.1 Propulsion

3.3.1.1 Propulsion, fixed wing

3.3.1.1.1 Engine compatibility and installation

The installed engine shall provide a safe, compatible and maintainable interface with the air vehicle under all air vehicle-operating conditions. The installed engine shall not surge, stall, incur uncommanded loss of power or incur mechanical damage due to: any effect caused by air vehicle subsystems interfaces, air vehicle maneuvers, throttle transients, armament operation, or operation of the air induction and exhaust systems.

The air vehicle with the integrated engine shall meet the air vehicle performance as well as the propulsion interface requirements throughout air vehicle ground and flight operations and envelopes.

REQUIREMENT RATIONALE (3.3.1.1.1)

The installed integrated propulsion system must be capable of functioning satisfactorily and being maintainable under all air vehicle design operating conditions and environments. Typically, inlets and the air vehicle environment produce nonuniform total pressure and temperature profiles (distortion) at the engine inlet (aerodynamic interface plane) which can be detrimental to successful engine operation or cause aeromechanical induced damage to engine hardware.

REQUIREMENT GUIDANCE (3.3.1.1.1)

The required performance and functional capabilities of the total integrated propulsion system should be assessed relative to the mission requirements of the air vehicle. In some cases, there may be a scenario in which more than one compatibility envelope may need to be defined, such as might be the case with a missile deployment and launch operation. These other envelopes would need to be added to the requirement.

Installation aspects to consider are as follows:

Clearances: A positive clearance (typically not less than one inch) should be maintained between the air vehicle and the engine, except at physical interface points, under all operating conditions within the ground and flight envelopes including shipboard landing and takeoff. This should apply to but not be limited to the following:

a. Between the engine, with its associated accessories, lines, harnesses or equipment, and the air vehicle nacelle, including any wire bundles, lines, equipment, firewalls, etc., in the engine compartment;

b. For maximum size (tolerance) engines, minimum size engines, maximum load on the air vehicle (maximum bending of the engine), and maximum temperature of the engine; and

c. The transmission and power transmitting components.

Accessibility and maintainability requirements must also be considered when determining clearance requirements.

Cooling: The nacelle and engine compartment should provide cooling and ventilation to the engine(s), engine(s) installation, engine accessories, compartment equipment, and supporting structure to maintain the propulsion system within allowable operational temperatures during all ground and flight operations and after engine shutdown. The nacelle and engine compartment cooling and ventilation systems, engine bleed air systems, and fire suppression systems must be compatible. During engine shutdown procedure ensure compressor bleed air has finished exhausting before fire suppression system is activated. Heating may be required in lieu of cooling to stay above the minimum operational temperature limits. Filtering may be required for cooling and ventilating air. Provisions should be made for inspectable and maintainable seals.

Drainage: The propulsion installation should have a means of handling fluid/vapor leakage, venting, and spillage throughout required ground and flight attitudes and regimes that is consistent with the system's safety, fire and explosion prevention, maintainability and survivability requirements. All closed compartments in the engine installation or nacelle and pylon, such as the engine accessory section, spaces enclosing fuel, oil and hydraulic lines and equipment, vent areas and other pockets where fluids may collect, should have suitable drainage provisions for all normal ground and flight attitudes. All drains should be identified with labels or other markings to assist in diagnostics and safety. Inadvertent liquid spillage and accidents as well as combat air vehicle battle damage should be considered when sizing and locating drains. Overboard drain lines should be routed to permit fluid to exit free of the air vehicle fuselage, nacelle, wing and pylon and should be protected from chafing when passing through bulkheads and cowlings. Drain masts should be compatible with the most adverse fluid they may come in contact with externally. Drain exits from the air vehicle should be scarfed in the air stream direction so that a scavenging suction effect is produced in flight by airflow around the drain discharge opening assuring positive drainage of all fluids. The drain opening should be located in an area where the local airstreams are such that drained fluids and vapors will exit freely and will not be driven back into the drained compartment or any other compartment or the engine exhaust gas wake. Central collection points for on the ground fluid removal may include devices such as ecology kits or tanks to collect drained fluids for protection of the environment. Ecology kits and tanks should have the capability to retain fluids without overflow under maximum normal drainage rates. Drain holes should be provided in pylons, bulkheads, stiffeners, and the skin in order to permit the normal flow of accumulated fluids to collect at low points. Drains may be interconnected if line sizes are adequate to ensure proper drainage. Interconnection should not be permitted where return of any fluid or vapor may create a fire hazard or damage any of the components whose drains are interconnected. When a single drain opening is used for the entire engine accessory section drain system, it should be sized to accommodate all leakage. Individual drain holes and drain tubing should be sized with an internal diameter that will prevent clogging due to dirt, insects, or debris. The drain system should not contain traps where condensation and fluids can accumulate, freeze, or cause corrosion. Drain line materials should be compatible with the drained fluids and the compartment environment. Lines connected to structural bulkheads should be of flex lines and fittings. Electrical component drains should not be combined with fluid system drains. Fluid drains of combustion areas should be such that excess combustible fluids will not collect in these areas after engine shutdown or false starts with the engine in a level position, a nose up position or nose down position. Drainage of engine augmentor ducts should be provided to prevent accumulation of fuel in the duct while the engine is in its normal nonoperating position.

REQUIREMENT LESSONS LEARNED (3.3.1.1.1)

The effects of inlet temperature and pressure distortion on engine surge margin are typically characterized by a series of distortion descriptors and limits provided by the engine manufacturer. Inlet airflow distortion limits are provided by the engine manufacturer throughout the air vehicle operating envelope. The distortion limits are defined in terms of both spatial and planar content (ARP 1420 can be used to calculate the distortion descriptors).

The cooling and ventilation system should be of sufficient capacity to ensure that all established temperature limits within the engine installation are not exceeded under any operating condition. The air vehicle contractor should establish the maximum ambient temperature environments to which the engine and engine compartment plumbing, wiring, equipment, accessories, and structural components may be exposed during all periods of air vehicle flight operation and ground operation, and after engine shutdown.

In establishing these limits, the air vehicle contractor should comply with the temperature limitations of the engine (as established by the engine manufacturer), engine components, and other installed equipment. In establishing post-shutdown temperature limitations, the contractor should 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 further be restricted due to adverse operating conditions, such as blowing dust and salt spray, which 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 need for auxiliary ground cooling equipment. Cooling and ventilating air intakes should be located so fuel, oil, and hydraulic fluid liquids and vapors and engine exhaust gases cannot enter the system. 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, the intake should have suitable ice protection.

The cooling system should not take air from the engine air inlet duct or plenum. In cases in which this cannot be avoided, the cooling system should be designed to withstand the maximum pressure loading resulting from an engine stall. Components of the cooling system in the engine air inlet duct should cause no significant inlet distortion and should not become a source of engine Foreign Object Damage (FOD). Air from the cooling and ventilation systems may discharge into the engine compartment(s) provided the air temperature is 200°F or less, and cannot be contaminated with flammable, corrosive, or explosive agents which may result from normal or accidental leakage throughout any flight altitude or engine operating mode. Airflow used to cool and ventilate any engine compartment should be discharged overboard and should clear air vehicle structure to minimize the chance of damage in the event of a compartment fire. Engine cooling and ventilating airflow should not be discharged into any other cooling and ventilation system except that used for exhaust nozzle cooling. Cooling air discharge from accessories such as oil coolers and generators should be discharged overboard. When an engine compartment or nacelle is divided by one or more liquid and vapor barriers, separate cooling and ventilation systems should be provided for each compartment. There should be no air exchange between engine compartments.

4.3.1.1.1 Engine compatibility and installation verification

(Note: The verifications of 3.3.1.1.1.1 Air induction system and 3.3.1.1.1.2 Nozzle and exhaust systems are also included in this paragraph.)

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Requirement elements to be verified specifically as part of this paragraph						
The installed engine shall provide a safe, compatible and maintainable interface with the air vehicle under all air vehicle-operating conditions	Physical compatibility (Pass/Fail) Functional compatibility (Pass/Fail) Performance compatibility (Pass/Fail)	A	I,A	I,A,S	A,T	A,T
The installed engine (including air induction, nozzle and exhaust systems) shall not surge, stall, incur uncommanded loss of power, or incur mechanical damage	Pass/Fail	A	I,A	I,A,S	A,T	A,T
Requirement element to be verified as part of other performance requirement verifications						
The air vehicle with the integrated engine shall meet the air vehicle performance as well as the propulsion interface requirements throughout air vehicle ground and flight operations and envelopes.	Performance characteristics specified in other air vehicle performance requirement paragraphs	A	A	A	A	A

VERIFICATION DISCUSSION (4.3.1.1.1)

The verification of this requirement will be tied closely to verification of other air vehicle requirements, including point performance, handling qualities and other pilot-air vehicle interfaces.

Requirement elements to be verified specifically as part of 4.3.1.1.1, 4.3.1.1.1.1, & 4.3.1.1.1.2 performance requirement verifications

Compatibility of the engine(s) with the air vehicle is generally validated by verifying that the physical, functional and performance interface characteristics are properly defined in terms of what the various supplying systems provide to the interface and what the receiving systems require from the interface in order to satisfy its requirements as well as physical definitions for establishing proper fit, alignment and loading. These interface characteristics and definitions are typically documented in an Interface Control Document (ICD) and evolve over the engineering and development phases. The general requirement verification for safe and maintainable installation includes consideration of clearances, cooling, and drainage. The subsystems that are typically required to interface and function with the engine include, accessory drive, engine starting, APUs, transmissions, gearboxes, hydraulic, electrical power, flight controls, fuel, vehicle control and management, other bleed air supplied systems, throttle, engine mounting and installation systems.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements to be verified as part of other performance requirement verifications.)

SRR/SFR: Analysis of the air vehicle design concept(s) indicates that the installed engine(s) will provide a compatible interface with the air vehicle under all air vehicle operating conditions and that interface factors such as positive clearances, cooling, drainage and ventilation are being considered. Analysis of the verifications for air vehicle 3.3.10 Safety and 3.1.5 Maintainability requirements indicate that installed engine safety and maintainability are being considered.

PDR: Inspection of the preliminary air vehicle design indicates that physical, functional and performance interface definitions have been addressed. Analysis of preliminary design indicates the installed engine(s) will provide compatible interface with the air vehicle under all air vehicle operating conditions.

CDR: Analyses of the air vehicle design and test results (integration lab, ground and/or test-bed flight) of engine subsystems confirm that compatibility of the installed engine with the air vehicle will be attained. Inspection of the updated ICD confirms that physical, functional and performance interface definitions (including fit, alignment and loads at each physical interface) are accurate. Simulation of the air vehicle with installed engine(s) in a flight simulator confirms specified compatibility for all air vehicle operating conditions, including takeoff and landing, aerial refueling, and other flight phases and tasks of the operational missions as specified.

FFR: Analyses of results from subsystem qualification tests and air vehicle integration tests (e.g., vehicle integration labs) confirm compatibility issues affecting first flight have been addressed. Ground tests of the air vehicle with installed engines confirm that all compatibility issues affecting first flight have been addressed. Analysis of the verifications for air vehicle 3.3.10 Safety and 3.1.5 Maintainability requirements confirm that installed engine safety issues affecting first flight have been addressed.

SVR: Ground and flight tests of the air vehicle with installed engine(s) confirm specified fit, alignment and loads at each physical interface and that all physical, functional and performance compatibility is achieved without stalling, surging, incurring uncommanded loss of power or mechanical damage throughout the operational envelope while simultaneously providing the necessary and sufficient combined mechanical (e.g., torque and speed), pneumatic (e.g., cabin or customer bleed), hydraulic (e.g., fuel pressure for exhaust nozzle actuation), and electrical (e.g., engine driven air vehicle generator) demands of the air vehicle subsystems. Analysis of the verifications for air vehicle 3.3.10 Safety and 3.1.5 Maintainability requirements confirm that installed engine safety and maintainability requirements are met.

Sample Final Verification Criteria

The requirement elements for a safe, compatible and maintainable interface between the installed engine(s) and the air vehicle without surge, stall, uncommanded loss, or mechanical damage shall be satisfied when __(1)__ inspections, __(2)__ analyses, __(3)__ simulations, and __(4)__ tests confirm specified performance is achieved without surge, stall, uncommanded loss of power, or mechanical damage.

Blank 1. Identify the type and scope of inspections required to provide confidence that the requirement has been satisfied. Inspections might include examining the ICDs to confirm that the physical, functional and performance interface definitions are correctly identified.

Blank 2. Identify the type and scope of analyses required to provide confidence that the requirement has been satisfied. Analyses might include results from engine and propulsion system tests and performance models used to validate functional and performance interface definitions.

Analyses should include all lower-level engine and component test data (integration lab, ground and flight) necessary to confirm power and thrust response under all specified ground and flight conditions. The FMECA and analysis of fail-operational, fail-degraded, and fail-safe operational tests should be analyzed to ensure no adverse impact to air vehicle.

Blank 3. Identify the type and scope of simulation(s) required to provide confidence that the requirement has been satisfied. Simulations that include failure states and extreme environmental considerations should be used to verify interfaces at conditions that may be deemed unsafe, impractical or too expensive for test.

Blank 4. Identify the type and scope of tests required to provide confidence that the requirement has been satisfied. Ground and flight tests should demonstrate the ability of the engine to meet or exceed installed performance and operate without stalling, surging, incurring uncommanded loss of power or mechanical damage throughout the operational envelope while simultaneously providing the necessary and sufficient combined mechanical, pneumatic, hydraulic, and electrical demands of the air vehicle subsystems.

Ground tests should include all conditions of bleed and power extraction, anti-icing operation, retractable screen operation, inlet and exhaust control operation, power transients, and shutdown operations. Ground tests should be performed to determine safe, compatible and maintainable interfaces, including examination of clearances during installation and removal, cooling during ground operations, thermal expansion, drainage and ventilation.

Flight tests should be conducted across the entire air vehicle envelope (speed, altitude and g range) to establish that all required interfaces are safe, compatible and maintainable without the air vehicle experiencing any surge, stall, or incurring uncommanded loss of power anywhere in the permissible ground and flight envelope. These tests should include transient maneuvers with maximum pitch, roll, and yaw rates up to the limit of the air vehicle structure or air vehicle control authority. Flight tests might include verification of positive clearance during take-off, landing, and flight loading, as well as thermal expansion conditions; adequate airflow; and cooling during all flight conditions.

Requirement elements to be verified as part of other performance requirements' verifications

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of all operational performance requirement verifications indicates that the integrated engine(s) and propulsion interface conditions/requirements are defined for the specified operations, missions and service life usage profile. Analysis indicates that air vehicle planned usage (including the numbers of engine cycles), maintenance concept, and any unique requirements that would adversely impact engine interface with the air vehicle are identified and are being considered for all associated requirement verifications. Analysis indicates flight operation and maintenance scenarios that would drive air vehicle to installed engine interface characteristics are incorporated into verification of those specific requirements, and that the impacts to engine interfaces expected to be encountered throughout the entire operating spectrum of the air vehicle are identified and defined.

PDR: Analysis of the verification plans for the operational performance requirement verifications indicates that the integrated engine interfaces/conditions are considered and any unique requirements that would adversely impact compatibility with the integrated engine(s) are considered.

CDR: Analysis of the verification plans for the operational performance requirement verifications confirms integrated engine interfaces are incorporated in all aspects of the design.

FFR: Analysis of all operational performance verifications for first flight readiness confirms that integrated engine interface requirements have been considered.

SVR: Analyses of all operational performance verification results confirm the performance of the air vehicle with integrated engine(s).

Sample Final Verification Criteria

Analysis of verification results for each air vehicle performance requirement specified herein confirms that the integrated engine interface requirements have been applied in defining the specific operational requirements/conditions for each air vehicle performance requirement.

VERIFICATION LESSONS LEARNED (4.3.1.1.1)

Some lubricating systems have incorporated oil sample drains that were inconvenient to use or had limited accessibility, preventing operating personnel from obtaining oil samples on a scheduled basis.

Past evaluations of proper clearances have included consideration of maximum and minimum size engines with respect to design tolerances in this demonstration. Flight maneuver loads, hard carrier landings, bending modes in drive and transmission systems, and thermal growth of engines at maximum temperatures throughout the flight and operational envelopes and at shutdown are also areas of concern.

Previous verifications of cooling methods have included bleed air in conjunction with engine performance tests at sea level and altitude. The tests have included the air vehicle requirements and the maximum bleed flow specified by the engine contractor. This can eliminate any operability problems if the bleed flow is increased due to air vehicle changes.

Measurement inspection of ports and locations, surface temperature measurements, and engine tests at various bleed rates up to maximum specified flow rates have been performed.

Low power settings may require a large amount of anti-ice airflow; therefore, the pilot may be instructed to use high power in icing conditions.

Air and gas leakage have been verified to ensure no injury to personnel nor damage to nacelle equipment will occur. Typically, a performance analysis has been performed to account for air leakage. Data uncertainty associated with airflow measurements makes it difficult to determine the leakage flow using testing as the verification method.

Past drainage and ventilation verification methods have included analysis to determine the interface connections and routing of drain tubes on the engine, inspections to look for leaks and tests to measure the fluid flow from the drains. Analysis has also evaluated an air vehicle design's ability to drain under various anticipated air vehicle ground and flight attitudes. Analyses have included examination of in-flight external pressure distributions at drain and vent exits for adverse pressure gradients. Analyses of drain line sizing and collection provisions to determine required fluid flows, and review of material selection for fluid compatibility have also been verified. Assessment of the impact of any external drainage and ventilation as a fire hazard, or a air vehicle signature and from a maintainability perspective has been performed.

3.3.1.1.1.1 Air induction system

The air induction systems shall not cause the engine to surge, stall, incur uncommanded loss of power, or incur any damage above the tolerances defined by the air vehicle system or engine specification, due to any air vehicle permissible ground/flight maneuver or attitude, foreign object or environmental ingestion, or any duct control or actuation system.

REQUIREMENT RATIONALE (3.3.1.1.1.1)

The installed air induction system must be capable of functioning satisfactorily under all air vehicle design operating conditions. Engine ingestion of objects, particles, contaminants or ice in excess of that which the engine has been designed to tolerate may result in rapid engine wear, damage or possible catastrophic failure. Engine performance and operability losses that result from wear and damage may degrade air vehicle mission capabilities. Significant accumulations of ice on inlet system components can adversely affect engine operation and performance. The impacts of total ground and flight environment affecting the systems must be considered.

REQUIREMENT GUIDANCE (3.3.1.1.1.1)

Performance: The air induction system must provide a compatible interface, both internally and externally, between the propulsion system and the air vehicle under all ground and flight conditions. The system should provide total pressure variations, both instantaneous and discrete, at the engine compressor face within the limits established in engine/airframe Interface Control Document (ICD).

Ingestion: Engine ingestion of foreign objects, sand and dust, ice, armament gas and debris and other ground and airborne contaminants should not exceed that allowed by the engine. The air inlet should be located and positioned in an area where there is little probability of ingesting foreign objects including runway water, ice and debris thrown up by air vehicle wheels or blown off the runway into the inlet during thrust reversal. High engine airflow may generate vortices at the entrance to the inlet system, which can pick up runway water, ice and debris. This should be considered when locating inlets in close proximity to the ground. The relative locations of engine air inlets and armament stores should be considered so that the entrance of rocket and gunfire exhaust gases and debris into the inlet system may be prevented. The selected system location should be assessed to determine the types and quantities of objects, particles and contaminants that may potentially be ingested by the system in an operational environment. Applicable protective features should be provided when the anticipated ingestion exceeds that allowed by the engine specification. Air vehicle operating restrictions that do not affect mission capabilities may also be employed. The use of operating restrictions should be closely coordinated with the weapon system user prior to adoption.

Icing Environments: The air induction system should be capable of operating under the expected icing conditions throughout the air vehicle/engine ground and flight power range without the accumulation of ice on inlet system components. Any subsequent shedding of ice should not adversely affect engine operation, or cause damage, loss of power or thrust. Systems to detect and prevent or control the build up of ice should be considered but must be balanced with other air vehicle system requirements. Icing conditions are specified by the Federal Aviation Administration in FAR Part 25, Appendix C. MIL–HDBK-310 and JSSG-2007 also specify icing conditions. Mission scenarios should be evaluated to determine if or what icing condition requirements are applicable.

REQUIREMENT LESSONS LEARNED (3.3.1.1.1.1)

To Be Prepared

4.3.1.1.1.1 Air induction system verification

Verification for this requirement is included with 4.3.1.1.1 Engine compatibility and installation verification.

3.3.1.1.1.2 Nozzle and exhaust systems

The nozzle and exhaust systems shall not cause the propulsion system to surge, stall, incur uncommanded loss of power, or incur any damage above the tolerances defined by the air vehicle system or engine specifications, due to any control, actuation system or functional operation.

REQUIREMENT RATIONALE (3.3.1.1.1.2)

The installed nozzle and exhaust systems must be capable of functioning satisfactorily under all air vehicle design operating conditions without causing adverse impacts on air vehicle or engine performance.

REQUIREMENT GUIDANCE (3.3.1.1.1.2)

The exhaust and nozzle system should direct exhaust gases to the atmosphere clear of the crew, boarding or discharging personnel, noncompatible air vehicle structure, externally mounted equipment, fluid drains, air intakes, and stores. The system should be compatible with the temperature and pressure environment associated with all engine-operating conditions. Operation of exhaust system equipment should not cause foreign objects to be ingested by the engines.

Failure modes of special exhaust system equipment, such as thrust reversers, vectoring nozzles, infrared suppressors, radar cross section suppressors, noise suppressors, exhaust detectors, etc., should be fail safe. Thrust reversers, vectoring nozzles and exhaust deflectors or attenuators should be designed such that, in the event of a single failure, the device will remain in or assume the forward thrust position with no degradation in air vehicle or engine performance that would result in a flight condition.

Cooling or shielding, consistent with fire and explosion protection and bay/nacelle cooling requirements, should be provided for the exterior surfaces of the exhaust system.

REQUIREMENT LESSONS LEARNED (3.3.1.1.1.2)

To Be Prepared

4.3.1.1.1.2 Nozzle and exhaust systems verification

Verification for this requirement is included with 4.3.1.1.1 Engine compatibility and installation verification.

3.3.1.1.2 Air vehicle propulsion control

The air vehicle propulsion control system shall provide:

a. Modulated thrust and power response to unrestricted power demands from starting to maximum power to stopping the engine and prevent any uncommanded power changes.

b. Operator capability for individual and simultaneous engine operation and control.

REQUIREMENT RATIONALE (3.3.1.1.2)

A fault tolerant propulsion control system is necessary to ensure adequate thrust and response for the air vehicle in meeting its performance, operability and reliability requirements throughout the entire operating envelope all through the air vehicle life. Modulation of thrust from cutoff to maximum power to cutoff by means of unrestricted thrust and power demand excursions should reduce pilot workload, increase combat maneuverability, and mission effectiveness. Propulsion system control modes should be implemented to reduce pilot workload by providing linear correlation between power demand and power output. Integrated control modes can improve aircraft operation such as takeoff, carrier approach, landing, wave-off, aerial refueling, loiter, combat, and autorotation power recovery.

REQUIREMENT GUIDANCE (3.3.1.1.2)

Requirement establishes pilot input verses thrust or power response relationships which must be allocated to the various elements of the propulsion system which include engine, inlet, exhaust controls, load absorbers, throttle mechanization, and integrated air vehicle propulsion controls.

The control system input and output signals can be electrical, mechanical, hydraulic, or pneumatic. The input signals to the engine may include aircraft Mach number, altitude, armament reset, idle exhaust nozzle reset, nozzle vector position command, etc. The output signals may include engine parameters for cockpit display, e.g., oil pressure or engine condition monitoring equipment (for fault detection and isolation to the control system component weapon replacement assembly or line replaceable unit level) and other interrogation systems external to the engine.

The digital data bus, MIL-STD-1533, MIL-STD-1773, or other commercial equivalent standards should provide the integration of the engine air vehicle controls and transmit data from the engine control to the engine monitoring system. The type and amount of data transmitted should be in the format required by the engine monitoring system. The design of the control system, hardware and software, dedicated to conditioning and transmitting data to the engine monitoring system should be partitioned from normal control functions to eliminate fault propagation.

The specification writer may also consider other requirements that may be included for this level, the Tier III specification, or the interfaces section of either document. Examples are

a. The propulsion system shall respond to a pilot generated, time-variant thrust request signal in a linear and predictable fashion throughout the entire flight envelope. The transient thrust request could range from any throttle position between maximum power and idle power to any other position in the same range. Aircraft handling quality requirements shall drive propulsion system bandwidth requirements on thrust dynamic response. Additionally, the aircraft handling quality requirements shall drive the thrust response gain and phase roll-off characteristics. Thrust requests (steady state or transient), in any sequence and at any rate, shall not result in surge, stall, combustor blowout, augmentor instability, control instability, or mechanical failure of the propulsion system.

In addition to meeting thrust request, other nominal control modes may be required for safe aircraft operation. These could include such modes as engine starting, engine stopping, inlet anti-ice control, nozzle vectoring, switching between vertical and horizontal flight, variable geometry position control, afterburner fuel control and individual engine control (torque or thrust) in a multi-engine aircraft. Propulsion system integrated control modes should be implemented to reduce pilot workload and improve aircraft operation in carrier approach, landing, wave-off, aerial refueling, loiter, combat, and auto-rotation power recovery.

b. The control should also be fault tolerant such that, in the presence of a single or dual dissimilar, non-prime-reliable failure, the propulsion system should still be able to provide thrust or vectoring control sufficient to meet the appropriate minimal aircraft handling quality requirements. The airframe requirements should provide the maximum permissible thrust error from the pilot request during each possible failure event. Airframe tolerance for any of these propulsion system failures will drive the engine control system design and the identification of which parts will be identified as prime-reliable.

c. The propulsion system should communicate to the airframe the status of its ability to meet the specified thrust request (steady state or transient). Degraded capability should be communicated quantitatively to the aircraft control system. Functional failures should be detected through some combination of continuous self-test, pilot initiated built-in-test, startup built-in-test, or by visual indication. Functional failures do not include individual component failures that have no direct effect on the propulsion system performance.

REQUIREMENT LESSONS LEARNED (3.3.1.1.2)

At supersonic flight speed, airflow through the aircraft inlet duct needs to be controlled between an upper and lower limit to prevent supersonic flow anomalies such as “inlet buzz.” In the upper left hand corner of the flight envelope, with low inlet temperatures, low frequency combustion acoustic instability (rumble), i.e., at frequencies <100 Hz may occur. Fuel redistribution or cutting back on fuel flow will eliminate this instability. At sea level, intermediate fuel flow may be reduced to lower turbine temperature. At altitude, fan speed may be limited to prevent engine over-speed or fuel for augmentor lights may be limited to ensure successful lighting in the upper left hand corner of the envelope with lower turbine exit and atmospheric pressures.

Due to the average length of a development program, off the shelf technology may lead to obsolescence during development, whereas incorporating advanced technology may put the program at too high of a risk level since technology is unproven in the field.

4.3.1.1.2 Air vehicle propulsion control verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Modulated thrust and power response to unrestricted power demands	Pass/Fail	A	A	A,S	A,S, T	A,T
Prevent uncommanded power changes	Pass/Fail	A	I,A	I,S, A	A,S, T	A,T
Operator capability for individual and simultaneous engine operation and control	Pass/Fail	A	I,A	I,A	A,T	A,T, S

VERIFICATION DISCUSSION (4.3.1.1.2)

The verification of this requirement will be tied closely to verification of other air vehicle requirements, including handling qualities and other pilot air vehicle interfaces.

<u>Modulated thrust and power response to unrestricted power demands</u>

Verification of air vehicle power system response requirements is accomplished by analyses, inspections, simulations, and tests, to include failure modes and effects testing (FMET). Testing of the integrated propulsion control system should be conducted under ground and flight conditions affording verification of the propulsion control interfacing mechanisms and power response over the widest range of ambient temperature, weather and environmental conditions.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the preliminary design concept(s) indicate that the air vehicle will be able to provide modulated thrust or power in response to unrestricted power demands throughout all anticipated air vehicle operations.

PDR: Analysis of preliminary design indicates that the air vehicle modulated thrust and power response requirement will be met. At this stage of verification, there is a need to identifythe basis of the technology and the risk associated with the components proposed in the preliminary design(s). Analysis of the control system descriptions indicates that the functional capability of each subcomponent including the throttle quadrant(s), VCMS, FADEC unit(s), electrical harness, sensors, and the actuation, fuel management, and ignition systems are defined. Analysis indicates that the system is described as a function of power demand, including inlet and engine variable geometry modulation and fuel scheduling during engine starting, steady state and transient operation, augmentor sequencing, and shutdown. Analysis indicates that additional control system input parameters from the air vehicle, such as armament gas ingestion, FOD, icing, weight on wheels, distortion index, inlet airflow limiting, and Mach number, are considered and are described in sufficient detail to ensure specified, modulated thrust and power response.

CDR: Analysis of lower-level component and development tests, simulating the engine environment, confirms modulated thrust and power response performance meets the specified requirement element. Analysis of updated air vehicle design for the control system descriptions indicates that the functional capability is achievable for each subcomponent, such as throttle quadrant(s), VCMS, FADEC unit(s), electrical harness, sensors, and the actuation, fuel management, and ignition systems. The FMECA and analysis of engine control system component level fail-operational, fail-degraded, and fail-safe operational tests confirm no adverse impact to air vehicle modulated thrust and power response with throttle, inlet, and exhaust system controls, VCMS interface, FADEC, sensor and effector failures, or malfunctions. Analysis of component-level tests of automatic engine and flight control limiting, as an integrated system, confirms unrestricted power modulation. Analysis confirms linear correlation between power demand and thrust or speed output has been established. Results from engine altitude test of control laws and logic have been analyzed and implemented to ensure the elimination of pressure spikes and reduction of abrupt thrust step changes during augmentor sequencing. Analysis of the computer specification deck plots and tables confirms that the air vehicle integrated control modulates engine performance when it is limiting engine functions. Simulation of engine control modes and integrated air vehicle propulsion control modes in a flight simulator confirms specified, modulated thrust and power response for all air vehicle performance and operability, including takeoff and landing, aerial refueling, and other flight phases and tasks of the operational missions as specified.

FFR: Analysis of engine initial or first flight release altitude test reports confirms control system performance and the resulting thrust or power response throughout the installed engine initial or first flight envelope. Analysis of altitude test cell test results and lower-level component tests confirm the regions of control limiting functions meet the specified modulated thrust and power response requirement. Analysis of engine altitude test results confirms air vehicle operation with the engine control system in control failure modes meets the requirement element. Analysis of software verification and validation test results confirms the proper logic has been incorporated into the propulsion control system to achieve modulated thrust and power response to unrestricted power demands throughout the flight envelope. Simulation of engine control modes and integrated air vehicle and propulsion control modes in a flight simulator confirm specified modulated thrust and power response for air vehicle performance and operability including takeoff and landing, aerial refueling, and other flight phases and tasks of the operational missions as specified. Ground tests of the air vehicle with installed propulsion system confirm modulated thrust and power response to unrestricted power demands is achieved.

SVR: Analysis of engine full flight release altitude test results confirms that specified modulated thrust and power response performance throughout the full air vehicle flight envelope is achieved. Flight tests confirm installed air vehicle propulsion power or thrust response meets the specified requirement element and that the air vehicle exhibits fully modulated thrust or power response in the permissible ground and flight envelope.

Sample Final Verification Criteria

The air vehicle modulated thrust and power response to unrestricted power demands requirement element shall be satisfied when __(1)__ analyses, __(2)__ simulations, and __(3)__ tests confirm specified performance is achieved.

Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement has been satisfied.

Analyses should include all lower-level engine and component test data necessary to confirm power and thrust response under all specified ground and flight conditions. The FMECA and analysis of fail-operational, fail-degraded, and fail-safe operational tests should be performed to ensure no adverse impact to air vehicle modulated thrust and power response with throttle, inlet and exhaust system controls, VCMS interface, FADEC, sensor and effector failures, or malfunctions.

Blank 2. Identify the type and scope of simulation(s) required to provide confidence that the requirement has been satisfied.

Simulations that include failure states and extreme environmental considerations should be used to verify modulated thrust and power response capabilities at conditions that may be deemed unsafe, impractical or too expensive for test. Control system faults should be simulated covering control system inner and outer loops. Hardover, soft, and out of range sensor failures should be simulated and compared to the results of the FMECA.

Blank 3. Identify the type and scope of tests required to provide confidence that the requirement has been satisfied.

Ground tests should include all conditions of bleed and power extraction, anti-icing operation, retractable screen operation, inlet and exhaust control operation, power transients, and shutdown operations. Ground tests should be performed to determine thrust lapse rates characteristics and the effects of wind direction and velocity on air vehicle engine control system stability. Ground tests should determine that lost motion, hysteresis and friction control of power lever controls do not affect range or accuracy of control to establish control response and stability throughout the power range.

Flight tests should be conducted across the entire air vehicle envelope (speed, altitude and g range) to establish that steady-state and transient control operation is attainable. Flight tests also confirm that the air vehicle exhibits fully modulated thrust or power response without experiencing any surge, stall, or incurring uncommanded loss of power anywhere in the permissible ground and flight envelope. These tests should include transient maneuvers with maximum pitch, roll, and yaw rates up to the limit of the air vehicle structure or air vehicle control authority. Satisfactory in-flight operation of the manual control (backup) system should be demonstrated, including switch-over between manual and primary modes of control.

Prevent uncommanded power changes

Verification of the air vehicle capability to prevent uncommanded power changes should be accomplished by a combination of analyses, inspections, simulations, demonstrations, and tests to ensure the engine controls will maintain any set position or power demand without constant attention by the flight crewmember(s) and without creep due to control loads, vibration or electromagnetic environmental effects. Analyses of lower-level tests should include results of failure modes and effects testing (FMET). Testing of the integrated propulsion control system should be conducted under ground and flight conditions affording verification of the propulsion control interfacing mechanisms and power response over the widest range of ambient temperature, weather and environmental conditions.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the air vehicle design concept(s) indicate that propulsion control system provisions to prevent uncommanded power changes are being considered.

PDR: Analysis and inspection of preliminary air vehicle designs indicate propulsion control system mechanization and functionality will prevent uncommanded power changes as specified.

CDR: Analysis and inspection of detailed designs and component test reports for air vehicle propulsion control system mechanization and functionality confirm that the requirement to prevent uncommanded power changes will be met. Analysis of software development test results confirms the proper logic has been incorporated into the propulsion control system to prevent uncommanded power changes throughout the flight envelope. Simulations with the operator in-the-loop should confirm there are not any conditions in which uncommanded power or thrust changes occur. The FMECA and preliminary system safety hazard analysis (SSHA) confirm that single point failures and potential hazards that might result in uncommanded power changes are identified and are being addressed.

FFR: Analysis of safety of flight related qualification reports of air vehicle propulsion control system components tests confirm the requirement element to prevent uncommanded power changes has been met. Analysis of updated software verification and validation test results confirms the proper logic has been incorporated into the propulsion control system to prevent uncommanded power changes throughout the flight envelope. Simulations with the operator in-the-loop and ground tests confirm there are no conditions in which uncommanded power or thrust changes occur. Analysis of applicable Vehicle Integration Facility (VIF) compatibility and FMET test results confirm prevention of uncommanded power changes. Analysis of results of installed functional checks and installed ground propulsion system demonstrations and tests confirm proper control function and response. Analysis of SSHA confirms resolution of single point failures and potential hazards which might result in uncommanded power changes.

SVR: Ground and flight tests throughout the entire specified operating envelope of the air vehicle and analysis of flight test results confirm no control system response problems that would cause uncommanded power changes. Simulations should include operator in-the-loop, as well as failure states and extreme environmental considerations that may be deemed unsafe, unpractical or too expensive for test. Analysis of final software verification and validation test results confirms the proper logic has been incorporated into the propulsion control system to prevent uncommanded power changes throughout the flight envelope.

Sample Final Verification Criteria

The air vehicle requirement to prevent uncommanded power changes shall be satisfied when __(1)__ analyses, __(2)__ simulations, and __(3)__ tests confirm specified performance is achieved.

> Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement has been satisfied.
>
> Analyses should include all component functional design and results of ground and flight tests to demonstrate that the air vehicle engine control system is able to maintain any set position or power demand without constant attention by the flight crewmember(s) and without creep due to control loads or vibration. Analysis should also include evaluation of tests results from electromagnetic environmental effects and natural climates verifications specified elsewhere in this document. The FMECA and analysis of

fail-operational, fail-degraded, and fail-safe operational tests should be performed to ensure no potential failures which might cause the air vehicle to produce uncommanded power changes.

Blank 2. Identify the type and scope of simulations required to provide confidence that the requirement has been satisfied.

Simulations should include operator in-the-loop, as well as failure states and extreme environmental considerations that may be deemed unsafe, unpractical or too expensive for test.

Blank 3. Identify the type and scope of tests required to provide confidence that the requirement has been satisfied.

Air vehicle ground and flight tests should include bodies, power chops, and other operationally relatable power maneuvers to examine capability of the control system to maintain any set position or power demand without constant attention by the flight crewmember(s) and without creep due to control loads, electromagnetic environmental effects or vibration.

Ground tests should include all conditions of bleed and power extraction, anti-icing operation, retractable screen operation, inlet and exhaust control operation, power transients, start-up and shutdown operations. Ground tests should be performed to determine thrust lapse rates characteristics and the effects of wind direction and velocity on air vehicle engine control system stability. Ground tests should determine that lost motion, hysteresis and friction control of power lever controls do not affect range or accuracy of control to establish control response and stability throughout the power range.

Flight tests should be conducted across the air vehicle envelope (speed, altitude and g range) to establish that steady-state and transient control operations is attainable and that the air vehicle exhibits fully modulated thrust or power response without experiencing any surge, stall, or incurring uncommanded loss of power anywhere in the permissible ground and flight envelope. These tests should include transient maneuvers with maximum pitch, roll, and yaw rates up to the limit of the air vehicle structure or air vehicle control authority. Satisfactory in-flight operation of the manual control (backup) system should be validated, including switch-over between manual and primary modes of control.

Operator capability for individual and simultaneous engine operation and control

The capability for the air vehicle to provide the flight crew with individual and simultaneous engine operation and control is verified by various analyses, inspections, tests and demonstrations conducted throughout the development program. If the thrust or power control incorporates a fuel shutoff feature, verify that the control has a means to prevent the inadvertent movement or command of the control into the shutoff position. Systems that may not be capable of shutdown using the cockpit thrust or power demand mechanism, should verify the fault tolerant capability of the necessary signals or other means employed to shut off fuel to the engine.

Analysis, functional tests, and usage data generated during ground and flight tests should be used to verify that thrust and power controls allow for separate controlled operation of each propulsion system by the operator(s) to include engine start, idle to maximum power, thrust reversing (if incorporated) and shutdown.

Qualitative usage data from ground and flight test results and handling quality assessments should be used to verify that thrust and power controls allow for simultaneous control and operation of all engines by the operators(s) to the extent necessary to support accomplishment of all flight phases and tasks of the operational missions.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the preliminary air vehicle design concept(s) indicate that all air vehicle propulsion control system requirements for individual and simultaneous engine operation and control are being considered. Analysis indicates that alternate design concepts for air vehicle propulsion control system component mechanization and functionality are being considered, if applicable.

PDR: Analysis and inspection of preliminary designs of air vehicle propulsion control system mechanization and functionality indicate that the operator capability for individual and simultaneous engine operation and control will be achieved.

CDR: Analysis and inspection of detailed designs and component test reports for air vehicle propulsion control system mechanization and functionality confirm that operator capability for individual and simultaneous engine operation and control will be achieved. Analysis of FMECA and preliminary system safety hazard analysis confirm that single point failures and potential hazards which might adversely affect the operator capability for individual and simultaneous engine operation and control have been resolved.

FFR: Analysis of safety of flight related qualification reports of air vehicle propulsion control system components and analysis of any applicable Vehicle Integration Facility (VIF) compatibility and FMET results confirm that the requirement for operator capability for individual and simultaneous engine operation and control has been achieved. Analysis of installed functional checks and installed ground propulsion system demonstrations and tests confirm proper control function and response. Analysis of SSHA confirms resolution of single point failures and potential hazards.

SVR: Analysis of flight test reports and handling qualities assessments confirm no control system response problems. Simulations, ground and flight tests with an operator in-the-loop confirm that the air vehicle provides the operator with individual and simultaneous engine operation and control as specified.

Sample Final Verification Criteria

The requirement for the air vehicle capability to provide the operator with individual and simultaneous engine operation and control shall be satisfied when __(1)__ analyses, __(2)__ simulations, and __(3)__ tests confirm specified performance is achieved.

> Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement has been satisfied.
>
> Analyses should include all lower-level engine and component test data necessary to confirm air vehicle capability to provide the operator with individual and simultaneous engine operation and control under all specified ground and flight conditions. The FMECA and analysis of fail-operational, fail-degraded, and fail-safe operational tests should be performed to ensure no adverse impact to air vehicle capability to provide the operator with individual and simultaneous engine operation and control as a result of component failures or malfunctions.

Blank 2. Identify the type and scope of simulation(s) required to provide confidence that the requirement has been satisfied.

Simulations that include failure states and extreme environmental considerations should be used to verify specified capabilities at conditions that may be deemed unsafe, impractical or too expensive for test. Control system faults should be simulated covering control system inner and outer loops. Hardover, soft, and out of range sensor failures should be simulated and compared to the results of the FMECA.

Blank 3. Identify the type and scope of tests required to provide confidence that the requirement has been satisfied.

Ground tests should include all conditions of bleed and power extraction, anti-icing operation, retractable screen operation, inlet and exhaust control operation, power transients, start-up and shutdown operations. Ground tests should be performed to determine thrust lapse rates characteristics and the effects of wind direction and velocity on air vehicle engine control system stability.

Flight tests should be conducted across the air vehicle envelope (speed, altitude and g range) to establish that steady-state and transient control operation is attainable. Flight tests also confirm that the air vehicle exhibits fully modulated thrust or power response without experiencing any surge, stall, or incurring uncommanded loss of power anywhere in the permissible ground and flight envelope. These tests should include transient maneuvers with maximum pitch, roll, and yaw rates up to the limit of the air vehicle structure or air vehicle control authority. Satisfactory in-flight operation of the manual control (backup) system should be validated, including switch-over between manual and primary modes of control.

VERIFICATION LESSONS LEARNED (4.3.1.1.2)

Qualification testing of the engine control system should include all integrated air vehicle signals, (which requires the air vehicle flight control interaction algorithms). Historically, some of this testing has been left to the air vehicle contractor to complete.

The verification of these things (see Lessons Learned of 3.3.1.1.2 Air vehicle propulsion control) needs to separate control hardware and software testing and explain the importance of model validation. Integration testing is often done with models until late in the development program, sometimes they are primary until the aircraft is fully assembled and ready for ground test. The phasing of propulsion system capability is perhaps more appropriately tied to test events such as first engine to test, accelerated mission testing, fault detection testing, and model validation testing. This way there is specific proof that each airframe need is being met rather than waiting until first flight readiness review which is often just a formality.

3.3.2 Interchangeability

Parts, subassemblies, assemblies, and software having the same identification, independent of source of supply or manufacturer, should be functionally and physically interchangeable.

REQUIREMENT RATIONALE (3.3.2)

It is essential that parts, subassemblies, assemblies, and software with the same identification is interchangeable, maintaining the key product characteristics and associated tolerances of the original item. This reduces logistic support requirements, minimizes maintenance/repair problems, minimizes assembly problems during production, and assure that performance and operability are not compromised.

REQUIREMENT GUIDANCE (3.3.2)

This requirement generally applies to all situations and should be included in the air vehicle specification. The requirement may be tailored to address specific items if deemed necessary.

REQUIREMENT LESSONS LEARNED (3.3.2)

To Be Prepared

4.3.2 Interchangeability verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Parts, subassemblies, assemblies and software, with same identification, are functionally and physically interchangeable	Functional and physical interchangeability (form, fit, function, interface)	I	I	I	I	I

VERIFICATION DISCUSSION (4.3.2)

Parts, subassemblies, assemblies and software, with same identification, are functionally and physically interchangeable

During assembly, developmental test, and remove and replace activities substantial data is typically obtained that could be used to verify this requirement. Use of this type of data should be maximized to avoid the cost and schedule impacts of a formal demonstration.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Inspection of the conceptual design indicates a configuration management approach to identify and control parts, subassemblies, assemblies and software has been established.

PDR: Inspection of the preliminary design indicates parts, subassemblies, assemblies, and software that are currently planned to be interchangeable, regardless of source of supply, have been identified. All instances of nonconformance to the requirement discovered during the review of product definition have a corrective action plan.

CDR: Inspection of the detailed design confirms design requirements are established that permit parts, subassemblies, assemblies and software to be used in the parent assembly without regard to the source of supply or manufacturer. All instances of nonconformance to the requirement discovered during the review of product definition have a corrective action plan.

FFR: Inspection confirms all known instances of nonconformance to this requirement have been corrected by product definition change.

SVR: Inspection of available data from assembly, developmental test, and remove and replace actions confirms that hardware/software with same identification is functionally and physically interchangeable and any known instances of nonconformance to this requirement have been corrected by product definition change.

Sample Final Verification Criteria

The interchangeability requirement shall be satisfied when __(1)__ analyses and inspections confirm the required parts, subassemblies, assemblies, and software interchangeability.

> Blank 1. Identify the specific types and number of analysis/inspections required to confirm the required reserve capacity. For instance, inspection of available data from assembly, developmental test, and remove and replace actions confirm that hardware/software with same identification is functionally and physically interchangeable and any known instances of nonconformance to this requirement have been corrected by product definition change. Also, analysis of verification results for each air vehicle performance requirement specified herein confirms that the interchangeability requirements have been applied in defining the specific operational requirements/conditions for each air vehicle performance requirement.

VERIFICATION LESSONS LEARNED (4.3.2)

To Be Prepared

3.3.3 Computer resources

3.3.3.1 Computer hardware reserve capacity

The air vehicle computer hardware shall have a total reserve capacity of __(1)__ percent.

REQUIREMENT RATIONALE (3.3.3.1)

This requirement ensures the supportability of the system through the development period and over its life cycle and ensures that some capacity for undefined changes in functionality is included in the baseline design.

REQUIREMENT GUIDANCE (3.3.3.1)

> Blank 1. Complete with some percentage (e.g., 50 percent) reserve (spare) memory, and/or reserve throughput, and/or reserve bandwidth, etc. Careful consideration of the built-in reserve capacity is needed since this extra capacity costs money up-front but should avoid future costs. Installed reserve should be carefully considered due to extreme cost of later retrofit especially in smaller, weight constrained air vehicles.

REQUIREMENT LESSONS LEARNED (3.3.3.1)

The reserve capacity requirement should be flowed down and tailored to individual aircraft subsystems, since the need for reserve capacity will vary depending on the computer type, function, and expected change activity. For systems expected to be very stable or require minimal change over the lifecycle, minimal reserve capacity for operating margin or limited change activity is recommended. A value of 25 percent reserve should be adequate for such systems and should prevent artificial design constraints due to inadequate reserve. For mission system computers, unprecedented systems, or other systems expected to experience moderate to significant change over the life cycle, a larger reserve requirement (50 percent or higher) should be considered. Decisions should be based on a thorough study of the change activity on similar systems in the inventory. Experience from actual programs shows that unless sufficient reserve capacity is properly flowed down, specified, and carefully managed, it can easily be consumed during development by engineering change proposals (ECPs) or the design evolution of the system.

4.3.3.1 Computer hardware reserve capacity verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Reserve capacity	(1) (e.g., memory, throughput, bandwidth, in terms of % reserve)	A	A,I	A,I		A,D

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.3.3.1)

Hardware reserve capacity verification is based on positive determination through progressive analysis, inspection, and demonstration that the required computer reserve capacity is addressed in the design and is attained in the production system. Verification of hardware reserve capacity should thoroughly address not only the satisfaction of reserve capacity requirement measurands, but also verify system operation and stability when the reserve capacity is used to the fullest.

Verification activity can be considered as being comprised of two stages. For the early design stages through CDR, verification consists primarily of analysis and inspection of the design. This will assure adequate that system design and provisions are made to allow for system hardware reserve capacity per stated requirements. For SVR, analyze lower-level tests to verify the attainment of design objectives without affecting system operation and stability when the reserve capacity is exercised to the fullest.

The design of the reserve capacity should be incrementally verified using analysis and demonstration at the key development milestones.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Results of analysis, using computer capacity methodologies, indicate that the computer hardware reserve capacity requirements are properly allocated to each tier of the system.

PDR: Results of analysis, using computer capacity methodologies, and inspection of detailed design documentation, indicate that the computer hardware reserve capacity requirements are allocated to each tier of the system and are ready for detailed design.

CDR: Results of analysis using computer capacity methodologies, and inspection of final design documentation confirm that the computer hardware reserve capacity requirements are allocated and satisfy the allocated requirements and that the detailed design is ready for manufacture.

FFR: No unique verification action occurs at this milestone.

SVR: Analysis of lower-level test and demonstration confirm that the computer hardware reserve capacity requirements have been allocated and attained. In some cases, results from air vehicle level demonstrations may need to be analyzed to confirm compliance with the reserve capacity requirement.

Sample Final Verification Criteria

The computer hardware reserve capacity requirement shall be met when __(1)__ analyses and demonstrations confirm the availability of the required reserve capacity.

Blank 1. Identify the specific types and number of analysis/demonstrations required to confirm the required reserve capacity.

VERIFICATION LESSONS LEARNED (4.3.3.1)

To Be Prepared

3.3.3.2 Computer hardware extensibility

The air vehicle computer hardware shall provide for additional memory, processing capability, and input and output capacity, as defined in table 3.3.3.2-I below, to improve or extend the specified system (subsystems) operation and performance beyond the built-in, delivered reserve capacity.

TABLE 3.3.3.2-I. Computer hardware extensibility.

Extended Capability	Percent Extensibility	Type of Provisions

REQUIREMENT RATIONALE (3.3.3.2)

This requirement is necessary to ensure the system computers can be upgraded or modified without major hardware impacts over the life of the system. It requires that additional computer resources can be added to the system to support the future implementation of new subsystems or functionality. Extensibility is defined as the ability to extend (increase) the available computer resources without adversely affecting the utility of the delivered computer resources already in place (i.e., without scrapping the existing computer system, extending rather than replacing what exists). DoD 5000.2-R codifies use of open systems design.

REQUIREMENT GUIDANCE (3.3.3.2)

Guidance for completing table 3.3.3.2-I follows:

<u>Extended Capability</u>: List the extended capability (memory, throughput, I/O, etc.).

<u>Percent Extensibility</u>: List the percentage of the capability for which growth provisions should be provided.

<u>Type of Provisions</u>: List the type of provisions (Group A, space, power, cooling, etc.) which are required for each extended capability.

REQUIREMENT LESSONS LEARNED (3.3.3.2)

To Be Prepared

4.3.3.2 Computer hardware extensibility verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Extensibility (e.g., memory, processing capability, I/O)	Table 3.3.3.2-I, column 2 in terms of %	A	A,I	A,I		A,D

VERIFICATION DISCUSSION (4.3.3.2)

Computer hardware extensibility verification is based on positive determination through progressive analysis, inspection, and demonstration that the required computer hardware extensibility is addressed in the design and is attained in the production system.

The verification activity can be considered as being comprised of two stages. For the early design stages through CDR, verification should consist primarily of analysis and inspection of the design. This will assure that adequate system design and provisions are made to allow for system extensibility per stated requirements. For SVR, analyze lower-level tests to verify specified extensibility capacity can be attained.

Verification of hardware extensibility should thoroughly address not only the satisfaction of extensibility requirements, but also verify adequate provisioning by subsystems and total compatibility with subsystems that will be affected by the hardware extensions (i.e., cooling, power,… etc.). These systems provision areas should individually be verified with a fully extended computer system hardware configuration.

The design of the reserve capacity should be incrementally verified using analysis, inspection, and demonstration at the key development milestones.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Results of analysis indicate that the computer hardware extensibility requirements are properly allocated.

PDR: Results of analysis and inspection of the preliminary air vehicle design indicate that the computer hardware extensibility requirements are allocated and are ready for detailed design.

CDR: Results of analysis and inspection of final air vehicle design documentation confirm that the computer hardware extensibility provisions and capabilities are incorporated and will satisfy the allocated requirements and that the detailed design is ready for manufacture.

FFR: No unique verification actions occur at this milestone.

SVR: Analysis of lower-level tests and demonstrations confirm that the computer hardware extensibility requirements have been allocated and attained. In some cases results from air vehicle level demonstrations may need to be analyzed to confirm compliance with the extensibility requirement.

Sample Final Verification Criteria

The computer hardware extensibility requirement is met when __(1)__ analyses and demonstrations confirm the availability of the required extensibility.

Blank 1. Identify the specific types and number of analyses/demonstrations required to confirm the required extensibility.

VERIFICATION LESSONS LEARNED (4.3.3.2)

Without specific design and verification requirements, problems caused by inadequate computer extensibility are not discovered until the air vehicle is well along the development and production cycle. By that time, design changes will impact development and production schedules and become extremely expensive to implement. In the past, changing operational requirements and rapid advances in technology have oftentimes rendered production aircraft computer systems unable to adequately meet mission requirements. Thus the requirement for a thorough verification of computer hardware extensibility throughout the system development process becomes extremely important.

3.3.4 Architecture

The air vehicle shall have a functionally based*,* open systems architecture that exhibits the following open systems characteristics __(1)__.

REQUIREMENT RATIONALE (3.3.4)

Include this requirement to ensure the air vehicle architecture (functionally and physically, i.e., requirements, design, and design implementation) is flexible, robust, and in concert with the characteristics of open systems. The air vehicle architecture includes the hardware, software, and other elements (such as materials, etc.) for all elements/subsystems. A flexible, robust architecture can have significant benefits over the life cycle of the air vehicle. It enables the air vehicle to be more readily and affordably modified for repair; increased capability (growth); interchanging obsolescence parts and minimizes their impacts; incorporating new technologies; promotes simplicity; enables cost-effective production and support, and enables reprocurement of technology evolved replacement parts. This requirement is intended to achieve the features of “open systems” that are being advocated within DoD and industry. A key objective is achieving a system that is life cycle maintainable, modifiable, and which accommodates technology insertion as a natural course of business rather than only in terms of new development.

REQUIREMENT GUIDANCE (3.3.4)

Blank 1. Complete with the key open system characteristics, including any specific standards or measurable values for the key characteristics established. Consider the specific open system characteristics for hardware and software that are key to the program, such as well-defined open interfaces based on nonproprietary standards, use of COTS, modularity, reuse, ease of growth/upgrade/technology insertion, parts obsolescence avoidance, and affordability. Other key characteristics should be included, as appropriate. For example, one of many entries in blank 1 might be “Interfaces at all levels shall be defined by widely accepted nonproprietary standards.”

Most concern over how the air vehicle architecture is defined or developed deals with potential life-cycle management issues. The desire is to have a flexible and robust air vehicle architecture that can easily and affordably be modified, if necessary, to incorporate additional capability, new technology, or replace failed, worn or obsolete parts. The requirement, stated in general terms, describes the overarching characteristics (i.e., functionally based, supporting underlying engineering principles, and open systems) needed to achieve the intended purpose or end result.

An enabling characteristic of good architecture definition is a comprehensive, performance based product definition. This approach is where the performance, key product characteristics (including interfaces) and product acceptance criteria are defined/specified, but flexibility is given to change the design and/or manufacturing processes as long as the key product characteristics continue to be met. As long as the physical form and fit of the design changes meet the installation requirements; the functional performance of the air vehicle resulting from design changes is maintained/unaffected; and the interfaces to other system assets, items, components, modules, etc. are preserved, flexibility can be granted to the designer on the details of the design and components used as well as the specific manufacturing processes employed.

REQUIREMENT LESSONS LEARNED (3.3.4)

The definition of open systems is not enough in all cases to ensure that a product will actually meet all the specified requirements in addition to the requirement for a system/subsystem to have open systems architecture. Commercial products, for example, fall short in providing the right types of diagnostics needed for some military applications. In addition, a commercial product line will resist changes to meet the military needs simply due to the need to maintain their product line. Commercial standards often lack the features needed for meeting the environment that the military must endure.

Picking the wrong set of standards can lead to acceptance of a system design in which the government can no longer afford to upgrade the air vehicle at a future point in time. Some commercial airline standards, for example, are established so that the subcontractor to a commercial air vehicle manufacturer is responsible for maintenance and upgrades. Once this arrangement has been made, it becomes very difficult for the airlines to change vendors because of the proprietary nature of the vendors' hardware and software. The vendor's design becomes unique to the air vehicle and competition can be considerably more difficult. Selecting an airline centric equipment set can result in very expensive growth paths since the upgrade will likely be a completely new design.

Architecture can range from a simple bubble on a piece of paper that says hardware/software all the way to a completed design that's being flight tested. The architecture issues will not be completely addressed until the system has been flown and accepted by the user. The standards that the military may need to rely on tend to be those from commercial markets that have similar environments and a need for determinism. It's imperative that the contractor proposes an approach that relies upon a set of underlying engineering principles. These principles, such as rate monotonic scheduling (RMS) theory or rate monotonic analysis (RMA), allow the contractor to evaluate and demonstrate performance long before he begins to build his product.

There are various levels to which open systems can be applied. At one level, commercial processors, memory chips, etc. are identified and a supplier is tasked with building a back-plane and circuit cards that are based on commercial standards but modified to meet the military environment. This method is particularly effective for some of the transport programs in that changes were easily made to design out obsolete components. The use of a VME back plane opened up the availability of alternative vendors for parts and components.

At another level, commercial products designed for commercial uses are adopted by the military for use on systems that are similar to commercial systems. The intent to use commercial products that are already designed to the box level carries some unintended consequences that include higher levels of proprietary designs, reduced capability in some types of performance characteristics, and a number of other issue as well. Using commercial products is not a simple solution given that they may be developed using standards that don't support some of the military needs for verification and ease of change. Already designed off the shelve box level commercial products may have poor diagnostics, proprietary software solutions, low performance, and no alternative sources for replacement parts.

Open systems for avionics are simply the architecture that has been assessed to determine the cost drivers and the total ownership costs. Areas included in the assessment are methods of upgrading avionics that don't short change areas such as diagnostics, software upgrade, verification, growth, and competition. Many of the open system avionic solutions in the commercial airline market place assume that no upgrades will take place until the whole system is replaced. Minor software changes are allowed but no functional upgrades are usually made since the airliners have no threat and no need to change avionics depending on the dynamics of the world situation

Key to the development and life cycle maintenance of an air vehicle is the availability of a complete description of the air vehicle and capture of the rationale and decisions that resulted in the air vehicle architecture. Guidance on characteristics of the information expected is contained in the Performance Based Product Definition Guide.

Flexibility in a product's design can promote cost effective solutions but care must be taken to ensure that the engineering design issues are identified and addressed very early in a program so that commercial products that don't fit the military needs can be identified. Selecting interface standards can also be troublesome if care is not given to how these standards best fit the military requirements. A widely used standard can also be an obsolete standard that is on the downswing in the commercial world. Modularity and functional partitioning has been a requirement for military systems for decades but the interdependence between modules has increased greatly over the years as system complexity has increased. As processor throughput has increased exponentially for example, the interfaces supported by buses and networks has only increased in a linear fashion. This has created additional interdependencies that can get in the way of designing out obsolete components and be so complicated, in even a commercial system, that no one but one vendor can actually supply a workable product.

4.3.4 Architecture verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Function based architecture	(1)	A	A	A		A

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.3.4)

Verification of the air vehicle Architecture requirement consists of a positive determination through progressive analysis of lower-level inspections, tests, simulations and demonstrations that the air vehicle/subsystem architecture (functionally and physically, i.e., requirements, design, and design implementation) is flexible, robust, and in concert with the required characteristics of open systems.

Interactive design tools and simulations should be utilized to evaluate functional partitioning and interfaces, conduct alternative design trades, and achieve a robust and flexible air vehicle design and architecture. Simulation is a key ingredient for understanding how a system/subsystem will react when fully loaded and simulation is dependent on how well an architecture has been based on a sufficient set of underlying engineering principles.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analyses of the air vehicle design concept indicates the architecture of subsystems is open and functionally based. Analyses of the interface concepts indicate open interfaces will be implemented. Analyses of the subsystems design concepts indicate that the use of COTS, modularity, and ease of growth/upgrade/technology insertion are being addressed. Analyses of the subsystems design concepts indicate that parts obsolescence avoidance is being addressed. Analyses of trade study methodology indicate affordability/LCC are being addressed for open systems characteristics. The analyses above apply to the extent it is defined in blank 1 of the requirement.

PDR: Analyses of the preliminary air vehicle design indicate that the architecture of subsystems is functionally partitioned- Analyses of the preliminary interface definitions indicate open interfaces will be implemented. Analysis of lower-level subsystem simulations indicate open interfaces support functional requirements. Analyses of the preliminary subsystem design indicate that the use of COTS, modularity, and ease of growth/upgrade/technology insertion are included in the design approach. Analysis of lower-level subsystem simulations indicates the preliminary design approach easily accommodates growth/upgrade/technology insertion. Analyses of the preliminary subsystem design and the initial parts obsolescence plan indicate that parts obsolescence avoidance is being addressed. Analyses of preliminary trade study results indicate affordability/LCC are included in design decisions for open systems characteristics. The criteria above apply to the extent it is defined in blank 1 of the requirement.

CDR: Analyses of the final air vehicle design confirm that architecture of the subsystems is functionally partitioned. Analyses of the final interface definitions confirm open interfaces are implemented. Analysis of lower-level subsystem simulations confirm open interfaces support functional requirements. Analyses of the final subsystem design confirm that the use of COTS, modularity, and ease of growth/upgrade/technology insertion are included in the design. Analysis of lower-level subsystem simulations confirms the final design approach easily accommodates growth/upgrade/technology insertion. Analyses of the final subsystems design and the parts obsolescence plan indicate that the parts obsolescence avoidance plan is implemented and reflected in the design. Analyses of trade study results indicate affordability/LCC were included in the design decisions for open systems characteristics. The criteria above apply to the extent it is defined in blank 1 of the requirement.

FFR: No unique verification action occurs at this milestone.

SVR: Analyses of results from lower-level subsystem inspections, demonstrations, and simulations confirm the air vehicle architecture meets the functional based and open system characteristics requirements specified.

Sample Final Verification Criteria

The air vehicle Architecture requirement shall be satisfied when __(1)__ analyses confirm specified performance is achieved.

Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement has been satisfied. Typically, this would consist of analyses of lower-level subsystem inspections, simulations, and demonstrations.

The following are examples: examination of the subsystems architecture partitioning including items such as the avionics functional partitioning; avionics simulations (e.g., data bus loading, processor throughput, etc.); and laboratory tests such as avionics tests (e.g., bus loading, avionics integration testing, etc.).

VERIFICATION LESSONS LEARNED (4.3.4)

To Be Prepared

3.3.5 System usage

Air vehicle usage shall be __(1)__.

REQUIREMENT RATIONALE (3.3.5)

Ongoing assessments of current and projected threats against defense capabilities result in a definition of mission needs that includes operational life. The air vehicle usage requirement is directly determined by these mission needs and defines for how long the air vehicle is projected to be needed. The requirement is allocated to air vehicle elements to ensure that all elements provide the necessary utility for the required duration. This information forms the basis for design loads/stress criteria and the integrity program.

REQUIREMENT GUIDANCE (3.3.5)

The air vehicle usage should be fully described. This should include usage incurred during manufacturing, shipping, storage, transportation, basing, operational missions, on-equipment training, and required maintenance cycles, where appropriate.

Blank 1. The blank is best completed with a table (see example) showing the various operational requirements/cycles that the air vehicle will experience during its service life.

Usage requirement. - (Example table)

Flight Operations		
Mission #1	----	xxx flight hours, yyy sorties
Mission #2	----	yyy flight hours, zzz sorties
Mission #3	----	zzz flight hours, xxx sorties
Catapults	----	#
Arrestments	----	#
Basing		
Taxi	----	xxx operations
Power-on	----	yyy operations
Tow	----	zzz operations
Alert Shelters	----	50%
Flightline	----	50%
Manufacture / Checkout		
Power-on cycles	----	xxx
Engine run cycles	----	yyy
Storage		
Desert	----	xxx years, exposed to winds
Igloo	----	yyy years
Transportation		
Rail	----	xx shipments, at ___ °F
Air (C-5/C-17)	----	yyy shipments
Overhaul	----	xxx flight hours, xxx thermals

REQUIREMENT LESSONS LEARNED (3.3.5)

While flight operations are the most obvious use of an air vehicle during its lifetime, valuable service life is also expended during nonflight evolutions, such as alert (ramp) standby duty, maintenance and training evolutions, pre- and post-flight checkout, ground/deck handling, storage, transportation, and a myriad of other power-on or load-inducing actions. This usage must be considered during initial design to ensure adequate service life is available for all of the anticipated uses of the air vehicle.

4.3.5 System usage verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Air vehicle usage requirements	Usage data is utilized in relevant air vehicle requirement verifications	A	A	A		A

VERIFICATION DISCUSSION (4.3.5)

This requirement provides condition information that must be considered in developing all air vehicle performance requirements and verifications. Therefore, the verification of compliance with the usage information defined within this requirement should be accomplished within the other performance requirement verifications. The information below is provided to ensure that the air vehicle verification program is properly defined and applied in terms of the overall air vehicle usage information.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Air vehicle usage requirements are defined and complete for the specified operations, missions, and service life.

PDR: Air vehicle usage data are finalized and allocated to applicable air vehicle elements. Initial design requirements incorporate air vehicle usage considerations.

CDR: Design requirements incorporate air vehicle usage considerations.

FFR: No unique verification action occurs at this milestone.

SVR: Air vehicle usage conditions have been appropriately (consistent application technique) applied to the relevant (e.g., service life and reliability) air vehicle verifications.

Sample Final Verification Criteria

Analysis of verification criteria for relevant air vehicle performance requirements specified herein confirms that the air vehicle usage requirements have been applied.

VERIFICATION LESSONS LEARNED (4.3.5)

To Be Prepared

3.3.5.1 Service life

The air vehicle shall deliver the performance specified herein for not less than __(1)__, when operated to the expected usage spectra as defined in 3.3.5 System usage, by qualified operational and support personnel and associated resources. Service life is defined as the period of time from when an asset is initially introduced into the inventory for its operational use until the time it is either consumed in use or disposed of as being excess to all known materiel requirements. The service life of an air vehicle typically exceeds the lives of its components.

REQUIREMENT RATIONALE (3.3.5.1)

The requirement is that the air vehicle age gracefully. Nominal air vehicle functional performance should be at the level identified in the specification after accumulation of usage induced damage/degradation through the end of the air vehicle life. The air vehicle must be designed to withstand the expected environmental and usage loads for the life of the air vehicle. The service life for the individual air vehicle components is dictated by life cycle cost, air vehicle effectiveness, performance, and safety considerations in obtaining an optimal component architecture. Air vehicle component repair or replacement strategies for management of the specified air vehicle service life are iteratively defined during the development to harmonize cost and performance objectives.

REQUIREMENT GUIDANCE (3.3.5.1)

Blank 1. Complete by stating the service life in terms of years.

Qualified operational and support resources means those personnel trained to the standards dictated by training data; support equipment specified by the technical data; and built, and maintained to specification; spares, repair parts, and consumables meeting the performance specifications associated therewith, and using procedures specified in the technical and operational data.

REQUIREMENT LESSONS LEARNED (3.3.5.1)

Integrity is a disciplined approach to help ensure that the required operational capability is maintained for the projected life of the air vehicle. The elements of service life, durability and strength are not new. The concept of damage tolerance is somewhat new to subsystems but has been utilized on the airframe structure for years. Both analyses and test are necessary to ascertain component life. Up front analyses will identify component weak points prior to solidifying the design for build and test. The cost required for these analyses will typically be cost effective due to significantly reduced redesign and retest due to failures or environmental/design usage updates. Accelerated testing should be permitted if it is shown by analysis, test, or historical data that the usage and environments imposed produces damage levels equivalent to the damage levels produced by the usage environment. Qualification by similarity or building block testing can be used when justified by analysis.

4.3.5.1 Service life verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Service life	(1)	A	A	A	A	A

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.3.5.1)

Service life design based on usage data should be incrementally verified using analysis and inspection.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis using service life methodologies indicate that the service life requirements are properly allocated to each tier of the system typically including: initial Service Life Assessment (SLA), and unitial component and hardware design criteria.

PDR: Initial analysis indicates that the lower-level service life allocations were based on life cycle trades that addressed technology cycle time, reliability, repairability, durability, etc. Analysis using service life methodologies indicates that the service life requirements are allocated to each tier of the system and are ready for detailed design. These typically include updated SLA, updated component and hardware design criteria, initial service loads spectra, and initial usage variation and parts criticality study.

CDR: Analysis of lower-level development test results and inspection of final air vehicle design documentation using service life methodologies confirm that the requirements are incorporated and satisfy the allocated requirements and that the air vehicle detailed design is ready for manufacture. Analysis confirms that the updated lower-level service life allocations were based on life cycle trades that addressed technology cycle time, reliability, repairability, durability, etc.

FFR: Analysis confirming readiness for flight typically includes data from: reviewing initial aircraft tracking (IAT) models and update SLA and durability and damage tolerence (DADT) analysis.

SVR: Analysis of the updated DADT (to include ground and flight test results), results of one lifetime DADT testing (Critical parts), and final SLA are used, as a minimum, to confirm that the air vehicle service life requirements have been achieved:

Sample Final Verification Criteria

This requirement is met when the analysis of __(1)__, substantiates the required service life.

> Blank 1. Specify types and quantity of data (e.g., ground testing, flight testing, DADT, SLA).

VERIFICATION LESSONS LEARNED (4.3.5.1)

DADT testing should have begun and some number of cycles completed prior to first flight. This testing can be on the program critical path, so careful attention to schedule is warranted. Essential functions, especially life-limited functions and including critical support functions if any, must have been adequately demonstrated. In the past, definition of what was essential was not accomplished until the last minute, causing some concern.

3.3.5.1.1 Damage/fault tolerance

The air vehicle shall be capable of sustaining failure of a component in any safety- or mission-critical function without complete loss of said function or shall provide sufficient indication of degradation of said function, prior to catastrophic failure, to enable intervention by the pilot or maintenance personnel to suspend the failure process. Further, catastrophic failure of any component of a mission or safety-critical function shall not precipitate failure in adjacent or associated components in the same or any other mission or safety-critical function, without providing indication of said failure in sufficient time to enable the aircrew or maintenance personnel to suspend the failure process. All safety- or mission-critical functions shall be damage tolerant in the presence of nondetectable material defects, manufacturing and processing defects, or maintenance/service induced damage in the components which provide the function.

REQUIREMENT RATIONALE (3.3.5.1.1)

Safety- or mission-critical functions require special design considerations due to their criticality. Both avionics and subsystem designs achieve fault tolerance through redundancy meeting fail-safe evident criteria. However, when performance and cost impacts do not support such redundancy, component level damage tolerance must be achieved through fail safe, degraded mode operation, or reconfiguration and resource sharing design strategies.

REQUIREMENT GUIDANCE (3.3.5.1.1)

Damage/fault tolerance should be achieved by either fail-safe evident system design or by component damage tolerant design. Fail-safe evident system design should result in redundancy such that failure within a system should not result in loss of airplane or mission capability, both of which should be evident to the pilot in flight or to ground maintenance personnel. Component damage tolerance should be achieved by design approaches with slow crack growth, high durability margins, leak-before-burst, or in the case of composite parts, by demonstrating tolerance to impact damage, voids, and scratches.

REQUIREMENT LESSONS LEARNED (3.3.5.1.1)

Redundancy is not always fail-safe evident. It is not unprecedented to include a second component for redundancy, but not to know if both components are operational. Without some form of fault detection, one does not know that the redundancy will be present when needed.

4.3.5.1.1 Damage/fault tolerance verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
No unindicated total loss of function due to a single component failure	Pass/Fail	A	A	A		I,A,T
No unindicated secondary failure in presence of catastrophic component failure	Pass/Fail	A	A	A		I,A,T
Damage tolerance of safety- or mission-critical functions	Pass/Fail	A	A	A		I,A,T

VERIFICATION DISCUSSION (4.3.5.1.1)

The verification for 3.3.5.1 Service life should be considered when developing this verification.

When not otherwise defined, critical components and subsystems should be determined through a failure modes and effects analysis. This analysis should be implemented as an integral part of the individual integrity program for the specific procurement. This analysis should be continuously updated to ensure that changing requirements and equipment/subsystem design maturity are factored into the choice.

Many systems/subsystems are comprised of multiple or redundant components specifically designed to allow partial failure. Many components, especially some pressure vessels, are designed to leak or otherwise fail to function prior to failing catastrophically. Both concepts are considered as viable to satisfy damage tolerance requirements of this specification. This requirement provides specific criteria to ensure that in such cases the failure is obvious and that safety/mission completion can be assured over a specified service life period.

The procuring activity and/or the contractor may stipulate specific components/subsystems to be designated as fail safe evident/leak before break. Where practical, pressure vessels located near critical systems or airframe components should be designed to be leak before break. Fail safe concepts should be investigated in complex systems, particularly where slow crack growth may be impractical or may impose weight/cost/performance penalties.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analysis of the design concept indicates damage/fault tolerance requirements are achievable.

PDR: Analysis indicates the preliminary air vehicle design has the required damage/fault tolerance capabilities.

CDR: Analysis of the final air vehicle design confirms the presence of damage/fault tolerance capability.

FFR: No unique verification action occurs at this milestone.

SVR: Analysis of lower-level test results, inspections, ground and flight tests confirm the air vehicle components of safety- and mission-critical functions have the required damage/fault tolerance characteristics.

Sample Final Verification Criteria

Damage/fault tolerance shall be satisfied when __(1)__ inspections, __(2)__ analyses and __(3)__ tests confirm acceptable air vehicle component failure modes and detection capabilities.

> Blank 1. Identify the type and scope of inspections required to provide confidence that the requirement element has been met.
>
> Blank 2. Identify the type and scope of analyses required to provide confidence that the requirement element has been met.
>
> Blank 3. Identify the type and scope of tests required to provide confidence that the requirement element has been met.

VERIFICATION LESSONS LEARNED (4.3.5.1.1)

The actual number of components and/or subsystems which are designed to be damage tolerant should be carefully reviewed since the imposition of these requirements does not usually come without some price (e.g., cost, weight, etc.).

3.3.5.1.2 Operation period/inspection

The components of safety- and mission-critical functions shall retain their function and residual strength throughout the operational period (component service life) with embedded flaws the size and characteristic that cannot be detected at acceptance (initial flaw size) and during routine inspection (in-service inspection flaw size). Scheduled inspection intervals shall be not greater than half the component damage tolerance operational period (service life).

REQUIREMENT RATIONALE (3.3.5.1.2)

The design goal should always be to minimize maintenance actions and air vehicle downtime. This requires that the components be designed for damage tolerance (i.e., not to require scheduled inspections for flaw/damage growth over the life of the air vehicle). Since these components are by definition safety- or mission-critical, they must be inspected at a period less than the full design service life in order to account for errors in the analysis and for variability in properties, materials, etc. Historically, the inspection period is set at one half the demonstrated life. For metallic structure, the minimum acceptable period of unrepaired service usage for slow crack growth structure is two service usage lifetimes (i.e., the time for a flaw to propagate to failure from some initial damage must be in excess of two service usage lifetimes). For nonmetallic structure, the minimum acceptable period of unrepaired service usage is also two service usage lifetimes.

REQUIREMENT GUIDANCE (3.3.5.1.2)

To Be Prepared

REQUIREMENT LESSONS LEARNED (3.3.5.1.2)

In a few cases it will not be practical to design the components to be damage tolerant for two design service lives. For those components, an exception should be noted in this paragraph.

4.3.5.1.2 Operation period/inspection verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Retention of function and residual strength	Estimated service life	A	A	A		I,A,T
Scheduled inspection intervals	Inspection interval	A	A	A		I,A,T

VERIFICATION DISCUSSION (4.3.5.1.2)

The verification for 3.3.5.1 Service life should be considered when developing this verification.

Inspections, analyses and tests should be conducted to demonstrate that operation period/inspection requirements have been met. The inspections, analyses and tests should be conducted as part of the overall integrity program for the specific procurement.

The analyses should demonstrate slow crack growth life from initial flaws for at least the design life period specified for each critical component. The analyses should account for potential growth under repeated loads, sustained loads and environments as defined in the usage requirements. Analysis methods should be verified by test.

Limited testing should be accomplished to validate the damage tolerance design life predictions. These tests may be based on simple components and small elements which verify individual segments of the analysis or may be conducted on actual preflawed hardware.

For situations involving periodic in–service inspection, it should be demonstrated that these components are in fact inspectable. This involves a review of the critical flaw sizes and the potential to detect smaller values using customary NDI means. It is essential that the specific techniques of inspection and validated practices be available before making the decision to design components to damage tolerance periods less than one design service life.

Key Development Activities

Key development activities include, but are not limited to, the following

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analysis of the design concept indicates the retention of function and residual strength over the design life and the specified inspection interval requirements are achievable.

PDR: Analysis of the preliminary design indicates the air vehicle has the ability to survive the usage environment for the design life for all mission- and safety-critical functions within the stated inspection intervals.

CDR: Analysis of the final air vehicle design confirms the ability to survive the usage environment for the design life for all mission- and safety-critical functions within the stated inspection intervals.

FFR: No unique verification action occurs at this milestone.

SVR: Analysis of lower-level test results, inspections, ground and flight tests confirm the air vehicle components of safety- and mission-critical functions retain their function and residual strength throughout the operational period with the specified inspection intervals.

Sample Final Verification Criteria

The operation period/inspection requirement shall be satisfied when __(1)__ inspections, __(2)__ analyses and __(3)__ tests confirm acceptable air vehicle component residual strength and inspection intervals.

> Blank 1. Identify the type and scope of inspections required to provide confidence that the requirement element has been met.
>
> Blank 2. Identify the type and scope of analyses required to provide confidence that the requirement element has been met.
>
> Blank 3. Identify the type and scope of tests required to provide confidence that the requirement element has been met.

VERIFICATION LESSONS LEARNED (4.3.5.1.2)

To Be Prepared

3.3.6 Nameplates and marking

3.3.6.1 Asset identification

Air vehicle assets which are repairable, replaceable, salvageable, or consumable shall be permanently identified by a method that is observable and recognizable, at the appropriate level of maintenance, throughout the life of the asset and that does not adversely affect the life and utility of the asset. The identification shall include __(1)__.

REQUIREMENT RATIONALE (3.3.6.1)

The intent is to ensure that all designated items are marked in such a way that they are identifiable and traceable. Identification markings are necessary on any air vehicle item (hardware, software, etc.), component, and part that is designated for replacement, repair, and/or salvage. Identification markings should not be required on items, components, or parts that would not be replaced, repaired, and/or salvaged. For example, resistors on a board would not be required to have identification markings if replacement, repair, and/or salvage were at the board level only. Identification markings also facilitate maintenance, modification, spares procurement, logistic supply systems, deficiency reporting, and configuration management. Marking air vehicle items, components, and parts by serial number (or other identifiers) enables rapid identification of specific items and provides pertinent information to the personnel required to support the air vehicle.

REQUIREMENT GUIDANCE (3.3.6.1)

> Blank 1. Complete with required identification method or information content, such as national stock number (NSN), serial number, commercial and Government entity (CAGE) code, manufacturer's part number, etc. For example, it may be required to include as part of the markings, a notice that an item, component, or part is subject to warranty and the period or conditions of that warranty.

MIL-STD-130 can be consulted for additional guidance on this requirement. Nomenclature should be provided for radio call plates. Marking or identification of radioactive material and rescue entrances should be provided. Recommend use of MIL-P-15024, 1 through 4, for items that have nomenclature, in accordance with MIL-N-18307. Identification can be implemented by any method that meets the requirement for the given asset. Such methods could include electronic, bar code, etching/engraving, etc.

REQUIREMENT LESSONS LEARNED (3.3.6.1)

Inadequately marked items can result in logistic support issues that adversely affect readiness. Placing the identification markings in locations where they are difficult or impossible to view can result in wasted time and labor.

4.3.6.1 Asset identification verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Assets identification	Presence of identification; Durability of identification	A	I	I		I

VERIFICATION DISCUSSION (4.3.6.1)

Asset identification is used for accountability and begins with design, progresses through development testing, continues for production procurement, and is used throughout deployment until disposal of each asset.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis indicates the establishment of a configuration management approach to identify parts, subassemblies, assemblies and software.

PDR: Inspection of air vehicle preliminary design documentation indicates assets which are repairable, replaceable, salvageable, or consumable have identification provisions, and that the intended marking is sufficiently durable for the anticipated environment and contains all necessary information.

CDR: Inspection of air vehicle design documentation confirms assets which are repairable, replaceable, salvageable, or consumable have identification provisions, the intended marking is sufficiently durable for the anticipated environment and contains all necessary information.

FFR: No unique verification action occurs at this milestone.

SVR: Inspections of available data from assembly, development test, and remove and replace actions confirm that hardware and software have been identified in accordance with their respective identification requirement(s).

Sample Final Verification Criteria

The asset identification requirement shall be satisfied when __(1)__ inspections confirm that assets which are repairable, replaceable, salvageable, or consumable are permanently identified as required.

> Blank 1. Identify the type and scope of inspections required to provide confidence that the asset identification requirement has been satisfied. For instance, available data should be inspected to confirm that any known instances of requirement nonconformance have been corrected by product definition change.

VERIFICATION LESSON LEARNED (4.3.6.1)

During one development program iterative changes were made to one or more parts in the process of attempting to reconcile a repetitive flight test defect. Initially no attempt was made to identify the changing software, therefore when the problem was resolved it was uncertain which changes had resulted in the successful resolution of the problem. Accordingly, unnecessary additional testing was required to determine which assets resulted in the corrective action.

When problems occur, nameplates can provide the capability to locate and isolate the lot(s) with the defective items.

3.3.6.2 Marking of cargo compartments

Each cargo compartment shall be marked, consistent with the load distribution limits for structure and c.g., to indicate the compartment designation and load limits with __(1)__. Compartment designations and load limits shall be marked to be visible to crewmembers when the compartment is in both a loaded and unloaded condition. Markings shall retain function for the service life of the vehicle with respect to the nominal rigors of operational use of the cargo compartments.

REQUIREMENT RATIONALE (3.3.6.2)

These markings are needed to provide for proper placement of cargo and accurate computation of air vehicle weight and balance, to assure operation within applicable weight and balance limits.

REQUIREMENT GUIDANCE (3.3.6.2)

Blank 1. Complete by using the guidance provided by the Society of Allied Weight Engineers (SAWE) Recommended Practice No. 7.

REQUIREMENT LESSONS LEARNED (3.3.6.2)

To Be Prepared

4.3.6.2 Marking of cargo compartments verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Cargo Compartments Marked (designations and load limits)	(1)		A	I		
Marking visibility	Visible to crewmembers under all load conditions		A	A,I		D
Marking durability	Retain functionality throughout service life		A	I		A

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.3.6.2)

Verification of cargo compartment marking is essential to ensure that cargo weight and balance distributions and the allowable load limits of the air vehicle can be checked/maintained within the designated c.g. range throughout each designated mission.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: No unique verification action occurs at this milestone.

PDR: Analysis, to include the results of the weight and balance analysis, indicates that a marking method that complies with content, format, visibility, location and service life durability requirements has been defined.

CDR: Analysis confirms that visibility requirements can be satisfied regardless of specified payload conditions. Inspection of drawings indicates that compartment distributions and load limits; marking method(s) which can achieve durability requirements; and locations for the markings have been established and incorporated.

FFR: No unique verification activities occur at this milestone. First flight typically has no cargo requirements.

SVR: Demonstration confirms marking visibility requirements are satisfied. Analysis of marking durability confirms service life usage requirements.

Sample Final Verification Criteria

The cargo compartment marking requirements shall be verified by __(1)__ analysis and demonstrations.

> Blank 1. Identify the type and scope of demonstrations and analyses required to provide confidence that the marking of cargo compartments, marking visibility, and marking durability requirements have been satisfied.

VERIFICATION LESSONS LEARNED (4.3.6.2)

To Be Prepared

3.3.7 Diagnostics and health management

The air vehicle shall provide a diagnostics and health management capability that satisfies mission, safety, and maintenance support requirements. The diagnostics and health management function shall detect, report and record the loss or degradation of air vehicle safety and mission functions during, ground and flight operations in time to preclude loss or further degradation of safety and mission functions and shall unambiguously isolate such loss or degradation to the discrepant item. The diagnostics function, upon power-on, shall determine status of the air vehicle functions to verify readiness for operation and report said status to the maintainer and operator.

The air vehicle shall provide a health management function which will monitor the behavior of the air vehicle functions, analyze the health management data collected, predict and report future health to the air vehicle management function, the operator, and/or the maintainer in time to enable restoration, reconfiguration or retention of air vehicle health. The health management function shall provide sufficient coverage of potential deficit performance behaviors to enable the air vehicle to meet safety, service life, operability, reliability, and maintainability requirements stated herein.

4.3.7 Diagnostics and health management verification

Verification for this requirement is included with 4.3.7.1 Diagnostics fault detection and fault isolation verification

3.3.7.1 Diagnostics fault detection and fault isolation

Diagnostics shall detect not less than __(1)__ percent of all failed line replaceable assemblies and shall unambiguously isolate __(2)__ percent of those failures.

REQUIREMENT RATIONALE (3.3.7.1)

Diagnostics and health management information is required by operators, maintainers and by the equipment itself to enable safe and effective control of the air vehicle. The cornerstone of the supporting maintenance system capability is the capability to determine the status of all elements of the air vehicle and the unambiguous location of faults in a timely and life cycle cost effective manner. Health management information is required by the aircrew and the subsystems for safe and effective operation and control of the air vehicle. The cornerstone of the supporting maintenance system capability is the capability to determine the status of all elements of the air vehicle and the unambiguous location of faults in a timely and life cycle cost effective manner. Status reporting, fault detection and fault isolation times should be derived from mission, operational effectiveness, interface, safety and supportability requirements.

Effective support of the air vehicle requires knowledge of faults and fault history information collected during air vehicle operation. Also, implementation of integrity program life management requirements for the air vehicle's structure, mechanical, and electronic systems and equipment will require knowledge of environmental conditions encountered during air vehicle operations. Use of the collected data requires that it be related to specific air vehicle and equipment items by serial number.

REQUIREMENT GUIDANCE (3.3.7.1)

Diagnostics implementation may be continuous or based on some other condition such as "during function use." For safety- and mission-critical functions, continuous monitoring may be necessary. Other functions which are not safety- or mission-critical and which are only used occasionally may be subject to other monitoring conditions. As the requirement is written, the frequency of monitoring will be whatever is necessary to meet the mission, safety and maintenance support requirements for the air vehicle.

> Blanks 1 and 2. Quantitative detection and isolation requirements should be selected based on the ability to meet elements necessary to meet user requirements, enable operational reconfiguration and user supportability requirements associated with the planned maintenance concept.

REQUIREMENT LESSONS LEARNED (3.3.7.1)

The functional complexity of air vehicles requires the ready identification, isolation and removal/replacement of defective equipment via built-in test diagnostics. Consistent with equipment design and complexity, BIT capabilities need to be designed for accurate identification and isolation to minimize air vehicle down time, ease of maintenance and servicing.

Failures and unscheduled maintenance will occur during the air vehicle life cycle consistent with reliability and maintainability design attributes. Consistent with equipment design and complexity, BIT diagnostics need to be designed for accurate identification, isolation and removal to minimize air vehicle downtime and for ease of servicing.

Sensing and collecting the information should be integrated during the design of the systems and equipment, so that the overall design of the system is simplified; and so that few, if any, sensors are required solely to satisfy diagnostic fault isolation requirements for the equipment, subsystems, and systems should be followed throughout the diagnostic requirements derivation and allocation, and subsequent design and development processes.

Determination of status refers not only to determination of operating parameters and to detection of faults, but also to servicing and replenishment needs for consumables. The term faults refers not only to faults which are observable no matter when the faulty equipment is operated or tested, but also to performance eroding faults which manifest symptoms only in particular situations. Note that for this latter type of nonstationary fault, the diagnostic system should be capable of documenting the fault indications and interpreting these indications in the context of any previous (or subsequent) related indications in order to recognize any significant patterns.

Experience with the design of the B-2 on-board diagnostics system has shown that the judicious placement of sensors required for operation and control of airframe, propulsion, air vehicle utilities and subsystems can, by itself, enable a very high degree of fault isolation (ambiguity groups of two or fewer replaceable assemblies for all faults). Achievement of this capability requires that significant attention to the testability of these primarily mechanical systems be addressed from the beginning of the design effort.

It is well known that equipment may demonstrate faulty performance during air vehicle operation but, when operated on the ground, may appear to perform satisfactorily. Such incidents are reported in maintenance records as cannot duplicates (CNDs). CND rates in excess of 50% have been reported on many weapon systems currently in inventory. Several studies have shown that maintenance analysis of in-flight recorded failure data, including pertinent environmental data at the time of failure occurrence, can enable appropriate corrective maintenance actions. Such analysis of in-flight recorded failure data is the only known effective method for resolving such occurrences.

One of the largest problems faced by Naval Aviation systems in the last 20 years has been high BIT false alarm rates. This is when BIT indicates a problem when none exists. In user parlance, this is referred to as CND. These false BIT indications cause unnecessary removals of expensive line replaceable units and cause unnecessary maintenance burdens at all levels of maintenance. When equipment comes into a repair shop with nothing wrong, it ties up test stations while attempting to find a nonexistent problem. In addition, experience has shown that a high rate of false BIT indications degrades user confidence in aircraft diagnostics and eventually leads the users to ignore BIT indications. This has created situations in which the user has operated aircraft with failed systems. High false alarm rates contribute to increased total ownership costs, increased aircraft downtime, increased manpower requirements, increased spares requirements and decreased user confidence. The F/A-18E/F program is the first program that made major progress in minimizing BIT false alarms. The following lessons were learned from that program: (1) must apply a dedicated team approach that includes the prime contractor, major subs and Government, (2) dedicated Government and contractor resources must be applied during avionics integration to work BIT issues, (3) weekly BIT data review board to address, research and resolve all BIT anomalies, analyze data and develop periodic BIT progress reports, assign dedicated integration engineers to investigate each BIT anomaly,

(4) few false alarms were found in the lab most found during flight tests due to timing, switchology, integration issues, power, pilot/maintainer procedures, (5) use of common BIT data sources between the contractor and Government so all analyses use same source.

RAND report R-3604/2-AF documents the need for complete reporting of failure data, not only for faults, which are observable no matter when the faulty equipment is operated or tested, but also for performance eroding faults, which manifest symptoms, only in particular situations. For this latter type of non-stationary fault, the diagnostic system should be capable of documenting the fault indications and interpreting these indications in the context of any previous (or subsequent) related indications in order to recognize any significant patterns.

4.3.7.1 Diagnostics fault detection and fault isolation verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Diagnostics and health management	Diagnostic and health management functionality c.□ Fault detection Fault isolation	A	A	A	A	A,T, D

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.3.7.1)

Verification of air vehicle diagnostics and health management should be accomplished by carefully integrating appropriate diagnostic analyses, tests and demonstrations into the overall air vehicle development program. Verification of diagnostics and health management performance requires an iterative process to verify, at each step of the development process, the adequacy of air vehicle diagnostic performance.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Preliminary analyses shows the integrated diagnostics design is compatible with requirement based on systems design and maintenance concept and preliminary subsystem-level built-in test (BIT) predictions (and subcontract requirements, where available). The maintenance concepts (including on-board and off-board diagnostic tools) associated with peacetime and wartime have been defined to adequately enable air vehicle integrated diagnostics design refinement. General architecture of the integrated diagnostic design architecture should be established during this phase with emphasis on type of diagnostic information and means by which this information will be presented to the aircrew and maintainer. Consensus is reached on the verification/validation of diagnostic maturity (whether numerical or levels of detail) at program milestones. Verification test/demonstration methods and acceptance criteria based on agreed-to verification method employed have been incorporated into schedules, facilities requirements, manpower needs, and other programmatic imperatives. Measurement and maturity management of air vehicle diagnostics have been integrated into the overall management of the program.

PDR: Preliminary analysis confirms that the air vehicle integrated diagnostics design and preliminary subsystem fault detection and isolation predictions are consistent. Integrated diagnostic design architecture should define the types and means by which diagnostic information (Warning/Caution/Advisory, Exceedances, etc.) will be presented to the aircrew and maintainer consistent with the maintenance concept. Preliminary failure modes and effects criticality analyses (FMECA), testability analyses and fault detection and isolation predictions have been updated to include subcontractor information. Diagnostic analysis/modeling are integrated into higher-level requirements and analyses (maintainability, availability, etc.).

CDR: Assessment of final subsystem and air vehicle diagnostic functionality has been accomplished based on detailed design analyses. FMECA (or acceptable like analysis) addresses diagnostic capability (BIT coverage) to detect and isolate both internal failures of system as well as input failures to those same systems. All diagnostic information presented is substantiated through engineering and diagnostic analyses. The maintenance concept of air vehicle integrated diagnostics has been updated to reflect changes in diagnostics design, use of on-board or off-board diagnostic aids, etc.

FFR: FMECA (or acceptable like analysis) has been completed that addresses diagnostic capability to detect and isolate all failures. This includes the effects of diagnostics/ maintenance/inspection requirements to identify the presence of any mission- or safety-critical malfunctions. Diagnostics indications of failures deemed to be safety critical via FMECA or subsystem safety hazard analysis (SSHA) are addressed in flight crew and maintenance technical orders. Fault detection, isolation predictions and associated models are updated, as necessary, to reflect incorporation of subsystem diagnostic test/demonstration results. Diagnostic analysis/modeling integrated into higher-level requirements and analyses (maintainability, availability, etc.).

SVR: The integrated diagnostics maintenance concept has been updated to reflect test results. Adjustments for results of flight test information (BIT codes, compensating provisions, etc.) and other diagnostics tests/demonstration results have been incorporated in the FMECA. Analysis and flight test results of all diagnostics information confirms air vehicle diagnostics requirements have been met. Diagnostic analysis/modeling are integrated into higher-level requirements and analyses (maintainability, availability, etc.).

Sample Final Verification Criteria

The integrated diagnostic requirement shall be satisfied if analyses and flight test data generated during the __(1)__, meets or exceeds the specified fault detection and fault isolation requirements. Diagnostic relevancy criteria will be determined in accordance with the __(2)__. Analyses and flight test data shall also validate that the diagnostics monitoring capability correctly analyzes air vehicle functions to predict future health and reports this information to the operator and maintainer in a timely manner.

> Blank 1. Specify flight test period in which the air vehicle will be measured for compliance. For example, if the data collection period will run from first flight through a specific flight test milestone, specify that in blank 1.
>
> Blank 2. Include reference that describes process by which diagnostics will be evaluated (for example, the Joint Reliability Maintainability Evaluation Team charter).

VERIFICATION LESSONS LEARNED (4.3.7.1)

Qualification tests and demonstrations of supported subsystems and equipment must include tests and/or demonstrations to verify the adequacy of maintenance system capabilities, tools, equipment, and technical data to perform all required maintenance functions thereon. Note that this requirement is not intended to preclude the use of laboratory and other special test equipment for engineering development test activity support during flight test but is intended to force contractor reliance on identified operational maintenance system capabilities and equipment for all maintenance activities which could be anticipated to occur in weapon system operational use. Consider the following lessons, where appropriate:

Use the diagnostics to support all air vehicle flight test activities in conjunction with the support system's diagnostic functions. (This is not intended to preclude or eliminate the use of flight test instrumentation, but is intended to both supplement the flight test instrumentation and provide continuing, in-depth, verification of the diagnostics.)

Incrementally verify support system diagnostic interfaces and functions during weapon system development test and evaluation (DT&E) and operational test and evaluation (OT&E) by a combination of tests and demonstrations. The results of the in-process comparative analyses should be used as a checklist to verify that all maintenance system functions are physically verified.

Use built-in diagnostic capability to support final assembly checkout and flight test activities combined with comprehensive maintenance data collection and analysis.

Use the common tools and support equipment identified for operational use to support manufacturing, checkout, and flight test activities combined with comprehensive maintenance data collection and analysis (including collection and analysis of data analogous to "maintenance data" from the manufacturing and checkout operations).

Use development program manuals (DPMs) which are procedurally and physically as close to the planned technical orders (TOs) as possible to support flight test operational and maintenance activities.

Use a maintenance data collection and analysis system for flight test support that is (1) designed to interface with and support the contractor's reliability and maintainability data collection and analysis system, (2) designed to be compatible with the maintenance data collection and analysis system planned for operational use.

Use the technical order (TO) validation and verification process to verify integrated diagnostic compatibility with maintenance or servicing functions and related support equipment.

3.3.8 Recording

3.3.8.1 Information collection

The air vehicle shall provide the capability of retaining __(1)__ information from onboard sensors, displays and __(2)__ in a form, which shall enable subsequent retrieval and analysis.

REQUIREMENT RATIONALE (3.3.8.1)

This requirement ensures a capability for the air vehicle to provide post mission data for training and mission analysis.

REQUIREMENT GUIDANCE (3.3.8.1)

Blank 1. Complete with information such as pilot view of engagement, Battle Damage Assessment (BDA), mission playback, training, etc.

Blank 2. Complete with entries such as voice and video.

Audio cockpit signals, voice and tonal, associated with the aircrew's microphone and headset should be included in the recording function. A cockpit control should be provided which will allow the aircrew to manually activate such recording function.

REQUIREMENT LESSONS LEARNED (3.3.8.1)

To Be Prepared

4.3.8.1 Information collection verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Recorded mission information, including sensor data, display parameters, cockpit voice,	Captured parameters and storage capacity	A	A,I	A		A,D
Retrieval of recorded Information	Retrieved parameters	A	A,I	A		A,D

VERIFICATION DISCUSSION (4.3.8.1)

Verification activity needs to address the three key design areas. These are the information collection methods, the Information recording methods, and the in-flight or post-flight information retrieval methods.

However, due to commonality of requirement elements, verification approach and methodology, these design areas are addressed as a unit. Initial verification should consist of analysis activities and final verification should include both analyses and tests or demonstrations. Integration with other recording functions should also be considered as possible information sources. Verification of this requirement would typically be accomplished as part of other air vehicle verification tests. Use of this type of data should be used to avoid the cost and schedule impacts of formal stand-alone demonstrations.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analysis indicates the air vehicle conceptual design, including information collection, recording and retrieval satisfies the basic mission need. Analysis identifies mission parameters to be collected. Functional analysis indicates logical allocations to hardware and software elements.

PDR: Analysis of requirement, design trade study results, and preliminary designs for the various components of the information collection function indicates the individual elements have been functionally integrated within the air vehicle as well as integrated with the overall weapon system. Inspection of required parameters, sources, data rates, and data compression algorithms (if used) indicates readiness for detailed design. Analysis defines initial definition of the operational in-flight and post flight environment expected to be experienced by the information collection function and collection limitations.

CDR: Analyses of the air vehicle design, including lower-level development testing, the information collection function integration into the air vehicle, and the integration with all applicable air vehicle systems and functions, including support systems confirm a “ready for build” status. Analysis confirms that information parameters to be recorded include all data necessary for evaluation of the mission. Analysis of updated operational in-flight and post-flight environments expected to be experienced by the information collection function with collection limitations defined, confirms capability to achieve the requirement. Analyses of lower-level hardware and software tests, hardware-in-the-loop integrated systems tests, including integration with other air vehicle systems, confirm that the system can achieve functional requirements.

FFR: No unique verification actions occur at this milestone.

SVR: Air vehicle demonstrations, along with analysis of lower-level demonstrations and tests, confirm that collection, storage, and retrieval requirements have been achieved. Analysis and demonstrations confirm that the derived air vehicle functional condition parameters have been recorded.

Sample Final Verification Criteria

This requirement shall be satisfied when __(1)__analyses and demonstrations confirm that the air vehicle information collection capability provides for retaining required information from the specified sources, in a form, which enables subsequent retrieval.

> Blank 1. List the type and scope of analysis and demonstrations required to provide confidence that the requirement has been achieved.

VERIFICATION LESSONS LEARNED (4.3.8.1)

To Be Prepared

3.3.8.2 Crash recording

The air vehicle shall retain, in a survivable and post incident retrievable form, __(1)__ minutes of air vehicle state and functional condition information, including human voice and interface actions, prior to a catastrophic loss of the air vehicle. Such information shall be retrievable from a range of __(2)__ and for a duration of __(3)__. Such information shall include the data necessary to permit determination of the precipitative events or conditions responsible for the ultimate catastrophic loss.

REQUIREMENT RATIONALE (3.3.8.2)

Typically, throughout the life cycle of an air vehicle, specific types of flight data are required to be recorded for analysis relative to evolving areas of concern.

REQUIREMENT GUIDANCE (3.3.8.2)

> Blank 1. Complete by citing the minimum length of pre-incident data required. In completing blank 1, specification preparers should consider anticipated recording and storage resources needed and include potential for growth of recorded parameters in future development phases. Specification preparers should consult with the appropriate safety center to determine the time required.

Blank 2. Complete by specifying the distance (miles, fathoms, etc.) from which the crash recording function can be detected for purposes of retrieval.

Blank 3. Complete by specifying the length of time that the crash recording function must emit the necessary information to enable retrieval. Note that time/range may be different for land verses water retrieval.

Consideration should be made as to the location of the crash recording function on the air vehicle. A location should be selected which will facilitate survival of potential severe incidents. Selecting structure, which may be more prone to break away versus burn or crush, is a good general rule of thumb.

Commonality with other platforms with similar needs, potential use of COTS equipment, information types and intended use, and security, if applicable, should be considered. If an existing crash recording system is required, it may be more appropriate to specify a requirement for interface to the existing system rather than specify the requirement in this paragraph.

REQUIREMENT LESSONS LEARNED (3.3.8.2)

Recorders that have been previously incorporated in addition to the crash recorder(s) include the following: recorder for structural life monitoring, an embedded recorder for real time engine monitoring, mission data recorders, a cockpit voice recorder, and post crash safety data recorder. Legacy crash data recorders identify the parameters for each recording device to be included in the air vehicle (including such requirements as the data-recording rate, and the retention time for the recorded data, including cockpit voice recording device). They also specify which recording device(s) should include an underwater acoustic beacon locator. The Navy and Air Force Safety Centers expect a crash survivable flight incident recorder to be included in the air vehicle.

4.3.8.2 Crash recording verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Recorded functional condition information, including human voice and interface actions	Air vehicle functional condition parameters	A	A	A	A	A,T, D
Storage capability	(1) Minutes	A	A	A	A	A,T, D
Capability of retrieving information	(2) Range (3) Life (hrs)	A	A	A	A	A
Survivability	Environment during and after catastrophic event	A	A	A	A	A

*Numbers in parentheses in the Measurand column refer to numbered blanks in the requirement.

VERIFICATION DISCUSSION (4.3.8.2)

Verification activity can be segregated into three key design areas. These include the storage capacity of the unit, the need to locate the device after a mishap, and the mechanical design of the unit for crash survivability. However, due to commonality of requirement elements, verification approach and methodology, the design areas are addressed as a unit. Initial verification should consist of analysis activities and final verification should include both analyses and tests or demonstrations. Integration with other recording functions should also be considered as possible information sources.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analyses of a conceptual design, including storage capacity, locator, and crash survivability in terms of recorder's ability to satisfy a basic weapon system need should be available. Functional analysis should verify proper allocations to hardware and software elements.

PDR: Requirement analyses, design trade study results, and analyses of any preliminary designs for the various components of the crash recording function; preliminary analyses addressing risk associated with both functional and installation specific requirements; evidence the individual elements have been functionally integrated within the air vehicle as well as, integrated with the overall weapon system; required parameters, sources, data rates; data compression algorithms, if used, should be available. Initial definition of the operational and post crash environment, expected to be experienced by the crash recording function, should be accomplished and survivability limits defined.

CDR: Analyses of a detailed design, including development testing of individual elements for the defined requirements; crash recording function integration into the air vehicle, and integration with all applicable air vehicle systems and functions, including support systems should be completed. Analysis confirms that data parameters to be recorded include all data necessary for proper evaluation of all air vehicle systems in the event of a mishap. Updated definition of the operational and post crash environment, expected to be experienced by the crash recording function, should be accomplished and survivability limits defined.

FFR: Analysis, including analysis of formal subsystem testing/demonstrations, completed. Functional requirements validation in stand-alone hardware and software tests, hardware-in-the-loop integrated systems tests including integration with other aircraft systems completed. Applicable limitations documented.

SVR: Analyses, including analysis of subsystem demonstrations and tests, verify storage capability, retrieval capability, and crash survivability requirements are met. In addition, analysis/demonstrations confirm that the appropriate air vehicle functional condition parameters are recorded.

Sample Final Verification Criteria

Analyses, tests and/or demonstrations shall ensure __(1)__ minutes of air vehicle state and functional condition information, including human voice and interface actions, prior to a catastrophic loss of the air vehicle, is recorded. Crash recording function shall be verified by test supported analyses, to survive specified crash conditions.

Blank 1. Repeat the length of data recording cited in the requirement.

VERIFICATION LESSONS LEARNED (4.3.8.2)

For establishing recording times at the PDR timeframe or earlier, it is beneficial to establish a typical “flight." Since mishap recorders usually employ some kind of data compression scheme the more active the flight the more data that is recorded. To ease verification issues at a later date, it is a good idea to establish a typical or normalized mission scenario to fly for verification of the recording time limit.

The industry typically uses a European standard called EUROCAE (reference EUROCAE ED 55 in 1995) to establish the requirements for crash survivability. EUROCAE also includes information on verification approaches.

Verification of penetration force should examine geometry of unit and attempt penetration at most vulnerable point. Historically the penetration point was the middle of some selected face of the unit. The middle though, is likely to have a structural rib, so it is not an ideal place to select for through penetration testing.

Verification of impact survivability is usually done with low G and high G impact test. The verification test should be designed for repeatability and have the capability to measure and control the energy distribution exerted on the unit. Energy curves can be found in the EUROCAE standard ED55 or newer. The test should also incorporate multiple impacts at various axes of the unit. Historically corner impacts have the greatest probability for failure and thus should be impacted.

In conducting verification of impact or static crush tests, careful consideration should be given to the test fixtures. These tests quickly become invalid if there is excessive movement of the crash unit within the test fixture. Fixtures should be designed to eliminate movement that is not parallel to the test force being applied. Fixtures are a primary mechanism for controlling the energy exerted on a unit during these types of survivability tests.

Validation of data recording requires a tool that has the flexibility to synchronize crash recorder data with instrumentation recorded data. Crash recorders will begin recording as designed (at startup), but instrumentation data will not begin recording until it is deemed needed (when someone flips the on switch). This difference in the start of recording causes the crash recorder data needing to be verified with instrumentation data to require synchronization before verification can begin. The F-22 found that the best analysis tool was one capable of graphically representing the two data sets and then synchronizing the graphical representations to a common time.

When flight testing an instrumented test air vehicle, the flight test program is usually not dependent on a crash recorder, so crash survivability is not much of an issue at FFR. If this is a retrofit or add-on to an operational air vehicle, some limited survivability capability may need to be demonstrated/tested at FFR.

3.3.9 Security

The air vehicle shall deny access to sensitive assets, capabilities, and information by unauthorized parties or functions. Air vehicle functions shall be protected from security threats as specified in table 3.3.9-I.

TABLE 3.3.9-I. Air vehicle security threats.

Air Vehicle Functions	Function Sensitivity	Threat

REQUIREMENT RATIONALE (3.3.9)

Air vehicle security is required to eliminate or reduce characteristics that could result in deficiencies, which adversely impact the mission and national security. This includes protection of classified information and protection against intentional or inadvertent misuse of the air vehicle and air vehicle subsystems. The goal of the requirement is selectively and effectively to apply security countermeasures that are cost-effective and consistent with program risk management principles. The application of air vehicle security varies depending on the scope of the program and user requirements. Paragraph 4.4.5 of DoD 5000.2R requires that acquisition programs identify elements of the program that require protection.

REQUIREMENT GUIDANCE (3.3.9)

After it is determined that system security is applicable to the air vehicle, the necessary requirements are identified. This will vary from program to program depending on many variables. If an air vehicle is multi-service, that is, the air vehicle will perform on ships as well as ground stations and is linked to other air vehicles and satellites, the application will be more involved. The processes a program manager and the program security representative might initiate to complete the table include identification of the mission-critical elements of the air vehicle, assessing threats to those elements, risk analysis and countermeasure determination, if any, to be applied. The table should be completed with emphasis on program length from ORD development to demilitarization (if the air vehicle is to be demilitarized), Government and United States relationships with air vehicle developer, and interactions with foreign governments and developers.

Guidance for completing table 3.3.9-I follows:

<u>Air Vehicle Functions</u>: Identify the functions, which require protection. Some functions, which may be included, are safety- and mission-critical functions and classified components and data. There may be other functions unique to the system, which should also be included. Some functions to consider would include transmitted data, data resident on the air vehicle during normal ground handling, flight operations, and post air vehicle crash. Generally, physical, electronic, and software threats are applicable to functions that will be listed in the table.

<u>Functional Sensitivity</u>: Identifying the sensitivity of the function information or technology to be protected.

<u>Threat</u>: Identifying the threats to each function through the life cycle of the air vehicle. In order to defend against a threat, the threat must be identified and determined to be viable. The column

should include the most realistic threats and associated vulnerabilities to the weapon system through the life cycle.

REQUIREMENT LESSONS LEARNED (3.3.9)

The flight line reprogramming capability on the air vehicle enhances operational readiness, but brings security more vividly into the picture. What were formerly unclassified functions may now need security procedures and techniques to be included in the overall function design. An example is the digital flight control system. Although the control laws may be unclassified, the effects of sabotaged or inadvertently altered programs could have a catastrophic effect on the air vehicle. Thus, trusted software bases and accountability procedures may be warranted. On one program the system security engineering manager and the systems engineer developed strict configuration control of a software baseline that would detect tampering by use of a special algorithm.

Security measures (hardware, firmware, software, procedures, etc.) must be accredited and certified by appropriate Risk Acceptance Authority (RAA) and Designated Approval Authority (DAA) prior to its use. The DAA or RAA will indicate if there are any special requirements that need to be specified. Each service has an agency to help with certification and accreditation. The acquisition security specialist can provide the name and address of the appropriate organization. Often, the term certification official is used in place of RAA and DAA. The program acquisition security representative should assist in the preparation of table 3.3.9-I. As with most other specialties, failure to plan for and incorporate security into the program up front ultimately results in added costs later in the program due to retrofits, modifications, and operational restrictions. This is particularly so in the case when the RAA establishes the security requirements and must know the requirements before the project is started.

Since procedures are an integral part of most security systems, it is mandatory that all personnel be properly trained. The best security system is not effective if those who are responsible for it are not trained or capable of working within the security limits. Initial security training requirements/procedures must be established, monitored and analyzed to ensure that they are adequate and that personnel can operate and maintain the system within security guidelines. If trained development and operations personnel are not available, the air vehicle may not be accredited as acceptable for operation. Also, the system could be accidentally compromised through improper use.

Typically, the DAA will witness and examine and attempt circumvention with representative operating personnel. For some systems the DAA will attempt to make it a provision of certification that these named individuals must be responsible for operation of the security system. The process of accreditation/certification ensures the security system is capable of performing its mission/role in a variety of uses. It also provides the appropriate level of certification to perform its mission/role (e.g., National Security Agency (NSA)/CIA for intelligence systems, DNS/DIA for nuclear missions, NSA/DIA for encryption devices, etc.). The wider the variety of security system utility, the wider the range and level of accreditation and certification of RAA/DAA. Many of the security issues, like COMSEC, COMPUSEC, etc. have unique verification requirements. For example, for COMPUSEC there will be a DAA who pretty much has the final say as to whether you are authorized to operate the computer system (the DAA performs a technical evaluation, the RAA then says "Yes, I think the risk of operating this system with these controls in place is acceptable"). If there are communications devices involved you have to deal with protecting crypto keys. This will probably be done in the computer so now we have at least two disciplines affecting the same item (the computer resources). There are potentially other organizations that will have requirements for physical security or prevention of sabotage. Owners of some data (for example, NSA) want assurance that their data will be adequately protected. All of these organizations need to be satisfied. If they are not satisfied you will not get their data or be allowed to connect to their systems and your program will not be allowed to proceed until the issue is resolved, usually at considerable cost in schedule and effort. It will be beneficial to contact these people as soon as they can be identified so that all of their needs can be met. In some cases the program manager becomes the RAA with ultimate approval.

4.3.9 Security verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Air vehicle function (1) Threat (a)	Security provisions for accreditation/ certification at required level	A	A,I	A,I	A,D, I	A,D, I,T
Air vehicle function (1) Threat (b)…etc.	Security provisions for accreditation/ certification at required level	A	A,I	A,I	A,D, I	A,D, I,T
Air vehicle function (2) Threat (a)	Security provisions for accreditation/ certification at required level	A	A,I	A,I	A,D, I	A,D, I,T
Air vehicle function (2) Threat (b)…etc.	Security provisions for accreditation/ certification at required level	A	A,I	A,I	A,D, I	A,D, I,T
Air vehicle function (…) Threat (a)…etc.	Security provisions for accreditation/ certification at required level	A	A,I	A,I	A,D, I	A,D, I,T
Air vehicle function (…) Threat (b)…etc.	Security provisions for accreditation/ certification at required level	A	A,I	A,I	A,D, I	A,D, I,T
…etc.						

VERIFICATION DISCUSSION (4.3.9)

Final accreditation/certification for the aircraft vehicle can only be attained from the end user since part of the accreditation is personnel training and other issues, such as proper operating procedures. Security verification should therefore focus on the features that are under developer control, and be accomplished incrementally with a combination of analysis, modeling, simulation, inspection, demonstration and test. For each threat to each air vehicle function, a level of security accreditation/certification should be described by the government and the developer's features in support of that accreditation/certification should be verified. Threats should be addressed individually, and in combinations that are expected to occur in field operations, manufacturing, training, maintenance, transportation and handling. MIL-HDBK-1785, *System Security Engineering Program Management Requirements,* should be consulted for further guidance.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analysis of the air vehicle design concept indicates the integration of security provisions into the systems engineering process and that requirements have been allocated properly to the air vehicle and subsystems.

PDR: Analysis and inspections of the preliminary air vehicle design and lower-tier specifications indicate the derivation of appropriate lower-tier security requirements for the development, manufacturing and operational life of the air vehicle. Analysis of the design indicates appropriate security provisions for the aircrew and maintainer to operate and maintain the air vehicle and achieve successful mission performance under all specified security threats. This analysis should be done on an iterative basis as the developer modifies the design. Security vulnerability analysis identifies any air vehicle level security requirements that require consideration.

CDR: Analysis and inspections of the air vehicle design information, and updated analysis of lower-level test/demonstration data indicates an ability to achieve secure development, manufacturing and operational aircrew and maintainer mission performance under specified threat conditions. Analysis of the design indicates the presence of security functions for lifecycle information protection, for secure operation of the air vehicle and for aircrew situational awareness under threat conditions encountered during the mission, fully supportive of government accreditation/certification requirements.

FFR: Analysis, demonstration and inspection of the air vehicle security design and provisions confirm security functions and operations are implemented for conduct of first flight.

SVR: Analysis of lower-level test and demonstration data, demonstration, inspection and test of the total air vehicle security provisions confirm that for each air vehicle function, security requirements are in place for protection of information throughout the lifecycle of the air vehicle. Additionally, the ability of the aircrew and maintainer to securely conduct all required mission operations under specified security threat conditions is confirmed.

Sample Final Verification Criteria

The security requirements shall be satisfied when __(1)__ analyses, __(2)__ inspections, __(3)__ demonstrations, and __(4)__ tests confirm that security requirements required to attain government accreditation/certification throughout the lifecycle of the air vehicle, for all air vehicle functions, are in place and operational.

Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement has been met.

Blank 2. Identify the type and scope of inspections required to provide confidence that the requirement has been met.

Blank 3. Identify the type and scope of demonstrations required to provide confidence that the requirement has been met.

Blank 4. Identify the type and scope of tests required to provide confidence that the requirement has been met.

VERIFICATION LESSONS LEARNED (4.3.9)

To Be Prepared

3.3.10 Safety

The air vehicle, when performing the prescribed missions within the environments specified herein, shall have a cumulative risk hazard index (RHI)* not greater than __(1)__ for all identified hazards with individual risk hazard index values not less than __(2)__. The identified hazards, each of which is comprised of the expected frequency of the hazard occurrence and the consequent loss of said occurrence, do not include those attributable to acts of war, combat, civil unrest and disorder. Nor do they include acts of nature except as specifically identified in the environments and missions delineated herein. The cumulative risk hazard index shall be the sum of the risk hazard indices associated with the frequency of occurrence and the consequence for each hazard, where such value for the risk hazard index shall be as defined in table 3.3.6-I.

*****Note: Risk hazard index (RHI) is equivalent to mishap risk assessment (MRA).

TABLE 3.3.10-I. Individual risk hazard indices.

	Hazard Frequency					
Hazard Consequence	__(F1)__	__(F2)__	__(F3)__	__(F4)__	__(F5)__	__(F6)__
__(C1)__						
__(C2)__						
__(C3)__						
__(C4)__						
__(C5)__						

Hazard Consequence. The following consequence definitions shall be used to quantify identified hazards:

C1: __(C1 Description)__

C2: __(C2 Description)__

C3: __(C3 Description)__

C4: __(C4 Description)__

C5: __(C5 Description)__

Hazard Frequency. The following hazard frequency definitions shall be used to quantify identified hazards:

F1: __(F1 Description)__

F2: __(F2 Description)__

F3: __(F3 Description)__

F4: __(F4 Description)__

F5: __(F5 Description)__

F6: __(F6 Description)__

REQUIREMENT RATIONALE (3.3.10)

This requirement establishes the overall requirement for air vehicle safety. Specifying an allowed maximum for hazards provides a performance basis for the requirement as well as providing the developing agent with a trade space for cost effective safety decisions. The requirement has been crafted to encompass the material, human, and environmental aspects of safety. Too often safety has been addressed procedurally or with prescribed solution approaches that have, at times, necessitated intense government oversight to ensure compliance. While such approaches have provided some degree of success, it is not evident that resulting designs have realized the degree of success or vehicle optimization that could be effected via use of performance requirements thereby enabling innovative solutions.

There are circumstances in which additional safety related, air vehicle requirements become necessary. For example, air vehicle noncombat related losses is one of the factors used in determining the buy quantity and such a requirement is included in this document.

REQUIREMENT GUIDANCE (3.3.10)

This requirement has been structured to control hazards within a region of risk hazard indices. The developing agent is required to ensure that the cumulative risk hazard index, for every hazard above a given level, is not exceeded. That is, every hazard in the air vehicle is characterized in terms of its consequences of occurrence and its frequency of occurrence. Each hazard is then assigned a risk hazard index based on its frequency of occurrence and its consequence of occurrence. For all hazards with a risk hazard index greater than the threshold value established (the value specified in blank 2 of the requirement), the risk hazard index is summed. The cumulative value computed must not exceed the allowed cumulative value specified in blank 1 of the requirement.

For example, assume individual risk hazard indices are as shown in example table #1 below and that the cumulative value for all hazards specified in blank 1 was 1000 and that the threshold value specified in blank 2 was 6. Hazards with risk hazard indices less than or equal to 6 (the light blue cells) are not counted against the summed RHIs. The developing agent is still responsible for identifying and characterizing all the hazards. However, those hazards with RHI’s less than the threshold (the light blue cells) will not be subject to the same level of management attention as the other hazards. When the joint government and industry team devised this requirement, there was a strong emphasis to provide an enabling mechanism to eliminate excessive design and management efforts for factors having negligible payoffs. As this requirement is formulated, the specifying agency can choose where that threshold lies for their program. For example, the threshold could be lowered to “1” (in blank 2) and all hazards would be subject to a similar level of technical and management scrutiny. Specification of higher values for the threshold that result in some categories (and as a consequence, some hazards) to not be addressed as part of the “cumulative” requirement controlled by blank 1, does not mean they are ignored. As part of the verification of the requirement, specific criteria should address the degree of confirmation necessary to establish the existence of safety hazards and their associated consequences and frequencies. The developing agent should confirm that reasonable attention has been given to the identification of all safety hazards and that the characteristics of each hazard have been adequately characterized.

Continuing the example, the cells in green identify the hazards that must not exceed the cumulative requirement. Suppose that there were 100 hazards identified in the initial vehicle design with an RHI greater than 6. Clearly, if 33 of those hazards were categorized as both “Catastrophic” and “Frequent” the requirement would not be met. The developing agent would be redesigning the vehicle to drive the risk hazard indices lower. The trade space enabled by the requirement expands the options available to the designer to include increasing the frequency of occurrence of one hazard if, for example, its design implementation decreased the consequences of others.

Individual hazard risk indices. - (Filled-in example table #1)

	Hazard Frequency					
Hazard Consequence	Frequent	Probable	Occasional	Unlikely	Remote	Improbable
Catastrophic	30	25	20	15	10	5
Critical	24	20	16	12	8	4
Significant	18	15	12	9	6	3
Marginal	12	10	8	6	4	2
Negligible	6	5	4	3	2	1

It is also possible to include a “forbidden zone” in the matrix. That is, precluding a given set of hazard characteristics and force a condition that requires remedy by the developing agent. This can be accomplished by setting the RHI value for the appropriate frequency and consequence greater than the cumulative value allowed. For instance, extending the above example to preclude “Frequent” and “Probable,” “Catastrophic” and “Critical” hazards can be accomplished by entering “1001” in the cells as illustrated in example table #2 below in red.

Individual hazard risk indices. - (Filled-in example table #2)

	Hazard Frequency					
Hazard Consequence	Frequent	Probable	Occasional	Unlikely	Remote	Improbable
Catastrophic	1001	1001	20	15	10	5
Critical	1001	1001	16	12	8	4
Significant	18	15	12	9	6	3
Marginal	12	10	8	6	4	2
Negligible	6	5	4	3	2	1

Define the consequence and frequency criteria specified in table 3.3.10-I, to be appropriate to the extent and nature of the air vehicle. Completion of blanks 1 and 2 will require determination of the acceptable loss by assessment of the cost of consequent losses resulting from hazards involved in the peacetime operation of the air vehicle that can be tolerated. Such loss must be considered in the context of the effectiveness of the air vehicle with respect to countering the threat to which the air vehicle responds. Given this assessment, the total acceptable loss, less a subjective, semi-quantitative margin to account for all of the hazards (identified and not identified) that belong to the set of hazards of lesser consequence and frequency set in the value of blank 2 of 3.3.10, becomes the value of blank 1.

Guidance for completing table 3.3.10-I follows:

Table 3.3.10-I is a derivative of the content of similar tables in MIL-STD-882. Both the Hazard Consequences and Hazard Frequencies can be tailored as needed for a given program.

Hazard Consequence: For each row under the "Hazard Consequence" heading, identify a consequence criteria identifier. Suggested identifiers are

Blank C1: Catastrophic

Blank C2: Critical

Blank C3 Significant

Blank C4: Marginal

Blank C5: Negligible

Each of these identifiers should be defined. Definitions should include dollar criteria (financial consequence of a hazard occurrence), a human criteria (human consequence of a hazard occurrence, and environmental criteria (environmental consequence of hazard occurrence). Suggested criteria follow:

Blank C1. Catastrophic

a. Dollar: loss of a capital asset or damage thereto and resources in excess of one million dollars (production acquisition value).

b. Human: injury to the public or the operator resulting in death or permanent disability.

c. Environmental: irreversible severe environmental damage that violates law or regulation.

d. Combined (blank C1 description): consequences shall be considered as any event that leads to loss of a capital asset or damage thereto and resources in excess of one million dollars (production acquisition value) or injury to the public or the operator resulting in death or permanent disability or irreversible severe environmental damage that violates law or regulation.

Blank C2. Critical

a. Dollar: capital equipment or resource loss or damage of less than one million dollars but more than $250,000.

b. Human: one or more injuries that result in partial disability.

c. Environmental: reversible environmental damage causing a violation of law or regulation.

d. Combined (blank C2 Description): consequences include those that result in capital equipment or resource loss or damage of less than one million dollars but more than $250,000 and/or resulting in one or more injuries that result in partial disability or reversible environmental damage causing a violation of law or regulation.

Blank C3. Significant:

a. Dollar: capital equipment and resource loss or damage of less than $250,000 and more than $100,000.

b. Human: personal injury, or injuries, resulting in temporary partial or complete disability of greater than fifteen (15) days.

c. Environmental: mitigable environmental damage causing a violation of law or regulation.

d. Combined (blank C3 Description): consequences include those that result in capital equipment and resource loss or damage of less than $250,000 and more than $100,000 or personal injury, or injuries, resulting in temporary partial or complete disability of greater than fifteen (15) days or mitigable environmental damage causing a violation of law or regulation.

Blank C4. Marginal

a. Dollar: capital equipment and resource loss or damage of less than $100,000 and more than $10,000.

b. Human: personal injury, or injuries, resulting in temporary disability of less than fifteen (15) days and more than one (1) lost day.

c. Environmental: mitigable environmental damage without violation of law or regulation where restoration activities can be accomplished.

d. Combined (blank C4 Description): consequences include those that result in capital equipment and resource loss or damage of less than $100,000 and more than $10,000 or personal injury, or injuries, resulting in temporary disability of less than fifteen (15) days and more than one (1) lost day or mitigable environmental damage without violation of law or regulation where restoration activities can be accomplished.

Blank C5. Negligible

a. Dollar: capital equipment and resource loss or damage of less than $10,000.

b. Human: personal injury, or injuries, resulting in first aid requirements and one (1) day or less lost to disability.

c. Environmental: minimal environmental damage not violating law or regulation.

d. Combined (blank C5 description): consequences include those that result in capital equipment and resource loss or damage of less than $10,000 and personal injury, or injuries, resulting in first aid requirements and one (1) day or less lost to disability or minimal environmental damage not violating law or regulation.

Hazard Frequency: There are two options for hazard frequency, either a probability of occurrence or rate is used. The safety community normally uses a probability of occurrence. If an absolute rate is used (for example, in the context of X occurrences per year) then an operating fleet size condition should be included in the requirement such as, “For the purposes of this requirement, the operating fleet size shall be assumed to be __(3)__.” Suggested identifiers for the headings row beneath “Hazard Frequency” are

Blank F1: Frequent

Blank F2: Probable

Blank F3: Occasional

Blank F4: Unlikely

Blank F5: Remote

Blank F6: Improbable

Each of these identifiers should be defined. An understanding of individual events and likely impacts across the fleet will be needed. Further, these can be directly applied to the service life (see 3.3.5.1) of the items.

Blank F1. Frequent: includes all hazards likely to occur often in the life of an item with a probability of occurrence greater than 0.1 in that life for an air vehicle operated in accordance with the operational scenarios and missions as defined herein.

Blank F2. Probable: includes all hazards that will occur several times in the life of an item with a probability of occurrence less than 0.1(10^{-1}) but greater than 0.01(10^{-2}) in that life for an air vehicle operated in accordance with the operational scenarios and missions as defined herein.

Blank F3. Occasional: includes all hazards that are likely to occur some time in the life of an item with a probability of occurrence less than 0.01(10^{-2}) but greater than 0.001(10^{-3}) in that life for an air vehicle operated in accordance with the operational scenarios and missions defined herein.

Blank F4. Unlikely: includes all hazards that are unlikely but possible to occur in the life of an item with a probability of occurrence less than 0.001(10^{-3}) but greater than 0.0001(10^{-4}) for an air vehicle operated in accordance with the operational scenarios and missions defined herein.

Blank F5. Remote: includes all hazards that are unlikely but possible to occur in the life of an item with a probability of occurrence less than 0.0001(10^{-4}) but greater than 0.000001(10^{-6}) for an air vehicle operated in accordance with the operational scenarios and missions defined herein.

Blank F6. Improbable: includes all hazards that are so unlikely it can be assumed occurrence may not be experienced with a probability of occurrence less than 0.000001(10^{-6}) in that life for an air vehicle operated in accordance with the operational scenarios and missions defined herein.

To fill out the Risk Hazard Index table, weights are often established for each consequence and frequency category with the product of the category weights for each cell used as the risk hazard index. An example of this is shown in the sample table #3 below.

Individual hazard risk indices. - (Example table #3 with weights assigned)

	Hazard Frequency					
Hazard Consequence (Weight)	Frequent (6)	Probable (5)	Occasional (4)	Unlikely (3)	Remote (2)	Improbable (1)
Catastrophic (5)	6 x 5 =30					
Critical (4)						
Significant (3)						
Marginal (2)						
Negligible (1)						

This guidance on using the weights to establish RHIs should not be taken as limiting. It could be argued that weights, if used, should represent the seriousness of the increase from category to category. For example, there is typically an order of magnitude difference in frequency from category to category. In consequence, the dollar values typically associated with the categories vary by a factor of 2.5-10 on a category-to-category basis. The implication being that a "Frequent" - "Catastrophic" hazard be considered in excess of one million times more serious than a "Negligible" – "Improbable" hazard in terms of relative RHI. Such distinctions may not matter as much when procedural requirements with intense oversight by the government are used. However, a performance-based requirement that allows a trade-space will require more care when building the table to ensure that the more serious and frequently occurring hazards are appropriately dealt with during development.

The values to use for blanks 1 and 2 (the cumulative value of RHIs that must not be exceed and the lower threshold for counting RHIs) could initially be derived based on historical data for a given air vehicle. However, the expectation would be that the historical information may be useful to enter PDR phase, but the exit from PDR should be based on actual design work accomplished as tempered by historical data and warfighter requirements to better target effective requirements. A starting point for selecting the threshold value could be examining the point at which the costs associated with in-depth management and oversight of the requirement to reduce or preclude the consequences or frequency of the hazard versus the cost of the consequences expected over the life of the air vehicle. For example, it may not be cost effective to try to manage, preclude or reduce the consequences of remote or improbable hazards evaluated as having negligible consequences.

A filled-in example of the table and definitions follows.

Individual hazard risk indices. - (Filled-in example table #4)

	Hazard Frequency					
Hazard Consequence	Frequent (32)	Probable (16)	Occasional (8)	Unlikely (4)	Remote (2)	Improbable (1)
Catastrophic (16)	512	256	128	64	32	16
Critical (8)	256	128	64	32	16	8
Significant (4)	128	64	32	16	8	4
Marginal (2)	64	32	16	8	4	2
Negligible (1)	32	16	8	4	2	1

<u>Hazard Consequence:</u> The following consequence definitions will be used to quantify identified hazards:

a. Catastrophic consequences shall be considered as any event that leads to loss of a capital asset or damage thereto and resources in excess of one million dollars (production acquisition value) or injury to the public or the operator resulting in death or permanent disability or irreversible severe environmental damage that violates law or regulation.

b. Critical consequences include those that result in capital equipment or resource loss or damage of less than one million dollars but more than $250,000 and/or resulting in one or more injuries that result in partial disability or reversible environmental damage causing a violation of law or regulation.

c. Significant consequences include those that result in capital equipment and resource loss or damage of less than $250,000 and more than $100,000 or personal injury, or injuries, resulting in temporary partial or complete disability of greater than fifteen (15) days or mitigable environmental damage causing a violation of law or regulation.

d. Marginal consequences include those that result in capital equipment and resource loss or damage of less than $100,000 and more than $10,000 or personal injury, or injuries, resulting in temporary disability of less than fifteen (15) days and more than one (1) lost day or mitigable environmental damage without violation of law or regulation where restoration activities can be accomplished.

e. Negligible consequences include those that result in capital equipment and resource loss or damage of less than $10,000 and personal injury, or injuries, resulting in first aid requirements and one (1) or less days lost to disability or minimal environmental damage not violating law or regulation.

Hazard Frequency. The following frequency of hazard definitions will be used to quantify identified hazards:

a. Frequent includes all hazards that are likely to occur often in the life of an item with a probability of occurrence greaterthan 0.1 in that life for an air vehicle operated in accordance with the operational scenarios and missions as defined herein.

b. Probable includes all hazards that will occur several times in the life of an item with a probability of occurrence less that 0.1(10-1) but greater than 0.01 (10-2) in that life for an air vehicle operated in accordance with the operational scenarios and missions as defined herein.

c. Occasional includes all hazards that are likely to occur some time in the life of an item with a probability of occurrence less than 0.01(10-2) but greater than 0.001(10-3) in that life for an air vehicle operated in accordance with the operational scenarios and missions defined herein.

d. Unlikely includes all hazards that are unlikely but possible to occur in the life of an item with a probability of occurrence less than 0.001(10-3) but greater than 0.0001 (10-4) for an air vehicle operated in accordance with the operational scenarios and missions defined herein.

e. Remote includes all hazards that are unlikely but possible to occur in the life of an item with a probability of occurrence less than 0.0001(10^{-4}) but greater than 0.000001(10^{-6}) for an air vehicle operated in accordance with the operational scenarios and missions defined herein.

f. Improbable includes all hazards that are so unlikely it can be assumed occurrence may not be experienced with a probability of occurrence less than 0.000001 (10^{-6}) in that life for an air vehicle operated in accordance with the operational scenarios and missions defined herein.

For example, using the example table #4 as a basis, all hazards with a risk hazard index greater than 12, arbitrarily set as the value of blank 2 in this example, would be accumulated and established as the value of blank 1. This value for blank 1 may be established as 100 hazards of average risk hazard index of 20 resulting in a specification value of 2000 in blank 1 for the air vehicle.

An air vehicle loss is a catastrophic event (capital asset in excess of $1M). The acceptable level of risk is generally measured in terms of losses per hundred thousand flying hours. Using an arbitrary planning factor of 5/100000hrs ($5x10^{-5}$) (the warfighters or force planners should make this estimate for the particular air vehicle), an average mission duration of 1 hour, a peacetime flying hour program of 20 missions/month, a service life of 20 years, and an operating fleet size of 500 air vehicles, “planned” losses would have approximately .21 probability of occurrence. This meets the criteria for “frequent” with a resulting risk hazard index of 30. A potential problem is that regardless of how high the acceptable risk factor gets, the hazard score never exceeds 30 for any given hazard. It may be prudent to also specify an acceptable loss rate for air vehicles.

REQUIREMENT LESSONS LEARNED (3.3.10)

Operators and maintainers of air vehicles must be capable of performing their job effectively in exceedingly challenging (i.e., stressful) environments. It is the developer’s responsibility to provide those operators and maintainers with equipment that is inherently safe and not rely on warnings, indicators, or additional training to achieve acceptably safe operating states. While this may not always be practicable, equipment operator intervention should be minimized, if not eliminated. To effect this, the air vehicle design practice(s) to preclude hazards should be in accordance with the following order of precedence:

a. Eliminate hazards through design.

b. If a hazard cannot be eliminated, reduce mishap risk through the use of protective safety features or devices.

c. Incorporation of detection and warning capability to alert personnel of the hazard.

d. Incorporation of special procedures, including personnel protective equipment, and training.

4.3.10 Safety verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Safety	(1) Cumulative RHI* (or MRA)	A	A	A	A	I,A,T

*****Number in parentheses refers to numbered blank in the requirement. Risk hazard index (RHI) is equivalent to mishap risk assessment (MRA).

VERIFICATION DISCUSSION (4.3.10)

The safety verification is accomplished to predict the occurrence of mishaps due to design attributes and shortcomings. At the air vehicle level, verification activities must encompass all of the air vehicle’s constituent items, to include subsystems and equipment, and must address air vehicle operations and maintenance. There are other air vehicle level verifications conducted that provide information to be analyzed in determining compliance with this requirement. For example, test and demonstrations to confirm compliance with requirement 3.1.6 Integrated combat turnaround time may expose safety issues with air vehicle equipment and operating procedures.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: A Preliminary Hazard Analysis (PHA) of the air vehicle design concept indicates the air vehicle will be able to meet the established RHI limits. Analysis of the design concept indicates a reasonable degree of assurance that all the consequence levels have been exposed and their interrelationships are understood. Tools such as fault trees and FMEA/FMECA are often used. Typically, the air vehicle System Safety Program Plan (SSPP) is provided for review and comment. Analyses of the design concept indicates the air vehicle safety program plan has been accomplished to mitigate known risk. This plan will address the approach used to accomplish the air vehicle safety management and engineering activities and how hazards are identified, analyzed and corrected. This plan needs to demonstrate capability and understanding of the tasks required to ensure a safe design.

PDR: Subsystem hazard analyses (SHA) of the preliminary design indicates the air vehicle will be able to meet the established RHI limits. These analyses indicate a reasonable degree of assurance that all hazards (including consequence, frequency, and interrelationships) impacting the requirement have been identified, quantified, and mitigated to the extent necessary to meet the requirement. Preliminary risk assessments should be accomplished early in the air vehicle development prior to the detailed design process. The assessments should identify critical air vehicle and subvehicle hazards and an approach to resolve these hazards to a lower level of risk through design changes. Tools such as fault trees and FMEA/FMECA are often used.

CDR: A hazard analysis (SHA) of the detailed design, to include the air vehicle's configuration items and their interfaces, indicate the vehicle will be able to meet the established RHI limits. These analyses indicate a reasonable degree of assurance that all hazards (including consequence, frequency, and interrelationships) impacting the requirement have been identified, quantified, and mitigated to the extent necessary to meet the requirement. Analysis confirms there are no unaddressed safety issues. The detailed design incorporates operational and support equipment and procedures. Tools such as fault trees and FMEA/FMECA are often used.

FFR: Analysis of the flight ready equipment and procedures, lower-level testing, and analysis of ground testing confirm that previously unidentified hazards have been quantified, and mitigated or accepted. Analysis of the final safety reports identify the hazards effecting first flight and the controls that have been employed to control or prevent their occurrence. These reports should address all facets of the air vehicle to include hardware, software, operations, training, and support equipment and procedures. A safety assessment report (SAR) and Operational and Support Hazard Analysis (O&SHA) are normally provided for review and comment.

SVR: Air vehicle level test, and analysis of lower-level tests confirm the vehicle satisfies the established RHI limits. Inspection confirms all design changes since CDR have been verified and reflected in the vehicle documentation.

Sample Final Verification Criteria

The safety requirement shall be satisfied when __(1)__ inspections, __(2)__ analyses, and __(3)__ tests confirm the air vehicle will be able to meet the established RHI limits.

> Blank 1. Identify the type and scope of inspections required to provide confidence that the requirement elements have been met.
>
> Blank 2. Identify the type and scope of analyses required to provide confidence that the requirement elements have been met.
>
> Blank 3. Identify the type and scope of tests required to provide confidence that the requirement elements have been met.

VERIFICATION LESSONS LEARNED (4.3.10)

To Be Prepared

3.3.10.1 Air vehicle noncombat loss rate

The air vehicle loss rate shall be not greater than __(1)__ per flight hour. This rate includes air vehicle losses resulting from ground and in-flight operations as well as material and design related losses.

REQUIREMENT RATIONALE (3.3.10.1)

This requirement establishes the air vehicle loss rate per flight hour.

REQUIREMENT GUIDANCE (3.3.10.1)

Air Force Safety Center, Army Safety Center and/or Naval Safety Center should be contacted to recommend typical loss rates for different types of air vehicles. They have extensive data that has been accumulated year by year for each model of air vehicle in the inventory. The data reflects the loss rates due to various causes, and indicates loss rates that have been achievable due to advances in technology and air vehicle design practices. Air vehicle losses due to noncombat causes are generally related to the types of missions the air vehicle is intended to fly and, consequently, for which aircrew must train. Planning factors generally reflect both the mission and number of engines. The warfighter and/or the service force planning organization can be an appropriate source of data.

REQUIREMENT LESSONS LEARNED (3.3.10.1)

Highly maneuverable air vehicles have historically had a high rate of catastrophic loss due to Controlled Flight Into Terrain (CFIT). These losses are typically caused by spatial disorientation, G loss of consciousness, inattention, and temporary incapacitation. An automatic recovery Ground Collision Avoidance System (GCAS) can minimize these losses. Experience shows that it is more advantageous to install this system early in the design versus modifying the air vehicle after it is fielded.

4.3.10.1 Air vehicle noncombat loss rate verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Loss rate	(1)	A	A	A	A	A

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.3.10.1)

The requirement 3.3.10.1 Air vehicle noncombat loss rate verification is determined using probabilistic failure data for the system being designed. This data utilizes failure modes and effects criticality analysis (FMECA) determinations to estimate the expected loss rates attributed to material failure modes and appropriate analyses for software. This data is based on historical mishap reports from similar types of aircraft systems and using best engineering judgment.

The rate can be expected to change as the design matures and system hazards are minimized through design changes. Single point failures should be mitigated using responsible design improvements that remove the possibility of a single failure leading to a catastrophic outcome.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the system safety program plan indicates there are acceptable procedures in place to achieve noncombat loss rate.

PDR: Analysis of the preliminary design including the initial FMECA indicates that the air vehicle will achieve the specified noncombat loss rate.

CDR: Analysis of the final design including updated FMECA and software analysis confirm that the air vehicle will achieve the specified noncombat loss rate.

FFR: Analyses of initial lower-level test data confirms that the air vehicle is safe for first flight and the design will achieve the specified noncombat loss rate.

SVR: Analysis of lower-level test data confirms the calculated noncombat loss rate has been achieved.

Sample Verification Criteria

The air vehicle noncombat loss rate shall be met when __(1)__ analyses confirm that the rate of air vehicle losses resulting from ground and in-flight operations, as well as material and design related losses, does not exceed the required value.

> Blank 1. Identify the type and scope of analyses, including analysis of lower-level tests, required to provide confidence that the requirement has been satisfied.

VERIFICATION LESSONS LEARNED (4.3.10.1)

To Be Prepared

3.3.10.1.1 Fire and explosion protection

The probability of air vehicle loss due to fire or explosion shall not exceed __(1)__ per flight hour.

REQUIREMENT RATIONALE (3.3.10.1.1)

Fire and explosion protection of personnel and air vehicle is a goal in military and commercial air vehicles. The DoD expectation is that air vehicle loss during peacetime operation due to fire and explosion should be extremely remote.

Fire and explosion hazard protection should 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. The air vehicle should be provided with fire and explosion prevention design; control designs; and control systems in all locations where potential hazards can exist or result, due to a single failure.

REQUIREMENT GUIDANCE (3.3.10.1.1)

The probability of aircraft loss due to fire or explosion should be less than the air vehicle loss rate. Determine this probability considering all air vehicle subsystems (such as: hydraulics, electrical, propulsion, avionics, controls and displays, sensors, fuels, and landing gear). If another number is specified in the weapon or elsewhere in the air vehicle specification, this number should be an allocation from that number. For instance, if the probability of loss of aircraft is 10^{-6}, then the probability of aircraft loss due to fire should be in the order of 10^{-7}.

REQUIREMENT LESSONS LEARNED (3.3.10.1.1)

The achievement of an effective fire and explosion hazard protection entails the assessment of the probability of occurrence of events such as combustible and an ignition source coming together; the application of preventive techniques 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 detection techniques and control techniques to counteract the resultant fire and explosion hazards. After all potential hazards and their locations have been identified; the air vehicle may then be compartmentalized into various types of hazard zones. The various types of hazard zones are commonly described as fire zones, flammable leakage zones, flammable zones, and ignition zones. Appropriate protection should then be provided for each type hazard of hazard zones. Methods of fire protection include; general fire prevention designs, and fire and explosion hazard controls. The following are examples of successful methods that have been used and cover both general fire and explosion prevention and hazard controls.

a. Prevention designs Prevention designs intended to preclude or reduce the occurrence of fire and explosion should be provided in all locations where potential hazards can exist or result, either directly or indirectly, due to a single failure. The recommended prevention designs may include, but at are not limited, to combustible material hazard reduction, isolation, separation, ventilation, cooling, drainage, electrical bonding, and lightning protection.

(1) Separation designs should be used to the fullest extend practicable to prevent the occurrence of fire and explosion due to the presence of flammable fluids and vapors, combustible materials, ignition sources, and oxidizer/reducing agents.

(2) Ventilation and cooling designs should be applied to flammable fluids and vapors and oxidizer/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/vapor leakage can occur. All compartments containing fluid components with potential leakage, compartments adjacent to fuel tanks, and compartments into which flammable vapor enter from other compartments should be ventilated. Fire zones should be ventilated at an airflow velocity sufficient to increase the minimum hot surface ignition temperature of all flammable fluids present to a temperature above the highest compartment surface temperature expected during normal operations.

(3) Drainage design features should be used to prevent fires or explosions caused by the accumulation of combustible fluids. All compartments containing flammable fluid components should be drained unless leakage from these compartments is extremely unlikely. Drains should be installed so that no drainage will come into contact with potential ignition source or impinge on or reenter the air vehicle under operating condition and cause an unsafe condition.

(4) Designs should use electrical bonding and lightening protection to prevent the occurrence of fire and explosion due to the uncontrolled presence of combustibles and ignition. Electrical bonding and lightning protection designs have been applied to fuel systems to eliminate ignition sources that may result from electrical equipment and wiring, static electricity generation, and lightning.

b. Fire and explosion hazard control. The need for fire and explosion hazard control design in a given air vehicle location is dependent on the probability of uncontrolled co-existence of the three basic elements of fire and explosion (fuel, igniter, and oxidizer). Control systems should be provided in areas that are fire or explosion potential areas and adjacent areas as required to ensure effective fire and explosion control. Control systems may include, but at not limited to ,fire extinguishing, fluid control, smoke/vapor control, fire detection and explosion suppression. The following control designs should be considered:

(1) For fire zones, fire barriers should be provided to prevent the spread of fire from the fire zone into adjoining compartments/areas.

(2) Fire hardening provisions should be used in fire zones and adjacent compartments as required 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 compartments. Fire-hardening provisions should be used as required to protect flight-critical components, flammable fluid systems, and critical structural components.

(3) Fluid control provisions should be made to terminate the flow of flammable fluids and oxidizer/reducing agents.

(4) Provisions should be made to ventilate smoke and other hazardous vapor out of any compartment occupied by the crew or passengers.

(5) Overheat and explosion hazard detection should 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. Detection systems may include, but are not limited to, fire and overheat detection.

(6) Ground fire fighting access provisions should include doors and /or penetrations designators and are to be compatible with standard ground fire fighting extinguishing agent dispensing systems.

(7) Fire extinguishing systems should be provided for fire control and termination, when fire cannot be controlled and contained by other lesser means.

(8) All those areas (cargo compartments, dry bays, fuel tanks, etc.) that are not designed to withstand over-pressures resulting from combustion reactions of the flammable fluids contained within, should be provided with explosion suppressive systems when prevention designs are not sufficient, practicable, or the most efficient means of providing the required over pressure protection.

Testing of composite cylinders with aluminum liner shows a significant hazard that should be of concern to any military aircraft designer. A small composite cylinder of this type with 2,150 psi oxygen included when shot with a 50-caliber incendiary bullet, releases a tremendous amount of energy. This energy could easily destroy an aircraft on which it is installed.

The air vehicle oxygen system is special concern as gaseous or liquid oxygen subsystems can easily lead to a fire or explosion. An oxygen system fire cannot be extinguished as the contained oxygen feeds the fire and the metal container(s) and supply equipment that delivers oxygen will burn.

4.3.10.1.1 Fire and explosion protection verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Loss of air vehicle due to fire and explosion	(1)	A	A,I	A,I	A	A,I,T, D

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.3.10.1.1)

Fire and explosion protection incremental verification is achieved through a structured set of efforts/tasks designed to provide the necessary level of insight into the attributes of the design, and the design refinement process.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analyses of the design concept include fire and explosion provisions that indicate a high probability for achieving the basic fire and explosion protection requirement. Preliminary fire and explosion hazard analysis of the air vehicle should evaluate each compartment and determine the potential hazards that may occur. Analysis indicates proper allocations to prevention designs, control designs, and control functions. Analysis indicates that top level fire and explosion requirements for the air vehicle are appropriately flowed down and allocated at the subsystem level.

PDR: Analysis of requirement, design trade study results, and preliminary designs for the various subsystems indicates necessary capabilities to comply with the specified levels of fire and explosion protection are provided. Analysis indicates the updated fire and explosion hazard analysis, failure modes and effects analysis address risk associated with both functional and installation of specific requirements and identify the hazards that can be eliminated through re-design to minimize risk. Inspection of drawings indicate individual fire protection elements have been functionally integrated within the air vehicle as well as, integrated with the overall weapon system.

CDR: Analyses and inspection of a detailed design, including development testing of lower-level elements for the defined prevention designs; control functions integration into the air vehicle, and integration with all applicable air vehicle, ground test results, including components tests confirms the fire and explosion protection requirement can be achieved. Analysis of the final hazard report confirms residual risk has been assessed and that all potential fire and explosion hazards controls have been implemented and verification methods defined. Analysis of lower-level test and demonstration confirms that the fire and explosion hazard control methods meet performance requirements.

FFR: Analysis of lower-level testing/demonstrations confirm acceptable risk for first flight. Analysis confirms functional requirement validation including integration with other air vehicle systems is successfully completed.

SVR: Inspection of production drawings, analyses of laboratory tests, components qualification tests; ground tests, flight tests and demonstrations confirm the air vehicle fire and explosion loss rate is achieved.

Sample Final Verification Criteria

The fire and explosion protection requirement shall be satisfied when __(1)__ analyses, __(2)__ tests, and __(3)__ demonstrations confirm specified performance is achieved.

Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement has been satisfied.

Blank 2. Identify the type and scope of tests required to provide confidence that the requirement has been satisfied.

Blank 3. Identify the type and scope of demonstrations required to provide confidence that the requirement has been satisfied.

VERIFICATION LESSONS LEARNED (4.3.10.1.1)

Fire testing should simulate the likely fire environment to prove the materials and components will provide the necessary fire containment to meet the above objectives when exposed to a fire situation in service. In addition gaseous emissions from fire protection materials should be precluded from entering the cabin air conditioning system.

The descriptors “fireproof” and “fire resistant” differ only in the time duration that the material or component should maintain its integrity or perform its function. “Fire resistant” means the material or component will function and maintain its integrity for a not less than 5 minutes when exposed to a 2000 degree F flame temperature. “Fireproof” means the material or component will maintain its integrity and function for a not less than 15 minutes when exposed to a 2000 degree F flame temperature.

A thorough analysis of the flammable fluid leak sources and relationship to any ignition sources should be conducted. The analysis should show that leaked flammable fluid would not impinge upon ignition sources. Local conditions within the compartment may be considered, such as ventilation and drainage provisions.

The fuel, flammable fluid and vapor system designs should be reviewed early in the design process to ensure that all fuel, flammable fluid, or vapor tanks, are properly identified and isolated from engines, engine compartments and other designated fire zones during both normal and emergency operations. In some cases, fuel or flammable fluid components must be located in an engine compartment or designated fire zone. In these cases, the analysis must show that the design provides an equal level of safety (considering the design, construction, tank supports, materials, fuel lines, fittings, and controls used in the system, or system segment, contained in the engine compartment or designated fire zone) to that of locating the flammable fluid source outside the fire zone.

There is a general industry practice that a temperature providing a safe margin under all normal or failure conditions is at least 50°F below the lowest expected auto-ignition temperature of the flammable fluid within the zone. The auto-ignition temperature of fuels will vary because of a variety of factors (ambient pressure, dwell time, fuel type, etc.) but the value generally accepted without further substantiation for kerosene type fuels, under static sea level conditions, is 450°F. This results in a maximum surface temperature of approximately 400°F for an affected component. A higher auto-ignition temperature can be substantiated for a particular design installation, taking into account factors such as geometry, ventilation rates, etc.

An analysis of each zone in the air vehicle that contains flammable fluids should be conducted to substantiate the classification of a region as a fire or flammable fluid leakage zone.

For a zone to be classified as a flammable fluid leakage zone, it is necessary to show that no single failure or probable combinations of failures will result in the presence of both an ignition source and a flammable fluid source within the zone.

Analysis and inspection should substantiate separation of flammable fluids leakage sources and ignition sources. An arc fault between an electrical wire and a metallic flammable fluid line may puncture the line and result in a fire. Maintain as much separation as possible between electrical wire, flammable fluid components and oxidizer agent lines. Do not use flammable fluid, flammable vapor, or oxidizer/reducing agent lines to support wiring or any other item. When wiring is run parallel to combustible fluid or oxygen lines, maintain as much separation as possible. Locate wires above or level with the fluid lines and, wherever possible, maintain a separation of not less than six inches. In tight spaces (such as the engine strut) where separation is reduced, install clamps or insulation material to assure fuel line contact and arcing are not possible.

For a zone to be classified as a flammable fluid leakage zone, components located in the zone must be qualified to meet explosion proof requirements during both normal and failure conditions to assure ignition of flammable fluid vapors will not occur.

Electrical components may be qualified for use within flammable fluid leakage zones by showing the unit meets the appropriate criteria, such as the explosion proof requirements as defined MIL-STD-810. Potting, hermetic sealing, flame quenching drainage provisions may also indicate compliance with explosion proof nature. Components must be shown to be free of potential arcing or friction ignition sources and have maximum surface temperatures that will not cause auto-ignition of flammable fluids or vapors within the zone. Analyses, component qualification tests and inspection should be conducted to verify that the ignition source reduction has been provided.

Zones that contain flammable fluid sources should be ventilated in such a way that, should a leak occur, a lean fuel-air mixture would result thereby reducing the likelihood of ignition. The leak type and the zone configuration affect the amount of ventilation that is required to maintain a lean mixture. Typically, three to five airflow changes per minute have been found to be acceptable for fire zones.

Analytically determined ventilation rates should be validated by flight test results by measuring pressures within each zone and calculating airflow rates using known areas and the differential pressures.

An analysis of the design should be conducted to establish the potential leak sources for each zone of the air vehicle, including potential leaks due to maintenance errors. Typically, drainage systems should provide adequate capacity to handle fluid flow rates that could occur due to failure of a single seal, or cracking of high-pressure lines. The drains that require verification by testing can be identified from the leak source analysis.

Compliance of compartment sealing and drainage provisions must be verified by ground and flight tests. A static ground test is required to demonstrate that no hazardous quantities of fluid can be trapped within a flammable fluid leakage zone or fire zone by the geometry of the compartment(s) that make up that zone, and to make an assessment of the overall suitability of the drainage paths. The airplane should be in a normal ground attitude. The test is typically performed by introducing a measured amount of fluid (usually 1 to 2 gallons of dyed water) into the test compartment in the vicinity of the potential leakage sources and by measuring the amount of water that is recovered from the compartment drains. A guideline that may be helpful in identifying excessive trapped fluid within the zone is to verify recovery of 90 percent of the test fluid, with no indication of excessive puddling (individual puddles must be smaller than 1.5 fluid ounces) and absence of drainage via hazardous paths.

A flight test is necessary to demonstrate that the intended drainage paths and compartment seals are effective under all flight conditions and to show that no fluid migrates to, or impinges on, an area of the air vehicle where it would create an additional hazard. Due to the difficulty in predicting complex airflow patterns and the number of different flight test conditions required, numerous flight test conditions are usually required.

Analyses, laboratory tests, component qualification tests and demonstrations should be accomplished as necessary to verify that the interior materials meet the requirements for flammability smoke generation, and toxic gas emission. The complex interaction between flammability, smoke generation and toxic gas emission requirements support that the system testing using mock-ups or full-scale test measures be used as much as possible.

Analyses, component qualification tests; and demonstration should be used to verify the adequacy of the provided postcrash fire prevention.

Analyses, laboratory tests, component qualification tests, ground tests; and demonstrations should be used to verify the adequacy of the provided fire extinguishing system. Under actual or simulated cruise, the fire extinguishing system should be discharge and agent concentration and duration goals should be verified by the use of an appropriate method of measuring agent concentration (such as Statham Analyzer).

Analyses, laboratory tests, component qualification tests, ground tests, and demonstrations should be used to verify the adequacy of the explosion suppression system.

3.3.10.2 Operational safety

3.3.10.2.1 Crash worthiness

The air vehicle crash worthiness shall be __(1)__.

REQUIREMENT RATIONALE (3.3.10.2.1)

Air vehicle crash worthiness is established to save the lives of the crew and passengers.

REQUIREMENT GUIDANCE (3.3.10.2.1)

Blank 1. Complete with one of the following:

a. For rotary wing aircraft, apply the following: At the flight design gross weight the air vehicle shall conform to the hard landing and crash conditions disclosed in __(2)__with the design to provide __(3)__vertical crash capability with the landing gear fully retracted. For blank 2, specify the acceptable crash conditions using text or figure(s). For blank 3, recommend a value of 27 feet per second.

b. For fixed wing aircraft, select the following: Equipment and assemblies of mass in the vicinity of crew/passenger positions shall remain in place without hazardous effects when exposed to loads of __(4)__. The crew/passenger seat/restraint system shall restrain the crewmember/passenger and remain in place when exposed to a dynamic load of __(5)__.

MIL-STD-1807 and FAR Part 25 have several sets of crash worthiness values for different types of fixed wing aircraft and different types of seats applicable to blanks 4 and 5.

Requirement values will be confirmed by the crash worthiness representative of the service procuring the air vehicle.

REQUIREMENT LESSONS LEARNED (3.3.10.2.1)

Requirement values should be confirmed by the crash worthiness representative of the service procuring the air vehicle.

4.3.10.2.1 Crash worthiness verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Equipment and assemblies of mass	Restraint when exposed to (4) loads	I,A	I,A	I,A	I,A	I,A
Seat/sestraint system	Restraint when exposed to (5) loads	I,A	I,A	I,A	I,A	I,A

*Numbers in parentheses in the Measurand column refer to numbered blanks in the requirement.

VERIFICATION DISCUSSION (4.3.10.2.1)

Crash worthiness verification attempts to assure that the aircrew and any passengers will not be injured by dislodged seats or flight equipment. The verification process tests the strength of the flight equipment and mounting structure to withstand a specified acceleration shock. The test intent is to prove via a simulated crash that equipment and its attachment has the structural strength to remain in place when exposed to the worst case rate of descent; estimated in MIL-STD-810 to be 40g's at impact in a survivable crash. Refer to Procedure V from MIL-STD-810E Method 516.4, titled, "Crash Hazard." Seats must be tested to demonstrate adequate strength when exposed to anticipated crash loading.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Inspection identifies Government Furnished Equipment (GFE), designated Contractor Furnished Equipment (CFE), and other contractor furnished equipment that may be installed in the vicinity of the aircrew/passengers. Analysis indicates that crash worthiness requirements for seats and equipment including assemblies of mass in the vicinity of crew/passenger positions have been established. Inspection of equipment design documentation identifies crash worthiness capability or compliance, and any associated technical risk has been identified.

PDR: Inspection of the product definition documentation identifies equipment that could break loose and present a hazards to the aircrew/passengers. Inspection reveals that seat crash worthiness requirements have been allocated to the seat designers for design incorporation. Analysis identifies items that have passed shock testing requirements on other air vehicle programs. Analysis of lower-level testing of equipment which has not previously been shock tested indicates compliance with the requirement.

Note: Unless otherwise deemed necessary (e.g., no equivalency), only equipment not otherwise exposed to shock tests in accordance with MIL-STD-810 should be tested. Minimally, testing should be performed on medium- to high-risk items.

CDR: Inspection and analysis of air vehicle design and lower-level test data confirm that the crash worthiness requirement can be achieved.

FFR: Inspections and analysis confirm crash worthiness requirements have been met for equipment included in the first flight air vehicle.

SVR: Inspections and analysis of lower-level test data confirms crash worthiness requirements have been met.

Sample Final Verification Criteria

The crash worthiness requirement shall be satisfied when __(1)__ inspections or __(2)__ analyses confirm the seat(s)/restraint system and flight equipment and assembles of mass in the vicinity of the aircrew/passenger has been met for specified crash worthiness.

> Blank 1. Identify the documentation to be inspected. Documents typically inspected include specification sheets for the applicable seat(s)/restraint system, equipment, and assemblies of mass.
>
> Blank 2. Analysis types could include one or more of the following: analysis of prior air vehicle applications indicate equivalent testing has been conducted; analysis of lower-level crashworthiness testing results on new and revised equipment; and/or analysis of supporting structure test results.

VERIFICATION LESSONS LEARNED (4.3.10.2.1)

To Be Prepared

3.3.10.2.2 Energetics

The air vehicle shall preclude unintentional ignition of all energetic components and subsystems during energetics installation, air vehicle handling, and operational use.

REQUIREMENT RATIONALE (3.3.10.2.2)

Energetics control provides for aircrew safety and maintainer safety. A compatible environment ensures energetic devices will not be exposed to conditions that will shorten life or alter performance.

REQUIREMENT GUIDANCE (3.3.10.2.2)

This requirement should be developed in concert with the requirements for the use of energetics components. Also, the air vehicle should provide access for maintainability and correct installation of energetic devices and subsystems. The air vehicle should maintain a compatible environment for energetics at defined locations. Maintainability requirements are addressed elsewhere in this specification guide.

REQUIREMENT LESSONS LEARNED (3.3.10.2.2)

The stated requirements and margins have proven to be effective in achieving aircrew and maintainer safety. To preclude conflicting requirements these requirements should be coordinated with requirement 3.2.1 Electromagnetic environmental effects. Energetic devices located in high temperature areas or locations with extreme temperature cycling can degrade performance, cause a shorter service life, reduce safety and require use of less desirable energetic materials. Electromagnetic radiation can cause ignition of insufficiently protected electroexplosive devices or devices with minor damage to protective shielding. Special emphasis should be given to maintainer access for energetic devices. Limited access can result in significant safety risks due to misinstallations and undetected damage.

4.3.10.2.2 Energetics verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Ignition of energetic components and subsystems only when intended	Precautions and design features for precluding energetic ignition	A	A,I	A	A,S, D,T	A,I, D,T

VERIFICATION DISCUSSION (4.3.10.2.2)

The verification approach leverages the use of analysis and inspection of the energetics ignition characteristics early in the development phases and ensures specification conformance through select air vehicle test and demonstrations.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analyses of energetics specifications and implementation scenarios identify characteristics associated with items such as all fire and no fire limits, maximum temperatures, and tolerance to drops, shock, vibration, electromagnetic environments, and bullet impacts which may unintentionally cause ignition during air vehicle handling, installation or operational. Analysis should be used to define required environments and flow down appropriate requirements to lower-level specifications.

PDR: Analysis indicates that each energetic (in its intended air vehicle application) has been examined to identify potential ignition characteristics (e.g., adverse electromagnetic induced effects on the energetics, all fire and no fire limits). Analysis of interface documentation for the selected energetics defines ignition characteristics associated with the energetics interface. Analysis of the preliminary air vehicle design and safety precautions should indicate that the air vehicle will preclude unintentional ignition of energetics. Analysis should also define specific environmental exposures that can be expected in operational installations. Inspection indicates a plan for air vehicle/energetic testing as well as future lower-level energetic test requirements. Initial FMECA should indicate low risk of unintentional ignition.

CDR: Analysis of lower-level energetics testing, air vehicle to energetics interface documentation, and energetics performance data indicates that the specified air vehicle requirements will be met. Analysis of the air vehicle design indicates that the air vehicle can preclude unintentional ignition of energetics. Updated FMECA indicates low risk of unintentional ignition.

FFR: Analysis of lower-level energetics testing and energetics performance data, as well as air vehicle ground tests, simulations, and demonstrations confirm that energetics associated with the first air vehicle flight meet specified requirements for environments and conditions that will be encountered in initial test flights.

SVR: Air vehicle ground and flight tests, simulations, demonstrations, analysis of lower-level energetics testing and performance data, and inspection of air vehicle interface documentation confirm that the specified requirements have been met for all operational environments and conditions.

Sample Final Verification Criteria

The energetic unintentional ignition requirement shall be met when __(1)__ inspections, __(2)__ analyses, __(3)__ demonstrations, and __(4)__ tests confirm that the air vehicle precludes unintentional ignition during air vehicle handling, energetics installation and operational use.

> Blank 1. Identify the type and scope of inspections required to provide confidence that the requirement has been satisfied. Inspections should consist of reviews of engineering drawing, schematics, interface control documents and hardware examination.
>
> Blank 2. Identify the type and scope of analyses required to provide confidence that the requirement has been satisfied.
>
> Blank 3. Identify the type and scope of demonstrations required to provide confidence that the requirement has been satisfied.
>
> Blank 4. Identify the type and scope of tests required to provide confidence that the requirement has been satisfied. Tests should include component qualifications, interface testing, and installation/subsystem testing.

VERIFICATION LESSONS LEARNED (4.3.10.2.2)

Induced currents due to electromagnetic radiation of the air vehicle can jeopardize the all fire and no fire limits of installed energetics, and have been known to activate energetics during the installation process. Energetics have been cooked off when the jet exhaust of one air vehicle has unintentionally been focused on the energetics installation of a nearby air vehicle.

A Navy test activity typically performs final energetics interface verification for every Navy air vehicle application. If the Navy is a participating service, this typically means the only acceptable energetic may be a Navy approved off-the-shelf energetic.

The following is included as information only; each program verification should be developed as necessary to verify specific program requirements. The Navy air vehicle to energetics interface verification generally consists of the following process:

> Plans for energetic applications should be inspected to determine if Government approved energetics have been selected. Each energetic in its intended air vehicle application should be analyzed by the contractor for potential electromagnetic deficiencies before the product definition package is submitted to the Government for their analysis and comments. Each energetic in its intended air vehicle application should be analyzed (i.e., the product definition documents are inspected and analyzed by Government energetic safety representatives for potential electromagnetic deficiencies in the air vehicle energetic application.) The initial inspection of the

energetic interface associated with previously proven stores may not require any further assessments. This initial analysis usually occurs at the Naval Air Station, Dahlgren, VA. As a result of the energetics analyses, product definition changes may be required to rectify the potential hazards disclosed by the Government. If so, the energetic inspection should be repeated on the revised product definition baseline. The second iteration is expected to pass the energetics analysis. The Dahlgren energetics safety representative will prescribe the requisite air vehicle configuration changes that must be incorporated into one developmental air vehicle to support energetic to air vehicle interface testing when exposed to the electromagnetic environmental radiation test replicating the shipboard environment. (The energetic interface test cannot be conducted using active energetic devices, so the air vehicle has to be specially configured to assess if air vehicle exposure to the test electromagnetic environment would activate the Government approved energetics in the developmental air vehicle.) Dahlgren is only responsible for the energetics interface portion of the air vehicle electromagnetic testing.

As indicated under requirement 3.3.10.2.2 Energetics lessons learned, the energetic interface test is typically conducted in conjunction with and as part of the air vehicle electromagnetic verification process. The instant of greatest hazard to any energetics installation procedure is during 'hot turnaround' when the armament (or armament launch device) using the approved energetic is being loaded onto or into the air vehicle in a shipboard flight deck electromagnetic environment. The air vehicle electromagnetic testing is conducted by a Navy activity other than the Dahlgren facility. Accordingly, coordination with the Government electromagnetic test activity should be conducted early in the program to determine the required electromagnetic ground tests that need to be completed before air vehicle electromagnetic testing can occur. Also, coordination should be initiated relative to the lead-time needed by the Government to schedule the developmental air vehicle electromagnetic testing at a Government test activity. For initial estimating purposes, availability of the Government test activity should be no sooner than six months after PDR.

Once the air vehicle electromagnetic testing has been conducted, the Government energetic interface representative analyzes the energetic test data to make a verification determination for each energetic interface. All instances of energetic interface requirements nonconformance discovered during analysis of test results should have a corrective action plan.

After FFR all instances of energetic interface nonconformance discovered during store simulation, analysis, test, or demonstration (from requirements in section 3.4.1.1 Store interface) should be corrected by a product definition change.

3.3.11 Flying qualities

3.3.11.1 Flying qualities, fixed wing

The air vehicle shall meet the flying quality requirements specified herein. These requirements shall be met for air vehicle states (see 6.4.6 Flying qualities definitions) encountered in flight phases and tasks of the operational missions. Operational missions include the spectrum of intended usage specified in requirement 3.1.2 Mission profile(s) performance.

REQUIREMENT RATIONALE (3.3.11.1)

These paragraphs contain the requirements for the flying and ground handling qualities of air vehicles. These requirements are intended to assure flying qualities that support adequate mission performance and flight safety regardless of the design implementation or flight control system augmentation. The requirements are to be applied during the design, construction, testing, and acceptance of the subject air vehicle.

REQUIREMENT GUIDANCE (3.3.11.1)

In order to apply the requirements of this specification, the contractor should have accomplished certain steps in the development process. These steps are described in detail in the Military Handbook on Flying Qualities of Piloted Aircraft (MIL-HDBK-1797). They can be summarized here as follows:

a. Determining the operational mission requirements (see requirement 3.1.1 Point performance).

b. Determining the applicable flight phases necessary to accomplish the operational missions (see requirement 3.1.1 Point performance).

c. Determining the appropriate air vehicle normal states for each flight phase (see 3.3.11.1.1.1 Allowable levels for air vehicle normal states and section 6.4.6 Flying qualities definitions).

d. Determining air vehicle failure states and special failure states (see requirements under 3.3.11.1.1.3 Primary requirements for failure states and section 6.4.6 Flying qualities definitions).

e. Defining the regions of handling for each air vehicle normal state and flight phase (see 3.3.11.1.1.1 Allowable levels for air vehicle normal states and section 6.4.6 Flying qualities definitions). In addition, the contractor should consider ride qualities in the development of the air vehicle.

Section 3.3.11.1 Flying qualities, fixed wing incorporates top-level requirements for flying qualities. Design guidance to enable compliance with these top-level requirements can be found in Appendix C and in MIL-HDBK-1797.

The requirements in section 3.3.11.1 Flying qualities, fixed wing and the design guidance in Appendix C bridge the gap between a specified qualitative level of flying qualities and the designers' need to have a quantifiable, measurable set of parameters that will shape and size the resulting air vehicle. These requirements are intended to assure flying qualities for adequate mission performance and flight safety regardless of the design implementation or flight control system augmentation. It is anticipated that Appendix C will eventually be incorporated in MIL-HDBK-1797. The contractor and the procuring activity should utilize appropriate information from Appendix C and MIL-HDBK-1797 consistent with the specific acquisition. This section, Appendix C and MIL-HDBK-1797 provide performance requirements and guidance that flow down to other design areas such as aerial refueling, armament (weapons), crew systems, flight control, structures, subsystems, etc.

No exceptional pilot skill or technique should be required to meet the flying quality requirements of section 3.3.11.1 Flying qualities, fixed wing.

REQUIREMENT LESSONS LEARNED (3.3.11.1)

To Be Prepared

4.3.11.1 Flying qualities, fixed wing verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Flying qualities, fixed wing	Performance characteristics specified in other air vehicle performance requirement paragraphs	A	A	A	A	A

VERIFICATION DISCUSSION (4.3.11.1)

This requirement provides condition information that must be considered in developing all air vehicle flying qualities performance requirements and verifications. The verification approach defined assumes that the flying qualities will be verified via the specific performance requirements specified below.

The requirements of section 3.3.11.1 Flying qualities, fixed wing apply for all air vehicle configurations and all loadings required or encountered in each applicable flight phase. However, it is impractical to analyze, simulate, demonstrate, and test all configurations and loadings, therefore the contractor should analyze, simulate, demonstrate, and test selected configurations and loadings for each applicable flight phase. The requirements also apply for all air vehicle loadings, but again, it is impractical to analyze, simulate, demonstrate, and test all loadings, therefore the contractor should analyze, simulate, demonstrate, and test selected air vehicle loadings throughout the range of all possible loadings required or encountered in each applicable flight phase. Consider the range of air vehicle loadings:

a. Throughout the longitudinal, lateral, and vertical envelopes of center of gravity and the corresponding weights that exist for each flight phase. These envelopes include the most forward and aft center-of-gravity positions, as well as the maximum center of gravity excursions attainable through failures in systems or components, such as fuel sequencing, hung stores, etc., for each flight phase;

b. For all moments and products of inertia of the air vehicle associated with all of the loadings above; and

c. For all combinations of internal and external stores (both symmetric and asymmetric) required by the operational missions. When the stores contain expendable loads, the requirements should be met throughout the range of store loadings, including sloshing and shifting.

Selected configurations and loadings should be analyzed and tested for each applicable flight phase. The selected configurations should include

a. All configurations required for mission accomplishment (see requirements 3.1.1 Point performance and 3.1.2 Mission profile(s) performance);

b. All configurations required for performance demonstration (see requirements 3.1.1 Point performance and 3.1.2 Mission profile(s) performance);

c. All configurations likely to be encountered; and

d. Any additional configurations the procuring agency feels necessary.

Selected air vehicle loadings throughout the range of all possible loadings required or encountered should be analyzed and tested for each applicable flight phase. The selected loadings for each flight phase should include

a. The most critical loading (in a flying qualities sense) for each individual requirement;

b. The maximum and minimum permissible weights;

c. The maximum and minimum weights attainable through failures in systems or components, such as fuel sequencing or hung stores;

d. The maximum and minimum permissible c.g. positions (longitudinal, lateral, and vertical);

e. The maximum c.g. excursions (longitudinal, lateral, and vertical) attainable through failures in systems or components;

f. The maximum and minimum permissible moments and products of inertia;

g. The maximum and minimum moments and products of inertia attainable through failures in systems or components;

h. The most critical stores combinations (internal and external, symmetric and asymmetric), including sloshing and shifting in stores containing expendable loads;

i. The most critical stores combinations (internal and external, symmetric and asymmetric) attainable through failures in systems or components, including sloshing and shifting in stores containing expendable loads;

j. The worst possible cases (in a flying qualities sense) that are not special failure states; and

k. Any additional loadings the procuring agency feels necessary.

The handling characteristics described in this specification guide are specified in terms of qualitative degrees of suitability and levels. Levels and degrees of suitability are based on the Cooper-Harper (C-H) Scale (see paragraph 6.4.6 Flying qualities definitions and figure 6.4.6-6) and Mil-HDBK-1797. In calm air, Level 1 is Satisfactory, Level 2 is Acceptable, and Level 3 is Controllable. In the presence of higher intensities of atmospheric disturbances, the relationship between levels and qualitative degrees of suitability is specified in 3.3.11.1.2 Flying qualities degradations in atmospheric disturbances.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the design concept indicates that flying qualities requirements are defined and analyzed for the specified operations and missions.

PDR: Analysis of the preliminary design indicates that flying qualities requirements are incorporated in the applicable design requirements.

CDR: Analysis of the final air vehicle design confirms that design requirements incorporate flying qualities considerations.

FFR: Analysis of flying qualities requirements confirms that the air vehicle meets safety of flight and design requirements.

SVR: Analysis confirms that flying qualities conditions have been appropriately (consistent application technique) applied to the air vehicle verifications.

Sample Final Verification Criteria

Analysis of verification criteria for each air vehicle performance requirement confirms that the flying qualities requirements have been applied in defining the specific operations requirements and conditions for each air vehicle performance requirement.

VERIFICATION LESSONS LEARNED (4.3.11.1)

Lessons learned can be found in MIL-HDBK-1797.

3.3.11.1.1 Primary requirements for air vehicle states in common atmospheric conditions

The levels of flying qualities for air vehicle states in common atmospheric conditions shall meet the requirements of 3.3.11.1.1.1 Allowable levels for air vehicle normal states through 3.3.11.1.1.3.3 Failures outside the ROTH.

REQUIREMENT RATIONALE (3.3.11.1.1)

Air vehicle flying qualities vary as a function of task, air vehicle loading, air vehicle configuration, flight condition, and atmospheric condition. It is impractical to expect perfect flying qualities for all tasks, all loadings, all configurations, and all atmospheric conditions throughout the entire flight envelope. The purpose of specifying different levels of flying qualities is to allow variation with these factors while still controlling the degree of variation. The requirements of section 3.3.11.1.1 Primary requirements for air vehicle states in common atmospheric conditions establish the expected level of flying qualities for various combinations of flight phase category (task), air vehicle state (loading and configuration), and regions of handling (flight condition) in calm air and common atmospheric disturbances. The requirements of section 3.3.11.1.2 Flying qualities degradations in atmospheric disturbances subsequently establish the degradation allowed for each of these combinations with larger atmospheric disturbances.

REQUIREMENT GUIDANCE (3.3.11.1.1)

See guidance of requirement 3.3.11.1 Flying qualities, fixed wing.

REQUIREMENT LESSONS LEARNED (3.3.11.1.1)

To Be Prepared

4.3.11.1.1 Primary requirements for air vehicle states in common atmospheric conditions verification

Requirement 3.3.11.1.1 Primary requirements for air vehicle states in common atmospheric conditions is a header paragraph to introduce the following subparagraphs. There is no associated verification.

3.3.11.1.1.1 Allowable levels for air vehicle normal states

The boundaries of the region of satisfactory handling (ROSH), region of tolerable handling (ROTH), and region of recoverable handling (RORH) for each air vehicle normal state shall be as shown in table 3.3.11.1.1.1-I.

Flying qualities for air vehicle normal states within the ROSH shall be Level 1 in calm air and in common atmospheric disturbances.

Flying qualities for air vehicle normal states within the ROTH but outside the ROSH shall be Level 2 or better in calm air and in common atmospheric disturbances.

From all points in the RORH and outside the ROTH, the air vehicle shall be capable of returning to the ROTH, without degradation to air vehicle or pilot functionality, in calm air and in common atmospheric disturbances.

For ground operations and terminal flight phases such as taxiing, takeoffs, and landings which involve operation outside the ROSH, ROTH, and RORH (such as “at or below” vs “or on the ground”), the levels shall be applied as if these conditions were in the ROSH.

TABLE 3.3.11.1.1.1- I. Boundaries of the regions of handling.

		Region of Satisfactory Handling (3)						Region of Tolerable Handling (4)						Region of Recoverable Handling (5)					
Air Vehicle Normal State	Flight Phase	Min Airspeed $V_{o_{min}}$	Max Airspeed $V_{o_{max}}$	Min Altitude $h_{o_{min}}$	Max Altitude $h_{o_{max}}$	Min Load Factor $n_{o_{min}}$	Max Load Factor $n_{o_{max}}$	Min Airspeed V_{min}	Max Airspeed V_{max}	Min Altitude	Max Altitude h_{max}	Min Load Factor n_{min}	Max Load Factor n_{max}	Min Airspeed	Max Airspeed	Min Altitude	Max Altitude h_L	Min Load Factor $n_{L_{min}}$	Max Load Factor $n_{L_{max}}$
(1)	(2)																		

REQUIREMENT RATIONALE (3.3.11.1.1.1)

These paragraphs are needed to guide the application of the rest of the requirements. Considered as a group, these requirements specify the minimum handling qualities to be attained for an air vehicle operating in a normal state, i.e., unfailed, in all regions of operation in calm air and common atmospheric disturbances. These normal states represent the usual modes of piloted flight. Levels of flying qualities apply generally within the ROSHs and ROTHs. Some basic requirements, generally qualitative in nature, apply in both the ROSHs and ROTHs. Provision must also be made for expected and allowable operation outside of these regions.

REQUIREMENT GUIDANCE (3.3.11.1.1.1)

To complete column (1) of table 3.3.11.1.1.1-I, the designer needs a specific mission statement to furnish guidance for consistent selection of quantitative requirements and for interpreting qualitative requirements. The word “mission” is used in several contexts not only in this specification, but also throughout the documents pertinent to acquiring a new weapon system. In the broadest sense, “operational missions” applies to classifying the air vehicle as a fighter, bomber, reconnaissance, etc., or to “accomplishing the mission” of bombing, strafing, etc. The objective of the mission statement is to define the function of the vehicle in general terms. It should be sufficient for the designer to refer to performance to define the overall performance requirements, the operational requirements, and the employment and deployment requirements.

Once the intended uses or operational missions are defined, the designer should conduct a flight phase analysis of each mission to complete column (2) of table 3.3.11.1.1.1-I. With the flight phases established, the designer can define the configurations and loading states, which will exist during each phase. After the configuration and loading states have been defined for a given flight phase, the designer can determine the ROTH and RORH, and more fully define the ROSHs.

The designer should define a table of air vehicle normal states for each applicable flight phase. If the position of any particular design feature can affect flying qualities, its possible positions should be tabulated as well. Bear in mind that items not normally considered such as setting or automatic operation of engine bypass doors, can affect flying qualities. Initially, the designer should tabulate the positions of such features in discrete steps small enough to allow accurate interpolation to find the most critical values or combinations. Once these critical cases are found, they should be added to the tabulation. Center-of-gravity (c.g.) positions that can be attained only with prohibited, failed, or malfunctioning fuel sequencing need not be considered for air vehicle normal states.

Definition of the regions of handling is basic to application of the flying qualities requirements. In table 3.3.11.1.1.1-I, columns 3, 4, and 5, indicate the three regions to be defined: the region of satisfactory handling (ROSH), the region of tolerable handling (ROTH), and the region of recoverable handling (RORH). The boundaries of these regions should be defined in terms of speed, altitude, load factor, and any other flight limits. The boundaries of the ROSH and ROTH should implicitly include the ranges of other parameters, such as sideslip, which can be expected within the speed, altitude, and load factor bounds. As a general policy, the designer should propose the boundaries and rationale for all regions. The contractor and procuring agency may need to negotiate the boundaries of these regions.

The contractor and procuring activity need to define the boundaries of the ROSH for each applicable air vehicle state within which the air vehicle must be capable of operating in order to accomplish the operational mission requirements of the air vehicle as defined by the customer or user. Level 1 (see figure 6.4.6-6) flying qualities should be required within these boundaries. By bounding the regions in which the best flying qualities are desired, unnecessary cost, weight, complexity, etc. can be avoided while assuring capability to perform the intended missions.

For each air vehicle normal state, the contractor and procuring activity should establish a ROTH derived from air vehicle performance margins (such as service ceiling) instead of from mission requirements. For each applicable flight phase and normal state, the boundaries of the ROTH should be coincident with or lie outside the corresponding ROSH boundaries.

The designer should define the RORHs, which encompass all regions in which operation of the air vehicle is both allowable and possible, and which the air vehicle is capable of safely encountering. Definition of the RORHs is a flight safety consideration.

High angle of attack (AOA) should be considered in determining the boundaries of the regions of handling (table 3.3.11.1.1.1-I). Stall and spin are related by their application at high AOA typically outside the ROTH. High AOA is considered to be at and above the AOA for stall warning (see appendix C), generally outside the ROTH. Thus, the AOA value considered high will vary with the situation, such as air vehicle class, configuration, and Mach number.

Bear in mind that the purpose of table 3.3.11.1.1.1-I is not to drive requirements on speed, altitude, and load factor. Those are driven by the performance requirements. The purpose of this table is to specify the regions where the air vehicle will have Level 1 and Level 2 handling qualities, and the limits of permissible flight. Prior to contract award, the contractor may not be able to provide explicit numbers for all of the values in table 3.3.11.1.1.1-I. At this stage, it should be sufficient to fill in the table with formulas similar to the ones provided in the recommended table. For example, prior to contract award, the stall speeds for different configurations will not be known, so the contractor would not be able to provide numbers for V_{omin} for these configurations. But it would be satisfactory for the contractor to put "1.15V_s" in the table. As the design matures and testing provides predictions for V_s, the formulas should be replaced with actual numbers. The table should be completely filled out with specific numbers by CDR or equivalent review. Because of the inherent uncertainties in these predictions, the values in this table should be treated with some tolerance. For the purpose of demonstrating compliance the following tolerances should be applied: minimum airspeeds should be within a tolerance of ±1 kt or ±1%, whichever is less; maximum airspeeds should be within a tolerance of ±10 kts or ±10%, whichever is less; maximum altitudes should be within a tolerance of ±1000 ft or ±5%, whichever is less; minimum load factors should be within a tolerance of ±0.1g or ±10%, whichever is less; and maximum load factors should be within a tolerance of ±0.5g or ±10%, whichever is less.

Recommended values for table 3.3.11.1.1.1- I

		Region of Satisfactory Handling						Region of Tolerable Handling						Region of Recoverable Handling					
Air Vehicle Normal State	Flight Phase			Min Airspeed $V_{o_{min}}$							Max Airspeed $V_{o_{max}}$						Min Altitude $h_{o_{min}}$		
	Air-to-air combat	1.15 V_S(CO)	V_{MAT}(CO)	MSL	Max Altitude $h_{o_{max}}$	Min Load Factor $n_{o_{min}}$	Max Load Factor $n_{o_{max}}$	Min Airspeed V_{min}	Max Airspeed V_{max}	Min Altitude	Max Altitude h_{max}	Min Load Factor n_{min}	Max Load Factor n_{max}	Min Airspeed	Max Airspeed	Min Altitude	Max Altitude h_L	Min Load Factor $n_{L_{min}}$	Max Load Factor $n_{L_{max}}$
	Ground attack	1.3 V_S(GA)	V_{MRT}(GA)	MSL	Combat ceiling(CO)	-1.0	$n_{L_{max}}$(CO)	V_{min}(CO)	V_{max}(CO)	MSL	Service ceiling(CO)	$n_{L_{min}}$(CO)	$n_{L_{max}}$(CO)	V_S(CO)	V_L(CO)	MSL	h_L(CO)	$n_{L_{min}}$(CO)	$n_{L_{max}}$(CO)
	Weapon Delivery/Launch	V_{range}(WD)	V_{MAT}(WD)	MSL	*	-1.0	$n_{L_{max}}$(GA)	V_{min}(GA)	V_{max}(GA)	MSL	Service ceiling(GA)	$n_{L_{min}}$(GA)	$n_{L_{max}}$(GA)	V_S(GA)	V_L(GA)	MSL	h_L(GA)	$n_{L_{min}}$(GA)	$n_{L_{max}}$(GA)
	Aerial Recovery	1.2 V_S(AR)	V_{MRT}(AR)	MSL	Combat ceiling(WD)	0.5	*	V_{min}(WD)	V_{max}(WD)	MSL	Service ceiling(WD)	n_{min}(WD)	n_{max}(WD)	V_S(WD)	V_L(WD)	MSL	h_L(WD)	$n_{L_{min}}$(WD)	$n_{L_{max}}$(WD)
	Reconnaissance	1.3 V_S(RC)	V_{MAT}(RC)	MSL	Combat ceiling(AR)	0.5	$n_{L_{max}}$(AR)	V_{min}(AR)	V_{max}(AR)	MSL	Service ceiling(AR)	n_{min}(AR)	$n_{L_{max}}$(AR)	V_S(AR)	V_L(AR)	MSL	h_L(AR)	$n_{L_{min}}$(AR)	$n_{L_{max}}$(AR)
	In-flight Refueling (Receiver)	1.2 V_S(RR)	V_{MRT}(RR)	MSL	Combat ceiling(RC)	*	*	V_{min}(RC)	V_{max}(RC)	MSL	Service ceiling(RC)	n_{min}(RC)	n_{max}(RC)	V_S(RC)	V_L(RC)	MSL	h_L(RC)	$n_{L_{min}}$(RC)	$n_{L_{max}}$(RC)
	Terrain-following	V_{range}(TF)	V_{MAT}(TF)	MSL	Combat ceiling(RR)	0.5aa	2.0	V_{min}(RR)	V_{max}(RR)	MSL	Service ceiling(RR)	n_{min}(RR)	n_{max}(RR)	V_S(RR)	V_L(RR)	MSL	h_L(RR)	$n_{L_{min}}$(RR)	$n_{L_{max}}$(RR)
	Anti-submarine Search	1.2 V_S(AS)	V_{MRT}(AS)	MSL	10,000 ft	0.0	3.5	V_{min}(TF)	V_{max}(TF)	MSL	Service ceiling(TF)	n_{min}(TF)	n_{max}(TF)	V_S(TF)	V_L(TF)	MSL	h_L(TF)	$n_{L_{min}}$(TF)	$n_{L_{max}}$(TF)
	Close-formation flying	1.4 V_S(FF)	V_{MAT}(FF)	MSL	*	0.0	2.0	V_{min}(AS)	V_{max}(AS)	MSL	Service ceiling(AS)	n_{min}(AS)	n_{max}(AS)	V_S(AS)	V_L(AS)	MSL	h_L(AS)	$n_{L_{min}}$(AS)	$n_{L_{max}}$(AS)
	Climb	.85 $V_{R/C}$(CL)	1.3 $V_{R/C}$(CL)	MSL	Combat ceiling(FF)	-1.0	$n_{L_{max}}$(FF)	V_{min}(FF)	V_{max}(FF)	MSL	Service ceiling(FF)	n_{min}(FF)	$n_{L_{max}}$(FF)	V_S(FF)	V_L(FF)	MSL	h_L(FF)	$n_{L_{min}}$(FF)	$n_{L_{max}}$(FF)
	Cruise	V_{range}(CR)	V_{NRT}(CR)	MSL	Cruise ceiling(CL)	0.5	2.0	V_{min}(CL)	V_{max}(CL)	MSL	Service ceiling(CL)	n_{min}(CL)	n_{max}(CL)	V_S(CL)	V_L(CL)	MSL	h_L(CL)	$n_{L_{min}}$(CL)	$n_{L_{max}}$(CL)
	Loiter	.85 V_{end}(LO)	1.3 V_{end}(LO)	MSL	Cruise ceiling(CR)	0.5	2.0	V_{min}(CR)	V_{max}(CR)	MSL	Service ceiling(CR)	n_{min}(CR)	n_{max}(CR)	V_S(CR)	V_L(CR)	MSL	h_L(CR)	$n_{L_{min}}$(CR)	$n_{L_{max}}$(CR)

Recommended values for table 3.3.11.1.1.1- I continued:

		Region of Satisfactory Handling						**Region of Tolerable Handling**						**Region of Recoverable Handling**					
Air Vehicle Normal State	Flight Phase	Min Airspeed $V_{o_{min}}$	Max Airspeed $V_{o_{max}}$	Min Altitude $h_{o_{min}}$	Max Altitude $h_{o_{max}}$	Min Load Factor $n_{o_{min}}$	Max Load Factor $n_{o_{max}}$	Min Airspeed V_{min}	Max Airspeed V_{max}	Min Altitude	Max Altitude h_{max}	Min Load Factor n_{min}	Max Load Factor n_{max}	Min Airspeed	Max Airspeed	Min Altitude	Max Altitude h_L	Min Load Factor $n_{L_{min}}$	Max Load Factor $n_{L_{max}}$
	In-flight Refueling (Tanker)	1.4 V_S(RT)	V_{MAT}(RT)	MSL	Cruise ceiling(LO)	0.5	2.0	V_{min}(LO)	V_{max}(LO)	MSL	Service ceiling(LO)	n_{min}(LO)	n_{max}(LO)	V_S(LO)	V_L(LO)	MSL	h_L(LO)	$n_{L_{min}}$(LO)	$n_{L_{max}}$(LO)
	Descent	1.4 V_S(D)	V_{MAT}(D)	MSL	Cruise ceiling(RT)	0.5	2.0	V_{min}(RT)	V_{max}(RT)	MSL	Service ceiling(RT)	n_{min}(RT)	n_{max}(RT)	V_S(RT)	V_L(RT)	MSL	h_L (RT)	$n_{L_{min}}$(RT)	$n_{L_{max}}$ (RT)
	Takeoff	$V_{o_{min}}$(TO)	V_{max}(TO)	MSL	10,000 ft	0.5	2.0	V_{min}(TO)	V_{max}(TO)	MSL	Service ceiling(TO)	n_{min}(TO)	n_{max}(TO)	V_S(TO)	V_L(TO)	MSL	h_L (TO)	$n_{L_{min}}$ (TO)	$n_{L_{max}}$ (TO)
	Catapult Takeoff	$V_{C_{min}}$(CT)	$V_{o_{min}}$(CT) + 30 kt	MSL	MSL	0.5	$n_{L_{max}}$(CT)	V_{min}(CT)	V_{max}(CT)	MSL	Service ceiling(CT)	n_{min}(CT)	$n_{L_{max}}$(CT)	V_S(CT)	V_L(CT)	MSL	h_L(CT)	$n_{L_{min}}$(CT)	$n_{L_{max}}$(CT)
	Approach	$V_{o_{min}}$(PA)	V_{max}(PA)	MSL	10,000 ft	0.5	2.0	V_{min}(PA)	V_{max}(PA)	MSL	Service ceiling(PA)	n_{min}(PA)	n_{max}(PA)	V_S(PA)	V_L(PA)	MSL	h_L(PA)	$n_{L_{min}}$(PA)	$n_{L_{max}}$(PA)
	Wave-off/Go-around	$V_{o_{min}}$(PA)	V_{max}(WO)	MSL	10,000 ft	0.5	2.0	V_{min}(WO)	V_{max}(WO)	MSL	Service ceiling(WO)	n_{min}(WO)	n_{max}(WO)	V_S(WO)	V_L(WO)	MSL	h_L(WO)	$n_{L_{min}}$(WO)	$n_{L_{max}}$(WO)
	Landing	$V_{o_{min}}$(L)	V_{max}(L)	MSL	10,000 ft	0.5	2.0	V_{min}(L)	V_{max}(L)	MSL	Service ceiling(L)	n_{min}(L)	n_{max}(L)	V_S(L)	V_L(L)	MSL	h_L(L)	$n_{L_{min}}$(L)	$n_{L_{max}}$(L)

REQUIREMENT LESSONS LEARNED (3.3.11.1.1.1)

Operational missions generally depart significantly from the design mission profile, even for the same type of mission. It is important to allow enough latitude to cover likely variations. Also, over the life of an air vehicle its operational missions will likely change in both type and detail. There are, of course, tradeoffs with cost, weight, and the like. For a particular procurement the extent of the ROSH beyond minimum operational needs should be as large, then, as these tradeoffs will reasonably permit. While stability and control augmentation can do wonders, such factors as basic control authority and rate, aeroelasticity, and stall speed are limiting at operational extremes and difficult and costly to change after the design freeze. Skimping on the ROSHs, then, can cause difficulties.

When designing for aerial refueling, consideration must be given to interference effects on the receiver from the tanker's flow field. When the air vehicle is a tanker, the air vehicle and its tanker aerial refueling subsystem(s) should provide an adequately stable platform for the receiver air vehicles to fly behind to permit safe contact and engagement of the tanker's aerial refueling subsystem interface with the appropriate receiver aerial refueling subsystem interface. When the air vehicle is a receiver, it should have adequate flying qualities and sufficient power within the flow field(s) behind the targeted tanker platform(s) to permit safe contact and engagement of its aerial refueling subsystem interface with the appropriate tanker aerial refueling subsystem interface(s) on the targeted tanker(s).

4.3.11.1.1.1 Allowable levels for air vehicle normal states verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Flying qualities within the boundaries of the ROSH, ROTH, and RORH including ground operations and terminal flight phases	Flying qualities level	A	A,S	A,S	A,S	A,S, D,T

VERIFICATION DISCUSSION (4.3.11.1.1.1)

The specific flight conditions to be evaluated should include the most common operating conditions, any operating conditions critical to the mission of the air vehicle, and any conditions predicted by analysis and simulation to be worse than the level of flying qualities required. Proof of compliance in these demonstration tasks will consist of pilot comments and Cooper-Harper (C-H) ratings. For Level 1, pilot comments will indicate satisfaction with air vehicle flying qualities, with no worse than "mildly unpleasant" deficiencies, and median C-H ratings should be no worse than 3.5 in Common atmospheric disturbances. For Level 2, pilot comments will indicate that, if any handling qualities deficiencies exist, air vehicle flying qualities are at least tolerable, and median C-H ratings for these tasks should be no worse than 6.5 in Common atmospheric disturbances. For conditions considered too dangerous to test in flight, verification can be shown in a manned simulation. Proof of compliance in these demonstrations will consist of pilot comments. The pilot comments should indicate that the air vehicle can be readily and safely returned to the ROTH or ROSH and that no exceptional pilot inputs are necessary to recover the air vehicle.

During the requirements definition process, the procuring activity together with the contractor(s) and the responsible test organization, should select several closed-loop tasks with which to evaluate the air vehicle in flight test. During system development, ground-based and in-flight simulations should be used to get an initial appraisal of how well the air vehicle will perform the tasks in flight. The simulations can also be used to train the test pilots and refine the tasks, performance objectives, and test procedures. Handling qualities evaluation during flight test should consist of four parts: 1) “Open-loop” tasks such as steps, doublets, and frequency sweeps for parameter identification to compare air vehicle dynamic response to the open-loop design parameters, 2) capture tasks to familiarize the pilot with air vehicle response and capture characteristics, 3) handling qualities during tracking (HQDT) for initial closed-loop handling qualities evaluation, and 4) “operational” closed-loop tasks to obtain Cooper-Harper ratings. The distinction between HQDT and “operational” tasks is discussed in MIL-HDBK-1797.

Selected air vehicle normal states should be analyzed and tested for each applicable flight phase. The selected air vehicle normal states should include all loadings and configurations encountered in flight phases and tasks of the operational missions plus a limited number of values of those parameters such as weight, moments of inertia, c.g. position, wing sweep, and throttle setting which vary continuously over a range of values during the flight phase. The values selected should include the most critical values and the extremes encountered during the flight phase in question. The evaluation tasks in the following table should be flown by test pilots at specific flight conditions throughout the ROSH and ROTH.

Suggested performance objectives for various evaluation tasks.

Suggested Tasks	Suggested Performance Objectives
Air-to-Air and Air-to-Ground Tracking: Gross Acquisition	Desired Performance Time to acquire: TBE by CDR Overshoots: No more than one greater than 5 mils, none to exceed 10 mils No PIO
	Adequate Performance Time to acquire: TBE by CDR Overshoots: No more than two greater than 5 mils, none to exceed 20 mils
Air-to-Air and Air-to-Ground Tracking: Fine Tracking	Desired Performance Keep the pipper within 5 mils of the target point for three continuous seconds No PIO
	Adequate Performance Keep the pipper within 10 mils of the target point for three continuous seconds
Close Formation	Desired Performance Excursions no greater than ±2 feet from the formation position No PIO
	Adequate Performance Excursions no greater than ±4 feet from the formation position

Suggested Tasks	Suggested Performance Objectives
Aerial Refueling: Boom Tracking	Desired Performance Keep pipper within 5 mils of the boom nozzle for at least 50% of the tracking time No PIO
	Adequate Performance Keep pipper within 10 mils of the boom nozzle for at least 50% of the tracking time
Aerial Refueling: Probe-and-Drogue	Desired Performance Hook-up without touching basket webbing in at least 50% of the attempts No PIO
	Adequate Performance Hook-up in at least 50% of attempts
Offset Precision Landing: Approach	Desired Performance Flightpath control: Remain within ±1 degree of glideslope angle or ± ½ dot on ILS Airspeed control: Maximum of 5 knots above approach speed, minimum TBE by CDR No PIO
	Adequate Performance Flightpath control: Remain within ±2 degrees of glideslope angle or ±1 dot on ILS Airspeed control: Maximum of 10 knots above approach speed, minimum TBE (by CDR), but not less than V_{stall}
Offset Precision Landing: Touchdown (Conventional Air Vehicles)	Desired Performance Touchdown zone: Within ±25 feet of aim point laterally, within -100 to +400 feet of aim point longitudinally Speed at touchdown: Maximum of 5 knots above landing speed, minimum TBE by CDR Attitude at touchdown: TBE by CDR Sink rate at touchdown: TBE by CDR No PIO
	Adequate Performance Touchdown zone: Within ±50 feet of aim point laterally, within -250 to +750 feet of aim point longitudinally Speed at touchdown: Maximum of 10 knots above landing speed, minimum TBE by CDR Attitude at touchdown: TBE by CDR Sink rate at touchdown: TBE by CDR

Suggested Tasks	Suggested Performance Objectives
Offset Precision Landing: Touchdown (STOL Air Vehicles)	Desired Performance Touchdown zone: Within ±10 feet of aim point laterally, within -25 to +75 feet of aim point longitudinally Speed at touchdown: Maximum of 2 knots above landing speed, minimum TBE by CDR Attitude at touchdown: TBE by CDR Sink rate at touchdown: TBE by CDR No PIO
	Adequate Performance Touchdown zone: Within ±25 feet of aim point laterally, within -100 to +400 feet of aim point longitudinally Speed at touchdown: Maximum of 5 knots above landing speed, minimum TBE by CDR Attitude at touchdown: TBE by CDR Sink rate at touchdown: TBE by CDR
Offset Precision Landing: Rollout and Takeoff Roll	Desired Performance Keep the nosewheel within ±10 feet of the runway centerline No PIO
	Adequate Performance Keep the nosewheel within ±25 feet of the runway centerline
Takeoff Rotation	Desired Performance Attitude control: Keep within ±1 degree of takeoff attitude Overshoots: No more than one overshoot, not to exceed TBE degrees (by CDR) No PIO
	Adequate Performance Attitude control: Keep within ±2 degrees of takeoff attitude Overshoots: No more than one overshoot, not to exceed TBE degrees (by CDR)
Takeoff Climbout	Desired Performance Flightpath control: Keep within ±1 degree of specified climbout angle Groundtrack: Keep air vehicle within ±10 feet of runway centerline or within ±2 degrees of runway heading No PIO
	Adequate Performance Flightpath control: Keep within ±2 degrees of specified climbout angle, but not less than 0° Groundtrack: Keep air vehicle within ±25 feet of runway centerline or within ±5 degrees of runway heading

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the design concept, using wind tunnel data, computational techniques, and empirical data indicates that data required for initial trade studies to tailor flying qualities and make preliminary assessments of flying qualities is available.

PDR: Analysis and simulation of the preliminary air vehicle design, via computational methods and pilot-in-the-loop simulation using wind tunnel data, mass and inertia characteristics, control laws, and propulsion data indicates flying qualities are consistent with the specified values. Analysis identifies flying qualities conformance.

CDR: Analysis and simulation of the final air vehicle design assesses flying qualities using computational analysis methods and pilot-in-the-loop simulation using updated aerodynamic data, aeroelastic effects, mass and inertia characteristics, flight control and other subsystem characteristics, and propulsion system data representative of the CDR configuration, indicates conformance to specified flying qualities.

FFR: Analysis and simulation confirm flying qualities, using computational methods and pilot-in-the-loop simulation, are safe for initial flight. Analysis confirms that all input data have been updated to the first flight configuration. Analyze sensitivity and robustness of flying qualities to uncertainties in aerodynamic and system parameters. Pilot-in-the-loop simulation also used to develop build-up techniques for hazardous tests. Pilot-in-the-loop assessment of air vehicle flying qualities in variable-stability air vehicle. In-flight simulation should include flying qualities evaluation of most critical tasks as well as sensitivity analysis.

SVR: Analysis, simulation, demonstration, and test confirm that all flying qualities of flight test vehicle(s) meet the required levels and requirements. Compliance with flying qualities requirements are confirmed by comparisons and correlations of all data gathered by pilot-in-the-loop assessment in simulators, the operationally functional simulator, and the flight test vehicle(s). Differences between production configuration and flight test configuration should be assessed using computational techniques to update analyses based on flight test results.

Sample Final Verification Criteria

The flying qualities requirements for allowable levels for air vehicle normal states shall be satisfied when __(1)__ analyses, __(2)__ simulations, __(3)__ demonstrations, and __(4)__ tests confirm specified performance is achieved.

> Blank 1. Identify the type and scope of the analyses required to provide confidence that the requirement has been met. For example, DATCOM and computational fluid dynamics to predict stability derivatives. Other examples are linear analysis, equivalent system, and off line simulation for determining longitudinal and lateral-directional dynamics, response to controller, closed-loop analysis with a pilot model, pilot-in-the-loop oscillation (PIO), time delay, time response characteristics, ride qualities, taxiing, takeoffs, and landings.
>
> Blank 2. Identify the type and scope of the simulations required to provide confidence that the requirement has been met. For example, piloted and in-flight simulations of control forces and displacements (such as steady-state control force and deflection per G, transient control force per G, control displacements in maneuvering flight, control force variations during rapid speed changes, control force versus control deflection, controller breakout forces, control force and travel in takeoff, longitudinal control force limits in dives within the ROTH, longitudinal control force limits in dives within the RORH, control sensitivity, control forces in steady turns), residual

oscillations, yaw control force and deflection in steady sideslips, bank angle in steady sideslips, roll control force and deflection in steady sideslips, roll control power in steady sideslips, lateral-directional control in crosswinds, lateral-directional control with asymmetric thrust, lateral-directional control with speed changes, yaw control forces in wave-off (go-around), cross-axis responses, high angle of attack requirements, carrier operations, V/STOL operations, approach to dangerous flight conditions (warning and indication and operation of devices for indication, warning, prevention, and recovery), buffet, release of stores, effects of armament delivery and special equipment, PIO, residual oscillations, taxiing, takeoffs, and landings. Typical flight maneuver blocks and operationally relevant manuevers are flown throughout the defined regions.

Blank 3. Identify the type and scope of the demonstrations required to provide confidence that the requirement has been met. For example, approach to dangerous flight conditions (warning and indication and operation of devices for indication, warning, prevention, and recovery), buffet, release of stores, effects of armament delivery and special equipment, residual oscillations, ride discomfort, taxiing, takeoffs, and landings. Evaluation tasks shall be defined to show that the air vehicle can be flown to particular flight conditions outside of the ROTH and return readily and safely to the ROTH or ROSH.

Blank 4. Identify the type and scope of the tests required to provide confidence that the requirement has been met. For example, wind tunnel testing to determine stability derivatives and parameter identification to update analysis and simulations. Other examples are flight test to determine control forces and displacements (such as steady-state control force and deflection per G, transient control force per G, control displacements in maneuvering flight, control force variations during rapid speed changes, control force versus control deflection, controller breakout forces, control force and travel in takeoff, longitudinal control force limits in dives within the ROTH, longitudinal control force limits in dives within the RORH, control sensitivity, control forces in steady turns), residual oscillations, yaw control force and deflection in steady sideslips, bank angle in steady sideslips, roll control force and deflection in steady sideslips, roll control power in steady sideslips, lateral-directional control in crosswinds, lateral-directional control with asymmetric thrust, lateral-directional control with speed changes, yaw control forces in wave-off (go-around), cross-axis responses, high angle of attack requirements, carrier operations, V/STOL operations, PIO, transfer to alternate control modes, rate of control surface displacement, cockpit controller characteristics (such as control force versus control deflection, control centering, control free play, control displacement limits, dynamic characteristics, control system damping, direct force controllers), displays and instruments, characteristics of secondary flight control systems (such as trim system irreversibility, rate of trim operation, stalling of trim systems, and automatic trim system), operation of secondary control devices and in-flight configuration change, and auxiliary dive recovery devices, taxiing, takeoffs, and landings. Typical flight maneuver blocks and various evaluation tasks are flown throughout the defined regions. Evaluation tasks shall be defined to show that the air vehicle can be flown to particular flight conditions outside of the ROTH and return readily and safely to the ROTH or ROSH.

VERIFICATION LESSONS LEARNED (4.3.11.1.1.1)

A variety of closed-loop tasks has been developed for the evaluation of air vehicle flying qualities. Recommended tasks for the evaluation of flying qualities can be found in MIL-HDBK-1797.

3.3.11.1.1.2 Allowable levels for air vehicle extreme states

The required level of flying qualities for air vehicle extreme states in common atmospheric disturbances shall be as indicated in the following table:

TABLE 3.3.11.1.1.2-I. Levels for air vehicle extreme states.

Air Vehicle Extreme State	Flight Phase	Region of the Flight Envelope	Required Level of Flying Qualities
(1)	(2)	(3)	(4)

REQUIREMENT RATIONALE (3.3.11.1.1.2)

Levels of flying qualities as defined in 6.4.6 Flying qualities definitions are employed in this document in realization of the possibility that the air vehicle may be required to operate under abnormal conditions. Such abnormalities that may occur as a result of extreme loadings are permitted to comply with a degraded level of flying qualities. This requirement is a flight safety consideration.

REQUIREMENT GUIDANCE (3.3.11.1.1.2)

Columns (1) through (4) should be completed jointly by the contractor and procuring activity. Level 1 flying qualities should be required for all air vehicle normal states in the ROSH and Level 2 in the ROTH, however, this may not always be practical. If there are a few exceptions (and there should only be a few), they should be listed here. Each air vehicle extreme state should be listed. The best practical level of flying qualities attainable should be required for each air vehicle extreme state. Since the best practical level of flying qualities attainable will probably depend on flight conditions, it may be necessary to require a different level of flying qualities in different regions of the flight envelope.

REQUIREMENT LESSONS LEARNED (3.3.11.1.1.2)

To Be Prepared

4.3.11.1.1.2 Allowable levels for air vehicle extreme states verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Flying qualities for air vehicle extreme states in common atmospheric disturbances	Column (4) of table 3.3.11.1.1.2-I	A	A,S	A,S	A,S	A,S, D,T

VERIFICATION DISCUSSION (4.3.11.1.1.2)

The specific flight conditions to be evaluated will include any operating conditions critical to the mission of the air vehicle and any conditions predicted by analysis or simulation to be worse than the Level required. Proof of compliance in these demonstration tasks will consist of pilot comments and C-H ratings. For Level 2, pilot comments should indicate that, if any handling qualities deficiencies exist, air vehicle flying qualities are at least tolerable, and median C-H ratings for these tasks should be no worse than 6.5 in common atmospheric disturbances. For Level 3, pilot comments should indicate that the air vehicle is at least controllable despite any flying qualities deficiencies, and median C-H ratings should be no worse than 9 in common atmospheric disturbances.

All air vehicle extreme states should be analyzed and tested for each applicable flight phase. Tasks similar to those in table 3.3.11-II should be defined. Ensure that the specific tasks and performance objectives selected for each extreme state are appropriate for that extreme state. These tasks should be flown by test pilots at specific flight conditions throughout the ROSH and ROTH.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the design concept, through use of wind tunnel data, computational techniques, and empirical data, indicates that data required for initial trade studies have been established to determine the extreme states, tailor flying qualities, and make preliminary assessments of flying qualities for the extreme states.

PDR: Analysis and simulation of the preliminary air vehicle design via computational methods and pilot-in-the-loop simulation using wind tunnel data, mass and inertia characteristics, control laws, and propulsion data indicates flying qualities for extreme states are consistent with the requirement values.

CDR: Analysis and simulation of the final design using computational analysis methods and pilot-in-the-loop simulation using updated aerodynamic data, aeroelastic effects, mass and inertia characteristics, flight control and other subsystem characteristics, and propulsion system data confirms that flying qualities for extreme states are representative of the specified values.

FFR: Analysis and simulation using computational methods and pilot-in-the-loop simulation confirm that flying qualities for extreme states meet the required values for first flight. Analysis confirms that all input data have been updated to the first flight configuration. (Analysis should include the sensitivity and robustness of flying qualities to uncertainties in aerodynamic and system parameters. Pilot-in-the-loop simulation may also be used to develop build-up techniques for hazardous tests. Simulation should also include pilot-in-the-loop assessment of air vehicle flying qualities for a variable-stability air vehicle. In-flight simulation should include flying qualities evaluation of most critical tasks and sensitivity analysis.)

SVR: Analysis, simulation, demonstration, and tests confirm that all flying qualities of flight test vehicle(s) meet the required levels and requirements for extreme states. Analysis confirms compliance with flying qualities requirements by comparisons and correlations of all data gathered by pilot-in-the-loop assessment in simulators, the operationally functional simulator, and the flight test vehicle(s). Differences between production configuration and flight test configuration should be assessed using computational techniques to update analyses based on flight test results.

Sample Final Verification Criteria

The flying qualities requirements for allowable levels for air vehicle extreme states shall be satisfied when __(1)__ analyses, __(2)__ simulations, __(3)__ demonstrations, and __(4)__ tests confirm specified performance is achieved.

Blank 1. Identify the type and scope of the analyses required to provide confidence that the requirement has been met. For example, DATCOM and computational fluid dynamics to predict stability derivatives. Other examples are linear analysis, equivalent system, and off line simulation for determining longitudinal and lateral-directional dynamics, response to controller, closed-loop analysis with a pilot model, PIO, time delay, time response characteristics, ride qualities, taxiing, takeoffs, and landings.

Blank 2. Identify the type and scope of the simulations required to provide confidence that the requirement has been met. For example, piloted and in-flight simulations analyses of control forces and displacements (such as steady-state control force and deflection per G, transient control force per G, control displacements in maneuvering flight, control force variations during rapid speed changes, control force versus control deflection, controller breakout forces, control force and travel in takeoff, longitudinal control force limits in dives within the ROTH, longitudinal control force limits in dives within the RORH, control sensitivity, control forces in steady turns), residual oscillations, yaw control force and deflection in steady sideslips, bank angle in steady sideslips, roll control force and deflection in steady sideslips, roll control power in steady sideslips, lateral-directional control in crosswinds, lateral-directional control with asymmetric thrust, lateral-directional control with speed changes, yaw control forces in wave-off (go-around), cross-axis responses, high angle of attack requirements, carrier operations, V/STOL operations, approach to dangerous flight conditions (warning and indication and operation of devices for indication, warning, prevention, and recovery), buffet, release of stores, effects of armament delivery and special equipment, PIO, residual oscillations, taxiing, takeoffs, and landings. Typical flight maneuver blocks and operationally relevant manuevers are flown throughout the defined regions. Evaluation tasks should be defined to show that the air vehicle can be flown to particular flight conditions outside of the ROTH and return readily and safely to the ROTH or ROSH.

Blank 3. Identify the type and scope of the demonstrations required in order to provide confidence that the requirement has been met. For example, approach to dangerous flight conditions (warning and indication and operation of devices for indication, warning, prevention, and recovery), buffet, release of stores, effects of armament delivery and special equipment, residual oscillations, and ride discomfort, taxiing, takeoffs, and landings. Evaluation tasks should be defined to show that the air vehicle can be flown to particular flight conditions outside of the ROTH and return readily and safely to the ROTH or ROSH.

Blank 4. Identify the type and scope of the test required to provide confidence that the requirement has been met. For example, wind tunnel testing to determine stability derivatives and parameter identification to update analysis and simulations. Other examples are flight test to determine control forces and displacements (such as steady-state control force and deflection per G, transient control force per G, control displacements in maneuvering flight, control force variations during rapid speed changes, control force versus control deflection, controller breakout forces, control force and travel in takeoff, longitudinal control force limits in dives within the

ROTH, longitudinal control force limits in dives within the RORH, control sensitivity, control forces in steady turns), residual oscillations, yaw control force and deflection in steady sideslips, bank angle in steady sideslips, roll control force and deflection in steady sideslips, roll control power in steady sideslips, lateral-directional control in crosswinds, lateral-directional control with asymmetric thrust, lateral-directional control with speed changes, yaw control forces in wave-off (go-around), cross-axis responses, high angle of attack requirements, carrier operations, V/STOL operations, PIO, transfer to alternate control modes, rate of control surface displacement, cockpit controller characteristics (such as control force versus control deflection, control centering, control free play, control displacement limits, dynamic characteristics, control system damping, direct force controllers), displays and instruments, characteristics of secondary flight control systems (such as trim system irreversibility, rate of trim operation, stalling of trim systems, and automatic trim system), operation of secondary control devices and in-flight configuration change, and auxiliary dive recovery devices, taxiing, takeoffs, and landings. Typical flight maneuver blocks and various evaluation tasks are flown throughout the defined regions.

VERIFICATION LESSONS LEARNED (4.3.11.1.1.2)

Lessons learned can be found in MIL-HDBK-1797.

3.3.11.1.1.3 Primary requirements for failure states

The levels of flying qualities shall meet the requirements of 3.3.11.1.1.3.1 Probability of encountering degraded levels of flying qualities due to failures while operating within the ROSH or ROTH through 3.3.11.1.1.3.3 Failures outside the ROTH.

REQUIREMENT RATIONALE (3.3.11.1.1.3)

Higher performance of air vehicles has led to ever-expanding flight envelopes, increased control system complexity, and the necessity to face the problem of equipment failures in a realistic manner. The specification of levels corresponding to failure states is intended to achieve adequate flying qualities without imposing undue requirements that could lead to unwarranted system complexity or decreased flight safety. For example, an air vehicle with two separate pitch controllers is safer from the standpoint of controller jam, but the probability of such a failure is higher. Without actually requiring a good handling basic airframe, the specification requires

a. A high probability of good flying qualities in which the air vehicle is expected to be used;

b. Acceptable flying qualities in reasonably likely, yet infrequently expected, conditions;

c. A floor to assure, to the greatest extent possible, at least a flyable air vehicle no matter what single failures occur; and

d. A process to assure that all of the ramifications of reliance on powered controls, stability augmentation, etc., receive proper attention.

REQUIREMENT GUIDANCE (3.3.11.1.1.3)

Two procedures are presented to allow the designer to quantify the allowable degradation in flying qualities due to failure states.

The procedure in 3.3.11.1.1.3.1 Probability of encountering degraded levels of flying qualities due to failures while operating within the ROSH or ROTH is unchanged from MIL-F-8785C. It involves the following failure probability calculations:

a. Identify those air vehicle failure states which have a significant effect on flying qualities (see guidance of 3.3.11.1 Flying qualities, fixed wing);

b. Calculate the probability of encountering various air vehicle failure states per flight. Determine the degree of flying qualities degradation associated with each failure state; and

c. Compute the total probability of encountering Level 2 and 3 flying qualities in the ROSH. This total will be the sum of the probability of each failure if the failures are statistically independent.

The procedure in 3.3.11.1.1.3.2 Allowable levels for specific air vehicle failure states assumes that certain listed failures and combinations of failures will occur sometime (with probability 1). Requirements are set on the degree of flying qualities degradation allowed for each of these failure states. As with the first procedure, the degraded flying qualities for each selected failure state are then evaluated and compared to the requirement for that failure state. This approach is referred to as specific failure analysis.

Generally, the requirements consider only degradations in a single flying quality. The designer should recognize that degradations in several flying qualities parameters can have an effect worse than any one of those degradations. However, data definitive enough for a specification is not available.

Also, note that the factors called out in 3.3.11.1.1.3.1 Probability of encountering degraded levels of flying qualities due to failures while operating within the ROSH or ROTH include air vehicle failure states and maneuvering flight appropriate to those failure states.

REQUIREMENT LESSONS LEARNED (3.3.11.1.1.3)

To Be Prepared

3.3.11.1.1.3.1 Probability of encountering degraded levels of flying qualities due to failures while operating within the ROSH or ROTH

Assuming calm air, the overall probability of encountering Level 2 flying qualities due to one or more failures shall be not greater than __(1)__ per flight hour within the ROSH. The overall probability of encountering Level 3 flying qualities due to one or more failures shall be not greater than __(2)__ per flight hour within the ROSH and not greater than __(3)__ per flight hour within the ROTH. In no case shall an air vehicle failure state (except a special failure state) degrade flying qualities below Level 3.

REQUIREMENT RATIONALE (3.3.11.1.1.3.1)

In an air vehicle failure state, degradation in flying qualities is permitted only if the probability of encountering a lower level than specified in 3.3.11.1.1.1 Allowable levels for air vehicle normal states is sufficiently small. The probability of a degraded level of flying qualities is related to, but not exactly the same as, mission or flight-safety reliability. A degraded flying qualities level is allowed for some infrequently expected events: failure of air vehicle systems or flight outside the ROSH, near the air vehicle's limits (by definition, the ROSHs encompass the design missions). Degradation in atmospheric disturbances is discussed in 3.3.11.1.2 Flying qualities degradations in atmospheric disturbances.

REQUIREMENT GUIDANCE (3.3.11.1.1.3.1)

Recommended values for blanks 1, 2, and 3 are shown in the table below.

Levels for air vehicle failure states:

Probability of Encountering	Within the ROSH	Within the ROTH
Level 2 after failure	$<10^{-3}$ per flight hour (1)	--
Level 3 after failure	$<10^{-4}$ per flight hour (2)	$<10^{-2}$ per flight hour (3)

Based on experience with past air vehicles and current projected state of the art, the recommended values of the above table are reasonable. However, the numerical values should reflect specific requirements for a given weapon system. The designer should, as a matter of course, confer with the procuring activity, the using-command, and the reliability engineers to assure that the probabilities associated with the levels are consistent with the overall design goals.

REQUIREMENT LESSONS LEARNED (3.3.11.1.1.3.1)

As in MIL-F-8785C and former MIL-STD-1797A, failure probabilities are specified per flight, rather than per flight hour. The numbers in the guidance table above were chosen so that failures that degrade flying qualities would not contribute disproportionately to reduction or loss of mission effectiveness, or to flight safety problems. The form is consistent with failure rate data, which usually are presented per flight hour, and with the critical takeoff and landing flight phases, which occur once per flight.

The numbers are given as orders of magnitude. When predicting the occurrence of events of such small probability that is about the most accuracy that can be expected. For comparison, AFGS-87242A recommended the following probability limits for the entire flight control system, manual and automatic, with somewhat different ground rules:

a. Probability of mission failure < 10-3 per flight; and

b. Probability of loss of control < 10-7 per flight.

By comparison, Federal Aviation Regulation (FAR) Part 25 paragraph 25.671 for the flight control system states

a. Probable malfunctions (malfunctions with a probability > 10-3 per hour) are allowed to have only minor effect; and

b. Extremely improbable failures (failures with a probability < 10-9 per hour) need not be considered.

For all other failures and failure combinations, continued safe flight and landing must be assured.

The probability of flying qualities degradation is influenced by a number of factors such as design implementation and complexity (including reconfiguration capability), computer reliability improvements, lightning protection, built-in test (BIT), maintenance practices, and dispatch rules. Peacetime versus wartime operation can be a necessary concern, although battle damage is a separate consideration.

4.3.11.1.1.3.1 Probability of encountering degraded levels of flying qualities due to failures while operating within the ROSH or ROTH verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Probability of encountering degraded levels of flying qualities due to one or more failures within each region	Occurrence(s) of degraded flying quality levels per flight hour	A	A,S	A,S	A,S	A,S, D,T

VERIFICATION DISCUSSION (4.3.11.1.1.3.1)

This approach addresses the reliability of flying qualities, rather than the reliability of hardware and software, per se. This requirement provides a solid analytical method for accounting for the effects of failures. It serves to compel a detailed failure modes and effects analysis (FMECA) from the flying qualities standpoint. Such an analysis is vital as both system complexity and the number of design options increase.

Until some time downstream in the design process, the flight control and related subsystems will not be defined in enough detail to permit a comprehensive listing of failure possibilities, much less to estimate their likelihood. Initially, this requirement serves as guidance in selecting a design approach and components and redundancy levels which can potentially achieve or surpass the stated probabilities of not encountering the degraded levels. As the design progresses, reliability analyses and failure modes and effects analyses will provide the means of determining compliance.

Definition of air vehicle special failure states is basic to application of the flying qualities requirements. Perfection is not a realistic expectation. This requirement is to determine the practical limits in each case.

During the FMECA and failure modes and effects test (FMET), the level of flying qualities for each air vehicle failure state should be determined in appropriate flight phases. These determinations should be based on analysis of quantitative flying qualities criteria and on the assessment of the effects of those failures that are evaluated in simulation and flight test. Based on the most accurate available data, the probability of occurrence of each air vehicle failure state per flight within the ROSH and ROTH should be determined. These determinations should be based on determinations of the probability of occurrence of each air vehicle failure state per flight within the ROSH and ROTH should be based on 3.3.11.1.1.3.1 Probability of encountering degraded levels of flying qualities due to failures while operating within the ROSH or ROTH, except that

a. All air vehicle systems are assumed to be operating for the entire flight, unless clearly operative only for a shorter period; and

b. Each specific failure is assumed to be present at whichever point is most critical (in the flying qualities sense) in the region of handling under consideration.

From these failure state probabilities and effects, the contractor should determine the overall probability, per flight hour, that flying qualities are degraded to Level 2 because of one or more failures. The contractor should also determine the probability that flying qualities are degraded to Level 3 because of one or more failures.

Certain components, systems, or combinations thereof may have extremely remote probability of failure during a given flight. These failure probabilities may, in turn, be very difficult to predict with any degree of accuracy. Subject to approval by the procuring activity, such failures may be identified as special failure states and need not be considered in complying with this requirement.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the design concept indicates that design concept is considering an approach that will achieve the desired probability of encountering degraded levels of flying qualities due to failures while operating within the ROSH or ROTH. Early analysis serves as guidance in selecting a design approach, components, and redundancy levels that can potentially achieve or surpass the stated probabilities of not encountering the degraded levels of flying qualities.

PDR: Analysis and simulation assess flying qualities via computational methods and pilot-in-the-loop simulation using wind tunnel data, mass and inertia characteristics, control laws, and propulsion data consistent with the PDR configuration. Initial reliability analyses and failure modes and effects analyses provide the means of determining compliance.

CDR: Analysis and simulation assess flying qualities using computational analysis methods and pilot-in-the-loop simulation using updated aerodynamic data, aeroelastic effects, mass and inertia characteristics, flight control and other subsystem characteristics, and propulsion system data representative of the CDR configuration. Updated reliability analyses and failure modes and effects analyses confirm that the air vehicle will achieve the desired probability of encountering degraded levels of flying qualities due to failures while operating within the ROSH or ROTH.

FFR: Analysis and simulation assess flying qualities using computational methods and pilot-in-the-loop simulation and confirm that the air vehicle flying qualities are ready for first flight. All input data is updated to the first flight configuration. Analyze sensitivity and robustness of flying qualities to uncertainties in aerodynamic and system parameters. Pilot-in-the-loop simulation also used to develop build-up techniques for hazardous tests. Pilot-in-the-loop assessment of air vehicle flying qualities in variable-stability air vehicle. In-flight simulation should include flying qualities evaluation of most critical tasks and most critical failure modes, as well as sensitivity analysis. Flying qualities of failure modes assessed using computational methods and pilot-in-the-loop simulation in an operationally functional simulator (actual flight hardware and software in-the-loop).

SVR: Analysis, simulation, demonstration, and test assess flying qualities of the air vehicle(s). Compliance with flying qualities requirements is confirmed by analysis using comparisons and correlations of all data gathered by pilot-in-the-loop assessment in simulators, the operationally functional simulator, and the flight test vehicle(s). Differences between production configuration and flight test configuration should be assessed using computational techniques to update analyses based on flight test results.

Sample Final Verification Criteria

The requirement for probability of encountering degraded levels of flying qualities due to failures while operating within the ROSH or ROTH shall be satisfied when __(1)__ analyses, __(2)__ simulations, __(3)__ demonstrations, and __(4)__ tests confirm specified performance is achieved.

Blank 1. Identify the type and scope of the analysis required to provide confidence that the requirement has been met. For example, reliability, and failure modes and effects analysis. Other examples are DATCOM and computational fluid dynamics to predict stability derivatives, linear analysis, equivalent system, and off-line simulation for determining the following: longitudinal and lateral-directional dynamics, response to controller, closed-loop analysis with a pilot model, PIO, time delay, time response characteristics, ride qualities, transients following failures, trim changes due to failures, trim for asymmetric thrust (air vehicles with more than two engines), flight characteristic of asymmetric thrust, taxiing, takeoffs, and landings.

Blank 2. Identify the type and scope of the simulations required to provide confidence that the requirement has been met. For example, piloted and in-flight simulations analyses of control forces and displacements (such as steady-state control force and deflection per G, transient control force per G, control displacements in maneuvering flight, control force variations during rapid speed changes, control force versus control deflection, controller breakout forces, control force and travel in takeoff, longitudinal control force limits in dives within the ROTH, longitudinal control force limits in dives within the RORH, control sensitivity, control forces in steady turns), residual oscillations, yaw control force and deflection in steady sideslips, bank angle in steady sideslips, roll control force and deflection in steady sideslips, roll control power in steady sideslips, lateral-directional control in crosswinds, lateral-directional control with asymmetric thrust, lateral-directional control with speed changes, yaw control forces in wave-off (go-around), cross-axis responses, high angle of attack requirements, carrier operations, V/STOL operations, approach to dangerous flight conditions (warning and indication, and operation of devices for indication, warning, prevention, and recovery), buffet, release of stores, effects of armament delivery and special equipment, PIO, residual oscillations, flight characteristic of asymmetric thrust, taxiing, takeoffs, and landings.

Typical flight maneuver blocks and operationally relevant manuevers are flown throughout the defined regions.

Blank 3. Identify the type and scope of the demonstrations required to provide confidence that the requirement has been met. For example, approach to dangerous flight conditions (warning and indication and operation of devices for indication, warning, prevention, and recovery), buffet, release of stores, effects of armament delivery and special equipment, residual oscillations, and ride discomfort, flight characteristic of asymmetric thrust, taxiing, takeoffs, and landings.

Blank 4. Identify the type and scope of the test required to provide confidence that the requirement has been met. For example, wind tunnel testing to determine stability derivatives, parameter identification to update analysis and simulations, and FMET using Iron Bird or hardware-in-the-loop testing to determine failures and level of flying qualities. Other examples are flight test to determine control forces and displacements (such as steady-state control force and deflection per G, transient control force per G, control displacements in maneuvering flight, control force variations during rapid speed changes, control force versus control deflection, controller breakout forces, control force and travel in takeoff, longitudinal control force limits in dives within the ROTH, longitudinal control force limits in dives within the RORH, control sensitivity, control forces in steady turns), residual oscillations, yaw control force and deflection in steady sideslips, bank angle in steady sideslips, roll control force and deflection in steady sideslips, roll control power in steady sideslips, lateral-directional control in crosswinds, lateral-directional control with asymmetric thrust, lateral-directional control with speed changes, yaw control forces in wave-off (go-around), cross-axis responses, high angle of attack requirements, carrier operations, V/STOL operations, PIO, transfer to alternate control modes, rate of control surface displacement, cockpit controller characteristics (such as control force versus control deflection, control centering, control free play, control displacement limits, dynamic characteristics, control system damping, direct force controllers), displays and instruments, characteristics of secondary flight control systems (such as trim system irreversibility, rate of trim operation, stalling of trim systems, and automatic trim system), operation of secondary control devices and in-flight configuration change, and auxiliary dive recovery devices, flight characteristic of asymmetric thrust, taxiing, takeoffs, and landings. Typical flight maneuver blocks and various evaluation tasks are flown throughout the defined regions.

VERIFICATION LESSONS LEARNED (4.3.11.1.1.3.1)

In most cases, a considerable amount of engineering judgment will influence the selection of air vehicle special failure states. Probabilities that are extremely remote are exceptionally difficult to predict accurately. Judgments will weigh the consequences against the feasibility of improvements or alternatives, and against the projected ability to keep high standards throughout design, qualification, production, use, and maintenance. Meeting other pertinent requirements -- such as flight control and structural requirements -- should be considered, as should experience with similar items. Generally, special failure states should be brought to the attention of those concerned with flight safety.

Regardless of the degree of redundancy, there remains a finite probability that all redundant paths will fail. A point of diminishing returns will be reached, beyond which the gains of additional channels are not worth the associated penalties:

a. Complete failure of hydraulic or electrical systems, etc., and

b. Complete or critical partial failure of stability augmentation that has been accepted as necessary to meet Level 3.

Some items might be excepted if special requirements are met. For example, some limited control should remain after failure of all engines, provided by accumulators or an auxiliary power source as appropriate.

When considering the admissibility of a special failure state on the basis of remote probability, the combined probability of having flying qualities worse than Level 3 (not just each individual failure state probability) must be kept extremely remote.

In the last analysis, the designer is responsible for judging design tradeoffs that bear upon safety. Rather than inhibiting imaginative design, then, this paragraph should be construed as forcing examination of failure possibilities as they affect flight safety through deterioration of flying qualities. The present state of the art can support some properly implemented reliance on stability augmentation to maintain Level 3 flying qualities, but it must be done carefully and for good reason.

Refer to MIL-HDBK-1797 for additional lessons learned.

3.3.11.1.1.3.2 Allowable levels for specific air vehicle failure states

The allowable flying qualities levels for specific air vehicle failure states in common atmospheric disturbances shall be as shown in table 3.3.11.1.1.3.2-I, regardless of the probability of occurrence.

TABLE 3.3.11.1.1.3.2-I. Levels of flying qualities for specific air vehicle failure states.

Air Vehicle Failure State	Flight Phase	Region of the Flight Envelope	Level
(1)	(2)	(3)	(4)

REQUIREMENT RATIONALE (3.3.11.1.1.3.2)

The requirements on the effects of specific types of failures, for example, propulsion or flight control system, etc., should be met on the basis that the specific type of failure has occurred, regardless of its probability of occurrence. This approach assumes that a given component, or series of components, will fail. Based on the comments made by users of MIL-F-8785B, this approach is a common current practice. This paragraph has been included to provide a way to specify the allowable degradation in handling qualities due to failures without making detailed probability calculations.

REQUIREMENT GUIDANCE (3.3.11.1.1.3.2)

Column values for (1) through (4) to be completed by the contractor and procuring activity. Because the selection of failure modes is highly dependent on the details of the design, close coordination between the designer, the procuring activity, and the using-command will be required when identifying failure modes to be analyzed and determining the allowable degradation.

Selection of failures to be considered should be based on preliminary estimates of handling qualities degradations. For example, the loss of one to three channels of a quad-redundant Stability Control Augmentation System (SCAS) may have no effect. Conversely the failure of a single-channel, limited-authority damper would warrant a complete analysis, possibly simulation too, to determine the resulting degradation in flying qualities. Requirements such as two-fail-operate assume a certain degree of reliability and so may penalize either the contractor or the user. In addition, the procuring activity may desire consideration of certain failures regardless of their probabilities.

When writing a specific failure requirement, it is best to associate the required levels of flying qualities with the number of failures in the system, and the task that must be performed, as indicated in the following example:

Air Vehicle Failure State	Flight Phase	Region of the Flight Envelope	Level
1. After two independent failures in the stability/control augmentation system	All	ROSH	1
2. After two independent failures in the air data system	RR, CR, PA, L	ROSH	2
3. After two independent failures in the electrical power system	RR, CR, PA, L	ROSH	2
4. After loss of all propulsion power	ED, L	ROSH	2 Means shall be provided to maintain stable and controlled flight for the time required to descend from cruise altitude to SL at the speed for best L/D, with a 5-minute reserve.
5. After two independent failures in a system (such as a fuel system) which can affect c.g. position	All	ROSH	2
6. Electric power interrupts or transients	All	ROSH	2 Shall not result in excessive air vehicle transients or loss of controlled flight.
7. After one failure in the hydraulic system	All	ROSH	2

It should be emphasized that this is only an example, not the recommended values for table 3.3.11.1.1.3.2-I. There will be failures that are not discussed in this example, such as generic software faults. Levels of flying qualities for these failure modes should be coordinated with each of the technical disciplines involved and documented in table 3.3.11.1.1.3.2-I.

REQUIREMENT LESSONS LEARNED (3.3.11.1.1.3.2)

Mission requirements should be considered when writing these requirements.

4.3.11.1.1.3.2 Allowable levels for specific air vehicle failure states verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Flying qualities for specific Air Vehicle Failure States in Common atmospheric disturbances regardless of the probability of occurrence	Table 3.3.11.1.1.3.2-I	A	A,S	A,S	A,S	A,S, D,T

VERIFICATION DISCUSSION (4.3.11.1.1.3.2)

Verification of specific failures is required to demonstrate that flying qualities meet specified levels when those failures occur. A comprehensive failure modes and effects analysis has been found essential for all but very simple designs. Initially, failure analysis will consist of determining that the flying qualities parameters in question fall within the prescribed boundaries for the specified Levels. Later, ground-based and/or in-flight simulation should be used to demonstrate that flying qualities meet the specific failure requirements. When evaluating the effects of failures, the failures should be assumed to occur in the most critical flight condition; for example, a yaw damper failure at the maximum service ceiling.

For each combination of failure state and flight phase listed in requirement 3.3.11.1.1.3.2 Allowable levels for specific air vehicle failure states, the resulting Level of flying qualities should be evaluated by simulation or flight test during the FMECA and FMET. Using the same tasks as those of requirements 3.3.11.1.1.1 Allowable levels for air vehicle normal states and 3.3.11.1.1.2 Allowable levels for air vehicle extreme states, failures should be introduced during the tasks and the resulting flying qualities evaluated by pilot comments and C-H ratings. The comments and ratings for each combination should indicate that the flying qualities are no worse than the required Level of flying qualities for that failure state and flight phase.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the design concept indicates that design concept is considering an approach that will achieve the allowable levels for specific air vehicle failure states. Early analysis serves as guidance in selecting a design approach, components, and redundancy levels which can potentially achieve or surpass the stated probabilities of not encountering the degraded levels of flying qualities.

PDR: Analysis and simulation assess flying qualities via computational methods and pilot-in-the-loop simulation using wind tunnel data, mass and inertia characteristics, control laws, and propulsion data consistent with the PDR configuration. Initial failure modes and effects analyses provide the means of determining compliance.

CDR: Analysis and simulation assess flying qualities using computational analysis methods and pilot-in-the-loop simulation using updated aerodynamic data, aeroelastic effects, mass and inertia characteristics, flight control and other subsystem characteristics, and propulsion system data representative of the CDR configuration. Updated failure modes and effects analyses confirm that the air vehicle will achieve the allowable levels for specific air vehicle failure states.

FFR: Analysis and simulation assess flying qualities using computational methods and pilot-in-the-loop simulation and confirm that the air vehicle flying qualities are ready for first flight. All input data updated to the first flight configuration. Analyze sensitivity and robustness of flying qualities to uncertainties in aerodynamic and system parameters. Pilot-in-the-loop simulation also used to develop build-up techniques for hazardous tests. Pilot-in-the-loop assessment of air vehicle flying qualities in variable-stability air vehicle. In-flight simulation should include flying qualities evaluation of most critical tasks and most critical failure modes, as well as sensitivity analysis. Flying qualities of failure modes assessed using computational methods and pilot-in-the-loop simulation in an operationally functional simulator (actual flight hardware and software-in-the-loop).

SVR: Analysis, simulation, demonstration, and test assess flying qualities of the air vehicle(s). Compliance with flying qualities requirements verified by comparisons and correlations of all data gathered by pilot-in-the-loop assessment in simulators, the operationally functional simulator, and the flight test vehicle(s). Differences between production configuration and flight test configuration should be assessed using computational techniques to update analyses based on flight test results.

Sample Final Verification Criteria

The flying qualities requirements for allowable levels for specific air vehicle failure states shall be satisfied when __(1)__ analyses, __(2)__ simulations, __(3)__ demonstrations, and __(4)__ tests confirm specified performance is achieved.

> Blank 1. Identify the type and scope of the analysis required to provide confidence that the requirement has been met. For example, reliability and failure modes and effects analysis. Other examples are DATCOM and computational fluid dynamics to predict stability derivatives. Other examples are linear analysis, equivalent system, and off line simulation for determining longitudinal and lateral-directional dynamics, response to controller, closed-loop analysis with a pilot model, PIO, time delay, time response characteristics, ride qualities, transients following failures, trim changes due to failures, trim for asymmetric thrust (air vehicles with more than two engines), flight characteristic of asymmetric thrust, taxiing, takeoffs, and landings.
>
> Blank 2. Identify the type and scope of the simulations required to provide confidence that the requirement has been met. For example, piloted and in-flight simulations analyses of control forces and displacements (such as steady-state control force and deflection per G, transient control force per G, control displacements in maneuvering flight, control force variations during rapid speed changes, control force versus control deflection, controller breakout forces, control force and travel in takeoff, longitudinal control force limits in dives within the ROTH, longitudinal control force limits in dives within the RORH, control sensitivity, control forces in steady turns), residual oscillations, yaw control force and deflection in steady sideslips, bank angle in steady sideslips, roll control force and deflection in steady sideslips, roll control power in steady sideslips, lateral-directional control in crosswinds, lateral-directional control with asymmetric thrust, lateral-directional control with speed changes, yaw control forces in wave-off (go-around), cross-axis responses, high angle of attack requirements, carrier operations, V/STOL operations, approach to dangerous flight conditions (warning and indication and operation of devices for indication, warning, prevention, and recovery), buffet, release of stores, effects of armament delivery and

special equipment, PIO, residual oscillations, flight characteristic of asymmetric thrust, taxiing, takeoffs, and landings. Typical flight maneuver blocks and operationally relevant manuevers are flown throughout the defined regions.

Blank 3. Identify the type and scope of the demonstrations required to provide confidence that the requirement has been met. For example, approach to dangerous flight conditions (warning and indication and operation of devices for indication, warning, prevention, and recovery), buffet, release of stores, effects of armament delivery and special equipment, residual oscillations, and ride discomfort, flight characteristic of asymmetric thrust, taxiing, takeoffs, and landings.

Blank 4. Identify the type and scope of the test required to provide confidence that the requirement has been met. For example, wind tunnel testing to determine stability derivatives, parameter identification to update analysis and simulations, and FMET using Iron bird or hardware-in-the-loop testing to determine failures and level of flying qualities. Other examples are flight test to determine control forces and displacements (such as steady-state control force and deflection per G, transient control force per G, control displacements in maneuvering flight, control force variations during rapid speed changes, control force versus control deflection, controller breakout forces, control force and travel in takeoff, longitudinal control force limits in dives within the ROTH, longitudinal control force limits in dives within the RORH, control sensitivity, control forces in steady turns), residual oscillations, yaw control force and deflection in steady sideslips, bank angle in steady sideslips, roll control force and deflection in steady sideslips, roll control power in steady sideslips, lateral-directional control in crosswinds, lateral-directional control with asymmetric thrust, lateral-directional control with speed changes, yaw control forces in wave-off (go-around), cross-axis responses, high angle of attack requirements, carrier operations, V/STOL operations, PIO, transfer to alternate control modes, rate of control surface displacement, cockpit controller characteristics (such as control force versus control deflection, control centering, control free play, control displacement limits, dynamic characteristics, control system damping, direct force controllers), displays and instruments, characteristics of secondary flight control systems (such as trim system irreversibility, rate of trim operation, stalling of trim systems, and automatic trim system), operation of secondary control devices and in-flight configuration change, and auxiliary dive recovery devices, flight characteristic of asymmetric thrust, taxiing, takeoffs, and landings. Typical flight maneuver blocks and various evaluation tasks are flown throughout the defined regions.

VERIFICATION LESSONS LEARNED (4.3.11.1.1.3.2)

Lessons learned can be found in MIL-HDBK-1797.

3.3.11.1.1.3.3 Failures outside the ROTH

The air vehicle shall be capable of returning to the ROSH or ROTH after the following failures outside of the ROTH but within the RORH: __(1)__.

REQUIREMENT RATIONALE (3.3.11.1.1.3.3)

If the air vehicle experiences certain failures while operating within the RORH, it will be necessary to recover the vehicle to the ROSH or ROTH.

REQUIREMENT GUIDANCE (3.3.11.1.1.3.3)

During development of the specification this requirement should be modified, if the program requires that the air vehicle return to the ROTH or ROSH without loss of control. At this stage, the only guidance possible is to raise the issue and to list some factors in avoiding loss of control:

a. Engine flame-out (duty cycle, throttle usage, or compressor stall);

b. Reaction controls;

c. Fail-operate or fail-soft;

d. Frequency of failure; and

e. Failure-warning reliability.

Blank 1. List applicable failure states.

REQUIREMENT LESSONS LEARNED (3.3.11.1.1.3.3)

As for normal operation, stability augmentation failure modes can have completely different effects in the post-stall region from their action in the ROSH and ROTH.

4.3.11.1.1.3.3 Failures outside the ROTH verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Capability of returning to the ROSH or ROTH after failures outside of the ROTH but within the RORH	Success in returning to ROTH or ROSH (Pass/Fail)	A	A,S	A,S	A,S	A,S, D,T

VERIFICATION DISCUSSION (4.3.11.1.1.3.3)

Flight safety will be a prime factor in determining the means of verification. Outside the ROTH, wind tunnel tests, structural analyses, propulsion limits, etc. should be a primary means of assessing that the requirement elements are met.

Verification should verify that the air vehicle can be flown to particular flight conditions outside the ROTH and return safely under the failure conditions listed in 3.3.11.1.1.3.3 Failures outside the ROTH. The particular flight conditions to be evaluated should include any conditions predicted by analysis or simulation to be worse than Level 3 under the relevant failure conditions. For conditions that are considered too dangerous to test in flight, verification can be shown in a manned simulation. Proof of compliance in these demonstrations will consist of pilot comments. The pilot comments should indicate that the air vehicle can be safely returned to the ROSH or ROTH.

Verification should include simulation or flight test in the performance of the tasks detailed in requirements 4.3.11.1.1.1 Allowable levels for air vehicle normal states verification and 4.3.11.1.1.2 Allowable levels for air vehicle extreme states verification under various levels of atmospheric disturbances. These tasks should be flown by test pilots at specific flight conditions throughout the ROSH and ROTH. The specific flight conditions to be evaluated should be the most common operating conditions, any operating conditions critical to the mission of the air vehicle, and any conditions determined by analysis or simulation to be worse than the level of flying qualities required by table 3.3.11.1.2-I. For conditions, which are considered too dangerous to test in flight, verification can be shown in a manned simulation. Proof of compliance in these demonstration tasks will consist of pilot comments and C-H ratings. The comments and ratings should indicate that the flying qualities are no worse than the required Level of flying qualities for each combination of air vehicle state, flight phase, and level of atmospheric disturbance.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the air vehicle design concept indicates that the design concept is considering an approach that will achieve the required flying qualities capability of returning to the ROSH or ROTH after specified failures outside of the ROTH but within the RORH. Early analysis serves as guidance in selecting a design approach, components, and redundancy levels that can potentially achieve or surpass the stated probabilities of not encountering the degraded levels of flying qualities.

PDR: Analysis and simulation assess flying qualities via computational methods and pilot-in-the-loop simulation using wind tunnel data, mass and inertia characteristics, control laws, and propulsion data consistent with the PDR configuration. Initial failure modes and effects analyses provide the means of determining compliance.

CDR: Analysis and simulation assess flying qualities using computational analysis methods and pilot-in-the-loop simulation using updated aerodynamic data, aeroelastic effects, mass and inertia characteristics, flight control and other subsystem characteristics, and propulsion system data representative of the CDR configuration. Updated failure modes and effects analyses confirm that the air vehicle has the capability of returning to the ROSH or ROTH after specified failures outside of the ROTH but within the RORH .

FFR: Analysis and simulation assess flying qualities using computational methods and pilot-in-the-loop simulation and confirm that the air vehicle flying qualities are ready for first flight. Analysis confirms that all input data has been updated to the first flight configuration. Analyze sensitivity and robustness of flying qualities to uncertainties in aerodynamic and system parameters. Pilot-in-the-loop simulation also used to develop build-up techniques for hazardous tests. Pilot-in-the-loop assessment of air vehicle flying qualities in variable-stability air vehicle. In-flight simulation should include flying qualities evaluation of most critical tasks and most critical failure modes, as well as sensitivity analysis. Flying qualities of failure modes assessed using computational methods and pilot-in-the-loop simulation in an operationally functional simulator (actual flight hardware and software in-the-loop).

SVR: Analysis, simulation, demonstration, and test assess flying qualities of the air vehicle(s). Compliance with flying qualities requirements are confirmed by comparisons and correlations of all data gathered by pilot-in-the-loop assessment in simulators, the operationally functional simulator, and the flight test vehicle(s). Differences between production configuration and flight test configuration should be assessed using computational techniques to update analyses based on flight test results.

Sample Final Verification Criteria

The flying qualities requirements for failures outside the ROTH shall be satisfied when __(1)__ analyses, __(2)__ simulations, __(3)__ demonstrations, and __(4)__ tests confirm specified performance is achieved.

Blank 1. Identify the type and scope of the analyses required to provide confidence that the requirement has been met. For example, DATCOM and computational fluid dynamics to predict stability derivatives. Other examples are linear analysis, equivalent system, and off-line simulation for determining longitudinal and lateral-directional dynamics, response to controller, closed-loop analysis with a pilot model, PIO, time delay, time response characteristics, ride qualities, taxiing, takeoffs, and landings.

Blank 2. Identify the type and scope of the simulations required to provide confidence that the requirement has been met. For example, piloted and in-flight simulations analyses of control forces and displacements (such as steady-state control force and deflection per G, transient control force per G, control displacements in maneuvering flight, control force variations during rapid speed changes, control force versus control deflection, controller breakout forces, control force and travel in takeoff, longitudinal control force limits in dives within the ROTH, longitudinal control force limits in dives within the RORH, control sensitivity, control forces in steady turns), residual oscillations, yaw control force and deflection in steady sideslips, bank angle in steady sideslips, roll control force and deflection in steady sideslips, roll control power in steady sideslips, lateral-directional control in crosswinds, lateral-directional control with asymmetric thrust, lateral-directional control with speed changes, yaw control forces in wave-off (go-around), cross-axis responses, high angle of attack requirements, carrier operations, V/STOL operations, approach to dangerous flight conditions (warning and indication and operation of devices for indication, warning, prevention, and recovery), buffet, release of stores, effects of armament delivery and special equipment, PIO, residual oscillations, taxiing, takeoffs, and landings. Typical flight maneuver blocks and operationally relevant manuevers are flown throughout the defined regions. Evaluation tasks should be defined to show that the air vehicle can be flown to particular flight conditions outside of the ROTH and return readily and safely to the ROTH or ROSH.

Blank 3. Identify the type and scope of the demonstrations required to provide confidence that the requirement has been met. For example, approach to dangerous flight conditions (warning and indication and operation of devices for indication, warning, prevention, and recovery), buffet, release of stores, effects of armament delivery and special equipment, residual oscillations, and ride discomfort, taxiing, takeoffs, and landings. Evaluation tasks should be defined to show that the air vehicle can be flown to particular flight conditions outside of the ROTH and return readily and safely to the ROTH or ROSH. Evaluation tasks should be defined to show that the air vehicle can be flown to particular flight conditions outside of the ROTH and return readily and safely to the ROTH or ROSH.

Blank 4. Identify the type and scope of the test required to provide confidence that the requirement has been met. For example, wind tunnel testing to determine stability derivatives and parameter identification to update analysis and simulations. Other examples are flight test to determine control forces and displacements (such as steady-state control force and deflection per G, transient control force per G, control displacements in maneuvering flight, control force variations during rapid speed changes, control force versus control deflection, controller breakout forces, control force and travel in takeoff, longitudinal control force limits in dives within the ROTH, longitudinal control force limits in dives within the RORH, control sensitivity, control forces in steady turns), residual oscillations, yaw control force and deflection in steady sideslips, bank angle in steady sideslips, roll control force and deflection in steady sideslips, roll control power in steady sideslips, lateral-directional control in crosswinds, lateral-directional control with asymmetric thrust, lateral-directional control with speed changes, yaw control forces in wave-off (go-around), cross-axis responses, high angle of attack requirements, carrier operations, V/STOL operations, PIO, transfer to alternate control modes, rate of control surface displacement, cockpit controller characteristics (such as control force versus control deflection, control centering, control free play, control displacement limits, dynamic characteristics, control system damping, direct force controllers), displays and instruments, characteristics of secondary flight control systems (such as trim system irreversibility, rate of trim operation, stalling of trim systems, and automatic trim system), operation of secondary control devices and in-flight configuration change, and auxiliary dive recovery devices, taxiing, takeoffs, and landings. Typical flight maneuver blocks and various evaluation tasks are flown throughout the defined regions.

VERIFICATION LESSONS LEARNED (4.3.11.1.1.3.3)

Lessons learned can be found in MIL-HDBK-1797.

3.3.11.1.2 Flying qualities degradations in atmospheric disturbances

The minimum required flying qualities for flight in atmospheric disturbances shall be as specified in table 3.3.11.1.2-I.

TABLE 3.3.11.1.2-I. Flying qualities degradation in atmospheric disturbances.

Range of Atmospheric Disturbances	Air Vehicle States Which are Level 1 in Calm Air	Air Vehicle States Which are Level 2 in Calm Air	Air Vehicle States Which are Level 3 in Calm Air
Calm to Common			
Common to Uncommon			
Uncommon to Extraordinary			

REQUIREMENT RATIONALE (3.3.11.1.2)

The flying qualities requirements must incorporate the universal recognition that pilot workload or performance or both generally degrade as the intensity of atmospheric disturbances increases. This requirement provides a rational means for specifying the allowable degradation in handling qualities in the presence of increased intensities of atmospheric disturbances. It is especially important to stress applicability in atmospheric disturbances because most flight testing is done in calm air. There is considerable evidence that atmospheric disturbances can expose handling qualities cliffs that are not apparent in calm air (for example, see FAA-RD-75-123).

REQUIREMENT GUIDANCE (3.3.11.1.2)

Quantitative level boundaries are applied in calm air, common, and uncommon disturbances. While most of the database includes consideration of these environmental disturbances, no basis in data or reason could be found for applying the quantitative requirements generally in extraordinary conditions.

In table 3.3.11.1.2-I, the qualitative requirements for each air vehicle state are a function of atmospheric disturbance intensity and the level of flying qualities for that state in calm air. The level of flying qualities in calm air is, in turn, determined from requirements 3.3.11.1.1.1 Allowable levels for air vehicle normal states, 3.3.11.1.1.2 Allowable levels for air vehicle extreme states, and section 3.3.11.1.1.3 Primary requirements for failure states . These qualitative requirements are a rough fit to the C-H scale. However, by direct comparison of adjacent blocks in the table we see that the quantitative requirements are not uniquely related to the qualitative descriptions or to the C-H scale. Indeed, for these environmental variations they cannot be.

Recommended values for completion of the blanks in table 3.3.11.1.2-I:

Range of Atmospheric Disturbances	Air Vehicle States Which Are Level 1 in Calm Air	Air Vehicle States Which Are Level 2 in Calm Air	Air Vehicle States Which Are Level 3 in Calm Air
Calm to Common	Quantitative requirements Level 1 and qualitative requirements satisfactory	Quantitative requirements Level 2 and qualitative requirements tolerable or better	Quantitative requirements Level 3 and qualitative requirements controllable or better
Common to Uncommon	Quantitative requirements Level 1 and qualitative requirements tolerable or better	Quantitative requirements Level 2 and qualitative requirements controllable or better	Quantitative requirements Level 3 and qualitative requirements recoverable or better
Uncommon to Extraordinary	Qualitative requirements controllable or better	Qualitative requirements recoverable or better	

REQUIREMENT LESSONS LEARNED (3.3.11.1.2)

It is natural for pilot rating of flying qualities to degrade with increasing atmospheric disturbances. Since this specification is used to procure air vehicles, not pilots, we must distinguish between degradation of pilot rating and degradation of air vehicle characteristics. This distinction is made in this requirement for all air vehicle states. These allowances, of course, should not be construed as a recommendation to degrade flying qualities with increasing intensities of atmospheric disturbances.

Accounting for the observed effects of atmospheric disturbances in a generally acceptable manner has been quite a problem. The point is that while pilot rating is allowed to degrade in uncommon disturbances, as we expect, we do not want to allow air vehicle characteristics also to degrade, as they might from saturation of stability augmentation or other nonlinearities. That would likely cause a further degradation in pilot rating. Therefore, we must somehow make a distinction between levels and C-H ratings. Their relationship must vary with the intensity of atmospheric disturbances.

In some cases the expected motions due to turbulence are sufficiently extreme that pilot ratings are not appropriate. In these cases, statements relating to recoverability are used in table 3.3.11.1.2-I.

4.3.11.1.2 Flying qualities degradations in atmospheric disturbances verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Flying qualities in atmospheric disturbances	Table 3.3.11.1.2-I	A	A,S	A,S	A,S	A,S, D,T

VERIFICATION DISCUSSION (4.3.11.1.2)

For the purposes of showing compliance with this requirement, atmospheric disturbances are defined in section 6.4.6 Flying qualities definitions. The recommended root-mean-square (rms) magnitudes of turbulence at medium to high altitudes are given in section 6, figure 6.4.6-4. These magnitudes apply to all axes. The dashed lines, labeled according to probability of encounter, are based on MIL-A-8861B and MIL-F-9490D. The solid lines approximate this model, except that a minimum rms magnitude of 3 ft/sec is specified at all altitudes in order to assure that air vehicle handling will be evaluated in the presence of some disturbance.

When using simulation to verify compliance, each range of atmospheric disturbance should be tested to its upper limits. For example, to show compliance with the requirements for calm to common disturbances, the wind speed at 20 feet should be 15 knots (table 6.4.6-I).

The combined effects of failures and turbulence should be investigated using piloted simulation. There may be aerodynamic and flight control system nonlinearities that are affected by very large disturbances. Such effects should be investigated in manned simulation with the extraordinary magnitudes of atmospheric disturbances defined 6.4.6 Flying qualities definitions.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the air vehicle design concept indicates that the design concept is considering an approach which will achieve the minimum required flying qualities for flight in specified atmospheric disturbances. Early analysis serves as guidance in selecting a design approach, components, and redundancy levels that can potentially achieve or surpass the stated probabilities of not encountering the degraded levels of flying qualities.

PDR: Analysis and simulation of the preliminary air vehicle design assess flying qualities via computational methods and pilot-in-the-loop simulation using wind tunnel data, mass and inertia characteristics, control laws, and propulsion data and indicates that the minimum required flying qualities for flight in specified atmospheric disturbances can be achieved.

CDR: Analysis and simulation assess flying qualities using computational analysis methods and pilot-in-the-loop simulation using updated aerodynamic data, aeroelastic effects, mass and inertia characteristics, flight control and other subsystem characteristics, and propulsion system data confirm that the air vehicle will achieve the minimum required flying qualities for flight in specified atmospheric disturbances.

FFR: Analysis and simulation assess flying qualities using computational methods and pilot-in-the-loop simulation and confirm that the air vehicle flying qualities are ready for first flight. Analysis confirms that all input data have been updated to the first flight configuration. Analyze sensitivity and robustness of flying qualities to uncertainties in aerodynamic and system parameters. Pilot-in-the-loop simulation also used to develop build-up techniques for hazardous tests. Pilot-in-the-loop assessment of air vehicle flying qualities in variable-stability air vehicle. In-flight simulation should include flying qualities evaluation of most critical tasks and most critical failure modes, as well as sensitivity analysis. Flying qualities of failure modes assessed using computational methods and pilot-in-the-loop simulation in an operationally functional simulator (actual flight hardware and software in-the-loop).

SVR: Analysis, simulation, demonstration, and test assesses air vehicle flying qualities. Compliance with flying qualities requirements are confirmed by analysis using comparisons and correlations of all data gathered by pilot-in-the-loop assessment in simulators, the operationally functional simulator, and the flight test vehicle(s). Differences between production configuration and flight test configuration should be assessed using computational techniques to update analyses based on flight test results.

Sample Final Verification Criteria

The requirements for flying qualities degradations in atmospheric disturbancesshall be satisfied when __(1)__ analyses, __(2)__ simulations, __(3)__ demonstrations, and __(4)__ tests confirm specified performance is achieved.

Blank 1. Identify the type and scope of the analysis required to provide confidence that the requirement has been met. For example, reliability and failure modes and effects analysis. Other examples are DATCOM and computational fluid dynamics to predict stability derivatives, linear analysis, equivalent system, and off-line simulation for determining longitudinal and lateral-directional dynamics, response to controller, closed-loop analysis with a pilot model, PIO, time delay, time response characteristics, ride qualities, transients following failures, trim changes due to failures, trim for asymmetric thrust (air vehicles with more than two engines), flight characteristic of asymmetric thrust, taxiing, takeoffs, and landings.

Blank 2. Identify the type and scope of the simulations required to provide confidence that the requirement has been met. For example, piloted and in-flight simulations analyses of control forces and displacements (such as steady-state control force and deflection per G, transient control force per G, control displacements in maneuvering flight, control force variations during rapid speed changes, control force versus control deflection, controller breakout forces, control force and travel in takeoff, longitudinal control force limits in dives within the ROTH, longitudinal control force limits in dives within the RORH, control sensitivity, control forces in steady turns), residual oscillations, yaw control force and deflection in steady sideslips, bank angle in steady sideslips, roll control force and deflection in steady sideslips, roll control power in steady sideslips, lateral-directional control in crosswinds, lateral-directional control with asymmetric thrust, lateral-directional control with speed changes, yaw control forces in wave-off (go-around), cross-axis responses, high angle of attack requirements, carrier operations, V/STOL operations, approach to dangerous flight conditions (warning and indication and operation of devices for indication, warning, prevention, and recovery), buffet, release of stores, effects of armament delivery and special equipment, PIO, residual oscillations, flight characteristic of asymmetric thrust, taxiing, takeoffs, and landings. Typical flight maneuver blocks and operationally relevant manuevers are flown throughout the defined regions. Evaluation tasks should be defined to show that the air vehicle can be flown to particular flight conditions outside of the ROTH and return readily and safely to the ROTH or ROSH.

Blank 3. Identify the type and scope of the demonstrations required to provide confidence that the requirement has been met. For example, approach to dangerous flight conditions (warning and indication and operation of devices for indication, warning, prevention, and recovery), buffet, release of stores, effects of armament delivery and special equipment, residual oscillations, and ride discomfort, flight characteristic of asymmetric thrust, taxiing, takeoffs, and landings. Evaluation tasks should be defined to show that the air vehicle can be flown to particular flight conditions outside of the ROTH and return readily and safely to the ROTH or ROSH.

Blank 4. Identify the type and scope of the test required to provide confidence that the requirement has been met. For example, wind tunnel testing to determine stability derivatives, parameter identification to update analysis and simulations, and FMET using Iron bird or hardware-in-the-loop testing to determine failures and level of flying qualities. Other examples are flight test to determine control forces and displacements (such as steady-state control force and deflection per G, transient control force per G, control displacements in maneuvering flight, control force variations during rapid speed changes, control force versus control deflection, controller breakout forces, control force and travel in takeoff, longitudinal control force limits in dives within the ROTH, longitudinal control force limits in dives within the RORH, control sensitivity, control forces in steady turns), residual oscillations, yaw control force and deflection in steady sideslips, bank angle in steady sideslips, roll control force and deflection in steady sideslips, roll control power in steady sideslips, lateral-directional control in crosswinds, lateral-directional control with asymmetric thrust, lateral-directional control with speed changes, yaw control forces in wave-off (go-around), cross-axis responses, high angle of attack requirements, carrier operations, V/STOL operations, PIO, transfer to alternate control modes, rate of control surface displacement, cockpit controller characteristics (such as control force versus control deflection, control centering, control free play, control displacement limits, dynamic characteristics, control system damping, direct force controllers), displays and instruments, characteristics of secondary flight control systems (such as trim system irreversibility, rate of trim operation, stalling of trim systems, and automatic trim system), operation of secondary control devices and in-flight configuration change, and auxiliary dive recovery devices, flight characteristic of asymmetric thrust, taxiing, takeoffs, and landings. Typical flight maneuver blocks and various evaluation tasks are flown throughout the defined regions.

VERIFICATION LESSONS LEARNED (4.3.11.1.2)

Experience has shown that the atmospheric disturbance environment, which is labeled as "Uncommon" is generally sufficient to force the pilot into the aggressive control activity that is expected to expose handling qualities deficiencies when they exist. Hence, it is recommended that in simulation the major effort be spent investigating the "Uncommon" disturbance level. During flight test there is no compelling reason to seek out mountain waves or thunderstorms to comply with the "Extraordinary" requirements. Of course, if the mission specifically dictates flight in extraordinary disturbances a significant portion of the time, these conditions should be considered accordingly. In any case, some flight testing should be done in turbulence as a general check of simulation.

Other lessons learned can be found in MIL-HDBK-1797.

3.3.11.1.3 Control margins

The air vehicle shall provide control margins throughout the RORH for all air vehicle normal, extreme, and failure states and in __(1)__ atmospheric disturbances.

REQUIREMENT RATIONALE (3.3.11.1.3)

This overall requirement is intended to assure adequate control margins exist for safety. It is intended to permit recovery from unusual situations within the RORH. Control power, control effector rate, and hinge moment capability are essential in establishing adequate control margins.

REQUIREMENT GUIDANCE (3.3.11.1.3)

Blank 1. Complete with the range of atmospheric disturbances (see 3.3.11.1.2 Flying qualities degradations in atmospheric disturbances, table 3.3.11.1.2-I) for which control margin must be provided.

REQUIREMENT LESSONS LEARNED (3.3.11.1.3)

To attain performance benefits, we no longer require control-surface-fixed stability. Whatever the cause, control saturation can be catastrophic in a basically unstable air vehicle. Then, control deflection for recovery, whether commanded by the pilot or automatically, is just not available. This differs from the stable case, in which if the deflection limit is reached for trim, full control authority is available for recovery. Control rate limiting can also induce instability if the basic airframe is unstable. This requirement is intended to require full consideration of all the implications of relaxed static stability and other control-configured vehicle (CCV) concepts.

In considering how much margin of control should be required there is no general quantitative answer, but it is possible to enumerate some cases to consider. Certainly there should be sufficient control authority to pitch the air vehicle out of any trim point to lower the AOA from any attainable value. That is, with full nose-down control the pitching moment should be negative at the most critical attainable AOA, for a c.g. on the aft limit and nominal trim setting. Attainable AOA is another issue in itself; however, lacking intolerable buffet or a limiter that is effective in every conceivable situation, angles to at least 90 degrees should be considered. Control margin is also necessary at negative AOA and large sideslips. In general, control margin should be demonstrated at the most critical points for any axis of motion for which the unaugmented air vehicle is unstable.

The flight task will dictate some minimum amount of nose-down control capability. Air combat maneuvering certainly imposes such a requirement, and so do terminal-area operations including landing flare out. Then, there should be some capability to counter atmospheric disturbances while maneuvering; counter c.g. movements due to fuel slosh while accelerating, diving, or climbing; stop rotation at the takeoff attitude; etc. roll inertial coupling has been a critical factor for many slender air vehicles.

In addition to conventional control modes, a CCV's direct-force controls can offer a number of new possibilities ranging from independent fuselage aiming to constant-attitude landing flares. The additional variables must be incorporated to assure adequate sizing of the control surfaces, and priorities may need to be established. The effectiveness of thrust vectoring varies with airspeed and altitude and, of course, with the commanded thrust level; thus, engine flameout or stall may be a consideration.

The instabilities and complications resulting from these factors can probably be rectified by stability augmentation if and only if control effectiveness is adequate. The controllability margin conventionally provided by static stability must be translated for CCV's into margins of controllability authority and rate. Control must be adequate for the combined tasks of trim (establishing the operating point), maneuvering, stabilization (regulation against disturbances), and handling of failures (flight control system, propulsion, etc.).

No single failure of any component or system or combination of single independent failures should result in dangerous or intolerable flying qualities. After the first failure it may be advisable to constrict flight envelopes for some assurance of flight safety in case, say, a second hydraulic system should fail. The contractor should weigh the expected frequency and operational consequences of such measures against predicted benefits.

Excessive stability, as well as excessive instability of the basic airframe, is of concern with respect to available control authority and rate. For example, large stable C_{ℓ_β} increases the roll control power needed to counteract gusts.

It is well known that hinge moments can limit both deflection and rate of control surfaces.

When using a surface for control in two axes, as with a horizontal stabilizer deflected symmetrically for pitching and differentially for rolling, priorities or combined limits must be set to assure safety (AIAA Paper 78-1500). Other demands on the hydraulic system can reduce control capability at times. Aeroelasticity can reduce control effectiveness directly, as well as alter the air vehicle stability. For the F-16, full nose-down control put in by stability augmentation has to be overridden in order to rock out of the locked-in deep stall. Control surfaces stall at an incidence somewhat less than 90 degrees; and if control is supplemented by thrust vectoring, for example, one must consider the control force or moment available in normal operation, the effect on forward thrust, and the possibility of flameout, as well as aerodynamic interference effects. All the possible interactions of active control must be taken into account.

Encountering the wake vortex of another air vehicle can be an extremely upsetting experience. These encounters are not uncommon in practice or real combat, and also may occur in the terminal area and elsewhere; prediction is difficult. Other atmospheric disturbances can also be severe (jetstreams, storms, wakes of buildings, gusts, wind shears, etc.).

The amount of control capability at extreme AOAs, positive and negative, must be enough to recover from situations that are not otherwise catastrophic. Avoidance of a locked-in deep stall has been known to limit the allowable relaxation of static stability. Also, control must be sufficient to counter the worst dynamic pitch-up tendency below stall or limit AOA. Propulsion and flight control system failure transients must be considered, along with possibly degraded control authority and rate after failure: spin/post-stall gyration susceptibility and characteristics may well be affected. The designer must allow for fuel system failure or mismanagement.

The range of maneuvers considered should account for both the stress of combat and the range of proficiency of service pilots. For example, in 1919 the British traced a number of losses of unstable air vehicles to control authority insufficient to complete a loop that had flattened on top (ARC R&M No. 917). Thus nose-up capability at negative AOAs can also be important. Poorly executed maneuvers may make greater demands on the flight control system for departure prevention or recovery. For CCVs as well as conventional air vehicles, limiters can help greatly, but their effectiveness and certainty of operation need to be considered. Spins attained in the F-15 and F-16 attest to the possibility of defeating limiters. AFWAL-TR-81- 3116 describes the A-7 departure boundary's closing in with increasing sideslip angle; angular rates also affect departure boundaries. Rapid rolling sometimes creates inertial coupling, which can put great demands on pitch control; nose-down pitching seems to accentuate the divergence tendency.

External stores change both c.g. and pitching moment ($C_{m\,0}$ and $C_{m\,\alpha}$). Experience with past air vehicles indicates a firm need to allow some margin to account for unforeseen store loadings. With relaxed static stability this can determine not only the safety but also the possibility of flight with stores not considered in the design process.

Uncertainties exist in the design stage. Nonlinear aerodynamics, particularly hard to predict even from wind tunnel tests, are almost certain to determine the critical conditions. The c.g., too, may not come out as desired, and in service, the c.g. location is only known with limited accuracy. There are also possible malfunctions and mismanagement in fuel usage to consider. We have even seen recent cases (e.g., F-111 and F-16) of misleading wind tunnel tests of basic static stability. Aeroelasticity and dynamic control effectiveness (e.g., F-15) can also reduce control margins.

Asymmetric loadings need to be considered. A critical case for the L-19 (subsequently known as the O-1) was the addition of a wire-laying mission involving carriage of a large reel under one wing. Some air vehicles(F-15 is a recent example) have been prone to develop significant fuel asymmetries due to prolonged inadvertent small sideslipping. Dive pullouts (n greater than 1) will accentuate the effects of loading asymmetries. Some F-100s were lost from asymmetric operation of leading edge slats (nonpowered, aerodynamically operated on their own, without pilot action) in dive-bombing pullouts.

Reconfigurable flight control systems add a new dimension to tracking and managing the available control power.

For CTOL flight, the control margin requirements must be met with aerodynamic control power only, without the use of other methods, such as thrust vectoring. This approach was chosen because experience to date with current technology inlets and engines operating at the distortion levels typical of high AOA at low speed dictates caution, due to the considerable uncertainty about reliability and dependability for use to stabilize and control the vehicle. Throttle usage is also a factor. While this requirement does not preclude the application of thrust vectoring for low-speed agility and super maneuverability performance enhancements in the future, it does reinforce the position that current technology engines/inlets should not be relied upon as the only means to assure flight safety, prevent loss of control, or provide recovery capability anywhere in the flight envelope. Should future technology advancements provide demonstrated engine/inlet reliability at low speeds and high AOAs, the procuring activity may allow this requirement to be modified for multiple engine air vehicles such that thrust vectoring with one engine out may be used to meet it.

4.3.11.1.3 Control margins verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Control margins throughout the RORH, for all air vehicle normal, extreme, and failure states, and in specified atmospheric disturbances	Presence of control margins	A	A,S	A,S	A,S	A,S, D,T

VERIFICATION DISCUSSION (4.3.11.1.3)

This is a flight safety item. Analysis and simulation should proceed or accompany careful build-up to suspected critical flight conditions. In dangerous cases it is not intended to show compliance with this requirement through flight demonstration. “Combined range of all attainable AOAs and sideslip” may even extend beyond the RORH, except for certain highly maneuverable fighter and trainer air vehicles. Flight test bounds should be established (see former MIL-F-83691 for guidance). For extreme flight conditions a combination of model testing (wind tunnel, free-flight if necessary, and hardware) and analysis will often be adequate. These extremes should be investigated in some way, whether or not the air vehicle incorporates a limiter. The scope of analysis, simulation, and testing needs careful consideration at the outset of a program. Then the progress must be monitored for possible additional troubles.

This requirement applies to the prevention of loss of control and to recovery from any situation, including deep stall trim conditions, for all maneuvering, including pertinent effects of factors such as pilot strength, regions of control-surface-fixed instability, inertial coupling, fuel slosh, the influence of symmetric and asymmetric stores, stall/post-stall/spin characteristics, atmospheric disturbances (see 3.3.11.1.2 Flying qualities degradations in atmospheric disturbances), and air vehicle failure states in 3.3.11.1.1.3 Primary requirements for failure states through 3.3.11.1.1.3.3 Failures outside the ROTH; failure transients and maneuvering flight appropriate to the failure state are to be included).

Verification should be by analysis and by simulation or flight test in the performance the tasks detailed in 4.3.11.1.1 Primary requirements for air vehicle states in common atmospheric conditions verification and 4.3.11.1.2 Flying qualities degradations in atmospheric disturbances verification under various levels of atmospheric disturbances. These tasks should be flown by test pilots at specific flight conditions throughout the ROSH and ROTH. The specific flight conditions to be evaluated should include the most common operating conditions, any operating conditions critical to the mission of the air vehicle, and any conditions determined by analysis or simulation to be worse than the Level of flying qualities required. For conditions considered too dangerous to test in flight, verification can be shown in a manned simulation. Proof of compliance in these demonstration tasks will consist of pilot comments and C-H ratings. The comments and ratings should indicate that the flying qualities are no worse than the required Level of flying qualities for each combination of air vehicle state, flight phase, and level of atmospheric disturbance.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the air vehicle design concept indicates that the design concept is considering an approach that will achieve the control as specified. Early analysis serves as guidance in selecting a design approach, components, and redundancy levels that can potentially achieve or surpass the stated probabilities of not encountering the degraded levels of flying qualities.

PDR: Analysis and simulation of the preliminary air vehicle design assess flying qualities via computational methods and pilot-in-the-loop simulation using wind tunnel data, mass and inertia characteristics, control laws, and propulsion data and indicates that the specified control margins can be achieved.

CDR: Analysis and simulation assess flying qualities using computational analysis methods and pilot-in-the-loop simulation using updated aerodynamic data, aeroelastic effects, mass and inertia characteristics, flight control and other subsystem characteristics, and propulsion system data representative of the CDR configuration.

FFR: Analysis and simulation assess flying qualities using computational methods and pilot-in-the-loop simulation and confirm that the air vehicle flying qualities control margin is adequate for first flight. Analysis confirms that all input data have been updated to the first flight configuration. Analyze sensitivity and robustness of flying qualities to uncertainties in aerodynamic and system parameters. Pilot-in-the-loop simulation also used to develop build-up techniques for hazardous tests. Pilot-in-the-loop assessment of air vehicle flying qualities in variable-stability air vehicle. In-flight simulation should include flying qualities evaluation of most critical tasks and most critical failure modes, as well as sensitivity analysis. Flying qualities of failure modes assessed using computational methods and pilot-in-the-loop simulation in an operationally functional simulator (actual flight hardware and software in-the-loop).

SVR: Analysis, simulation, demonstration, and test assesses air vehicle flying qualities. Compliance with the flying qualities control margin requirement is confirmed by analysis using comparisons and correlations of all data gathered by pilot-in-the-loop assessment in simulators, the operationally functional simulator, and the flight test vehicle(s). Differences between production configuration and flight test configuration should be assessed using computational techniques to update analyses based on flight test results.

Sample Final Verification Criteria (4.3.11.1.3)

The requirements for flying qualities control margins shall be satisfied when __(1)__ analyses, __(2)__ simulations, __(3)__ demonstrations, and __(4)__ tests confirm specified performance is achieved.

> Blank 1. Identify the type and scope of the analysis required to provide confidence that the requirement has been met. For example, reliability and failure modes and effects analysis. Other examples are DATCOM and computational fluid dynamics to predict stability derivatives. Other examples are linear analysis, equivalent system,

and off line simulation for determining longitudinal and lateral-directional dynamics, response to controller, closed-loop analysis with a pilot model PIO, time delay, time response characteristics, ride qualities, transients following failures, trim changes due to failures, trim for asymmetric thrust (air vehicles with more than two engines), flight characteristic of asymmetric thrust, longitudinal control margin, longitudinal control power in unaccelerated flight, longitudinal control power in maneuvering flight, peak pitch rate, load factor onset, longitudinal control power for takeoff, longitudinal control power in landing, flight path control power, flight path controller characteristics, roll control power (such as additional roll requirements for class iv air vehicles, controlled flight during roll maneuvers, roll termination, roll control power with asymmetric loads), V/STOL control power (such as control power in hovering flight, cross-axis coupling, angular (moment-generating) control power), taxiing, takeoffs, and landings.

Blank 2. Identify the type and scope of the simulations required to provide confidence that the requirement has been met. For example, piloted and in-flight simulations analyses of control forces and displacements (such as steady-state control force and deflection per G, transient control force per G, control displacements in maneuvering flight, control force variations during rapid speed changes, control force versus control deflection, controller breakout forces, control force and travel in takeoff, longitudinal control force limits in dives within the ROTH, longitudinal control force limits in dives within the RORH, control sensitivity, control forces in steady turns), residual oscillations, yaw control force and deflection in steady sideslips, bank angle in steady sideslips, roll control force and deflection in steady sideslips, roll control power in steady sideslips, lateral-directional control in crosswinds, lateral-directional control with asymmetric thrust, lateral-directional control with speed changes, yaw control forces in wave-off (go-around), cross-axis responses, high angle of attack requirements, carrier operations, V/STOL operations, approach to dangerous flight conditions (warning and indication and operation of devices for indication, warning, prevention, and recovery), buffet, release of stores, effects of armament delivery and special equipment, PIO, residual oscillations, flight characteristic of asymmetric thrust, longitudinal control margin, longitudinal control power in unaccelerated flight, longitudinal control power in maneuvering flight, peak pitch rate, load factor onset, longitudinal control power for takeoff, longitudinal control power in landing, flight path control power, flight path controller characteristics, roll control power (such as additional roll requirements for class iv air vehicles, controlled flight during roll maneuvers, roll termination, roll control power with asymmetric loads), V/STOL control power (such as control power in hovering flight, cross-axis coupling, angular (moment-generating) control power), taxiing, takeoffs, and landings. Typical flight maneuver blocks and operationally relevant manuevers are flown throughout the defined regions. Evaluation tasks should be defined to show that the air vehicle can be flown to particular flight conditions outside of the ROTH and return readily and safely to the ROTH or ROSH.

Blank 3. Identify the type and scope of the demonstrations required to provide confidence that the requirement has been met. For example, approach to dangerous flight conditions (warning and indication and operation of devices for indication, warning, prevention, and recovery), buffet, release of stores, effects of armament delivery and special equipment, residual oscillations, and ride discomfort, flight characteristic of asymmetric thrust, taxiing, takeoffs, and landings. Evaluation tasks should be defined to show that the air vehicle can be flown to particular flight conditions outside of the ROTH and return readily and safely to the ROTH or ROSH.

Blank 4. Identify the type and scope of the test required to provide confidence that the requirement has been met. For example, wind tunnel testing to determine stability derivatives, parameter identification to update analysis and simulations, and FMET using Iron bird or hardware-in-the-loop testing to determine failures and level of flying qualities. Other examples are flight test to determine control forces and displacements (such as steady-state control force and deflection per G, transient control force per G, control displacements in maneuvering flight, control force variations during rapid speed changes, control force versus control deflection, controller breakout forces, control force and travel in takeoff, longitudinal control force limits in dives within the ROTH, longitudinal control force limits in dives within the RORH, control sensitivity, control forces in steady turns), residual oscillations, yaw control force and deflection in steady sideslips, bank angle in steady sideslips, roll control force and deflection in steady sideslips, roll control power in steady sideslips, lateral-directional control in crosswinds, lateral-directional control with asymmetric thrust, lateral-directional control with speed changes, yaw control forces in wave-off (go-around), cross-axis responses, high angle of attack requirements, carrier operations, V/STOL operations, PIO, transfer to alternate control modes, rate of control surface displacement, cockpit controller characteristics (such as control force versus control deflection, control centering, control free play, control displacement limits, dynamic characteristics, control system damping, direct force controllers), displays and instruments, characteristics of secondary flight control systems (such as trim system irreversibility, rate of trim operation, stalling of trim systems, and automatic trim system), operation of secondary control devices and in-flight configuration change, and auxiliary dive recovery devices, flight characteristic of asymmetric thrust longitudinal control margin, longitudinal control power in unaccelerated flight, longitudinal control power in maneuvering flight, peak pitch rate, load factor onset, longitudinal control power for takeoff, longitudinal control power in landing, flight path control power, flight path controller characteristics, roll control power (such as additional roll requirements for class iv air vehicles, controlled flight during roll maneuvers, roll termination, roll control power with asymmetric loads), V/STOL control power (such as control power in hovering flight, cross-axis coupling, angular (moment-generating) control power), taxiing, takeoffs, and landings. Typical flight maneuver blocks and various evaluation tasks are flown throughout the defined regions.

VERIFICATION LESSONS LEARNED (4.3.11.1.3)

Lessons learned can be found in MIL-HDBK-1797.

3.3.12 Growth provisions

The air vehicle should have the growth capability as defined in table 3.3.12-I.

TABLE 3.3.12-I. Growth provisions.

Type of Provision	Capability	Growth Value	Conditions

REQUIREMENT RATIONALE (3.3.12)

Historically, military weapon systems incur numerous changes, upgrades, and modifications over their service life. Air vehicle modifications are required for many reasons (correction of deficiencies, performance upgrades, technology insertion, parts obsolescence, etc.) and can canvass a wide degree of changes (from basic software modifications to complete redesigns). This requirement is intended to incorporate growth provisions in the air vehicle design that would enable the air vehicle to accommodate some level of change and modification without continually requiring major, expensive redesigns.

When a known parallel development program or an outyear preplanned product improvement (P^3I) has been scheduled for integration into the air vehicle, provisions for the planned growth are established to facilitate and ensure the planned integration.

Growth is the inclusion of physical and/or functional characteristics/provisions that enable expansion or extension of air vehicle capability with minimum disruption of the air vehicle design.

REQUIREMENT GUIDANCE (3.3.12)

Guidance for completing table 3.3.12-I follows:

Type of Provision: Identify the type of provision required. This may include terms such as “Group A provisions,” “Group B provisions,” “complete provisions for,” ”power provisions,” “space provisions,” “weight provisions,” etc. A complete list of applicable terms, and their definitions can be found in 6.4.13 Provisions, contractor (expressions).

Capability: Define the capability for which a growth design allowance is needed. To the extent possible, describe the capability functionally. For example, unused volume, additional capabilities or functionality (e.g., air-to-surface), provisions for weight growth, power distribution, etc.

Growth Value: Define the magnitude or growth required. Identify whether this is growth provisions to extend the functional capability or whether this is a growth potential for incorporation of new functionality. For example, avionics cooling of XXXX BTUs, growth volume of 5 cubic feet, hard points for air-to-surface ordnance, unused power cable to “growth” equipment bays, etc. The growth value should be stated as uninstalled growth, installed growth or both.

Conditions: Define any conditions necessary for the envisioned application of the requirement. For example, if the requirement were for 5 cubic feet of volume it would be desirable to identify the minimum contiguous volumes necessary (such as 1 cubic foot). If allowances are being provided for pre-planned improvements, a location may also me necessary such as 2 cubic feet at the forward, bottom portion of the fuselage.

Provisions for growth beyond original design criteria can be a significant cost driver, and should be carefully considered and controlled.

Include this requirement to ensure the air vehicle has flexibility and growth provisions to accommodate required changes. Although the specific or exact changes or modifications that will be incurred by the system over its life can not be defined at the time of the air vehicle's initial development, historical precedence indicates that air vehicle changes are inevitable. Design approaches should be taken to define the air vehicle architecture in a way that provides growth capacity to make undefined future changes easier and less costly to implement. Recognizing that some changes, upgrades, and modifications may require major redesigns, the requirement should be defined consistent with a portion of the air vehicle service life. The requirement is stated in general terms, describing the overall characteristics desired to achieve the intended purpose or end result. If more specific characteristics or features are known or can be defined (i.e., the percent of growth capacity, number of spare pins, etc.), provide the more definitive requirement.

Defining growth provisions necessitates anticipation of both planned and unplanned requirements. Planned requirements typically address P^3I and evolutionary acquisition approaches.

Preplanned product improvement is the conscious, considered strategy which involves deferring the development of necessary performance capabilities associated with elements having significant risks or delays so that the system can be fielded while the deferred element is developed in a parallel or subsequent effort. Provisions, interfaces, and accessibility are integrated into the system design so that the deferred element can be incorporated in a cost-effective manner when available. The concept also applies to process improvements.

Evolutionary acquisition is an adaptive and incremental strategy applicable to high technology and software intensive systems when requirements beyond a core capability can generally, but not specifically, be defined.

Anticipating potential unplanned requirements might involve examinations of historical information on mission growth potential for the class of air vehicle being developed (for example, air combat fighters frequently are tasked to take on additional roles as air-to-surface air vehicles). Redesigning/redeveloping an air vehicle's structure and adding "hard points" can be prohibitively expensive after initial manufacture, but can be realized at modest costs and with minimal penalties during the original development. Applying provisions for potential growth that are inexpensive to implement in initial design and construction, but expensive to implement in already built articles (for example, adding additional wiring for power or information transfer capabilities during initial construction, or providing additional capacity for power and cooling) and examination of potential impact of mission relevant technologies that are promising but are not ready for transition during initial design should also be considered.

Regardless of why growth capability may be needed, a well thought out plan should be constructed with reasonable estimates of the costs, benefits, and penalties identified.

REQUIREMENT LESSONS LEARNED (3.3.12)

Often, budget constraints defer to the out years the implementation of predetermined air vehicle improvements known as pre-planned product improvements. In addition, the air vehicle development frequently occurs in parallel with a new subsystem development program(s) (e.g., armament, counter-countermeasures systems) that would be integrated with the air vehicle at a later date.

4.3.12 Growth provisions verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Growth capability	Table 3.3.12-I, Growth Value	A	A,I	A,I		A

VERIFICATION DISCUSSION (4.3.12)

Growth verification is based on positive determination through progressive analysis, inspection, and demonstration that the requirement for air vehicle growth is addressed in the design and is attained in the production system.

Verification of growth should thoroughly address not only the satisfaction of the growth requirements, but also verify adequate provisioning by subsystems and total compatibility with other systems/subsystems that will be affected by future growth (i.e., cooling, power, etc.). These air vehicles provisions should individually be verified with representative configurations.

Key Development Activities (4.3.12)

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the design concept indicates that air vehicle growth requirements are properly allocated.

PDR: Analysis and inspection of preliminary design indicates that air vehicle growth requirements are allocated and are ready for detailed design.

CDR: Analysis and inspection of final design documentation confirm that air vehicle growth provisions and capabilities are incorporated and will satisfy the requirements.

FFR: No unique verification actions occurs at this milestone.

SVR: Analysis of lower-level air vehicle tests and demonstrations confirm that the growth requirements have been allocated and attained. In some cases, results from air vehicle level demonstrations may need to be analyzed to confirm compliance with the growth provisions requirement.

Sample Final Verification Criteria.

The growth provisions requirement shall be satisfied when __(1)__ analyses confirm the availability of the required growth value.

> Blank 1 identify the specific types and scope of analyses required to provide confidence that the requirement has been satisfied. Analysis should include examination of the results of lower-level tests and demonstrations.

VERIFICATION LESSONS LEARNED (4.3.12)

To Be Prepared

3.4 Interfaces

REQUIREMENT RATIONALE (3.4)

This is a section heading facilitating document organization. This section addresses all air vehicle interface requirements including interoperability with civil airspace, international allies, airfields, fuels, and armament. It also includes consideration of air vehicle operational requirements that necessitate interfaces with the operating environment, such as mission planning, communications, and navigation accuracy.

REQUIREMENT GUIDANCE (3.4)

In preparing interface requirements, all necessary support and operating environments should be considered. Interoperability requirements may drive specific air vehicle interface requirements. Interoperability will be defined in the mission needs statement or operational requirements document, and/or the system specification. Examples of interoperability are as follows: Global Air Traffic Management (GATM), Joint Service Compatibility, North Atlantic Treaty Organization (NATO) Cross-Servicing, Fuel Standardization and Electrical Power Standardization. Air vehicle operational requirements set forth in section 3.1 Operations of this document may also be dependent upon interfacing with capabilities beyond the control of the air vehicle, such as communications systems, navigation accuracy, mission planning, etc. Established design and interface criteria for effective cross-servicing and interoperability are contained in the three-thousand series NATO Standardization Agreements (STANAGs) and their national implementing documents, and the corresponding ASCC Working Party 25 AIR Standards.

The impacts of interoperability requirements to air vehicle interface requirements should be addressed in the appropriate section 3.4 Interfaces . For example, if the air vehicle will be required to interface with a specific country's support equipment, such requirement should be included in support equipment interface requirement (see 3.4.9 Support equipment interface).

Considerations should include organizations and countries, as well as, equipment and functions necessary to achieve the needed interoperability, such as armament, ground servicing, external lighting, communications, mission planning, navigation and aerial refueling. Identify air vehicles requiring international interoperability by making selections from the following: NATO STANAGS, Allied Publications AAP-4, Air Standardization Coordinating Committee, and from the American-British-Canadian-Australian (ABCA) Reference Catalogues.

The DoD Joint Technical Architecture (JTA) is a key piece of DoD's overall strategy to achieve a seamless flow of information quickly among DoD's sensors, processing and command centers, and shooters. Specification developers should evaluate JTA standards and guidelines and establish program specific information interface requirements to achieve the interoperability needed for quick, seamless information flow across the DoD Warfighter battlespace. Specification developers should refer to the most recent version of JTA, Aviation Domain, for mandated interoperability requirements.

Interoperability refers to the ability of systems, units or forces to provide services to and accept services from other systems, units, or forces and to use the services so they may be exchanged to enable them to operate effectively together. This effectiveness can be considered to be achieved among communications-electronics systems or items of communications-electronics equipment when information or services can be exchanged directly and satisfactorily between them and/or their users. Examples of achieving some degree of interoperability would include the ability of US air combat fighters to employ allied weapons, or ability to use fuels and lubricants that allied forces use at their bases.

When the JTA mandates a standard, this standard should be considered for incorporation in the specification. Specification developers should refer to the most recent version of JTA, Aviation Domain, for mandated interoperability requirements.

REQUIREMENT LESSONS LEARNED (3.4)

Incompatible air vehicle fuels and fueling nozzles was an early indicator of the need for interoperability requirements. Subsequently, international treaties such as NATO formalized the requirement for interoperability.

3.4.1 Armament and stores

3.4.1.1 Store interface

The air vehicle (including the electrical and logical interface) shall be compatible with and capable of employing the stores and store suspension equipment as specified in table 3.4.1.1-I. The air vehicle shall not degrade the reliability or functionality of the stores. The air vehicle shall incorporate provisions for future carriage of stores as defined in table 3.4.1.1-II.

TABLE 3.4.1.1-I. Stores list.

Store Nomenclature	Identification Documentation	AA or AS	Minimum Required Modes	Carriage	Carriage Conditions	Jettison Conditions	Employment Conditions Pre-launch through Release	Applicable Loadouts

TABLE 3.4.1.1-II. Future store provisions.

Future Store	Quantity	Identification Documentation	Provisions

REQUIREMENT RATIONALE (3.4.1.1)

The air vehicle-store interface encompasses the functional, performance, physical, electrical, analog, digital, mechanical, and environmental characteristics required to satisfy weapon-system-level requirements. Proper weapon compatibility is paramount to fulfilling mission needs. The requirement identifies the need to tailor the characteristics (aerodynamics, hard points, etc.) of the air vehicle for store stations, weapon bays, weapon bay doors, etc., to provide compatibility with required stores. Compatibility involves the carriage (ensuring the environment; vibration, temperature, acoustics, electromagnetic, rocket/gun gas impingement/ingestion will not harm or degrade air vehicle or weapon performance/reliability and the system is structurally sound), release/launch/jettison (insuring the launch event is safe and effective) and other requirements as stipulated in MIL-HDBK-1763. Employment involves the integration of the store and air vehicle to complete the chain of events from mission planning, through trigger pull, to target destruction; this includes, but is not limited to, the communication to/from the weapon, proper and appropriate targeting requirements, PVI requirements, and necessary post launch support.

See MIL-HDBK-1763 for detailed definitions of compatibility, stores, and other related terms.

Store types

a. Jettisonable but nonreleasable: store suspension equipment, pylons, pods, fuel tanks, and other mission stores (such as jamming, reconnaissance, and photography).

b. Jettisonable and releasable: all armament, (live and training) to include weapons, missiles, rockets, bombs, mines, decoys.

c. Neither jettisonable nor releasable: internal gun, fixed pods/pylons

The air vehicle-to-stores interface is standardized to assure compatibility with existing weapons, joint service weapons, planned weapons, and NATO weapons and with the stores suspension equipment for launching and ejecting the stores, where applicable. Mechanical interfaces between the air vehicle and weapons have been standardized within the armed services and NATO.

The requirement to provide a compatible environment ensures blending of the aerodynamics, thermal and vibration environments, observables, landing characteristics (e.g., landing with stores retained), etc. of the air vehicle with store stations, weapons bays, weapon bay doors, etc., for compatibility with available stores.

REQUIREMENT GUIDANCE (3.4.1.1)

Whenever practicable, existing qualified racks and launchers should be used to avoid high system certification costs and logistical support impacts.

Development of (or adoption of an existing) Interface Control Document (ICD) is generally required for each air vehicle-to-store interface. When standard, proven interfaces are used, this document is already available and can be simply referenced. When new or unique requirements are being implemented, this will be a unique document and the work associated with the air vehicle and store manufacturer jointly developing, validating and controlling the interface must be included in the contract.

Guidance for completing table 3.4.1.1-I follows:

<u>Store Nomenclature</u>: List all of the weapons that the air vehicle must employ. Also list stores and suspension equipment. If there are multiple variants of each store, list each variant individually. Identify whether this is an existing store or a planned store. If planned, include appropriate standardization and developing information in the “Additional Information” column to ensure proper development of compatible interfaces. Additional nuclear weapon specific requirements are addressed elsewhere within this specification.

Identification Documentation: Store drawing numbers, interface control figures, interface control documentation, performance requirements, etc. should be referenced in this column.

AA or AS: Identify whether the weapon is utilized for air-to-air (AA) or air-to-surface (AS) applications.

Minimum Required Modes: Identify the weapon modes that must be employed by the air vehicle. If the air vehicle must be capable of employing the weapon in all its available modes, enter "All." If only partial functionality is required, only list the functionality or specific modes required.

Carriage: Identify whether the weapon will be carried internal or external to the air vehicle. If the air vehicle must be capable of both internal and external carriage of a weapon, enter "Internal and External."

Carriage Conditions: Identify the carriage conditions of the air vehicle for utilization of the store. Appropriate information for this column may include the following: Max speed, Min-Max "G," roll, pitch, yaw, rate of roll, and altitude range.

Jettison Conditions: Identify the jettison conditions of the air vehicle for the specific store. Appropriate information for this column may include the following: Min-Max speed, Min-Max "G," roll, pitch, yaw, rate of roll, and altitude range.

Employment Conditions: Pre-launch through Release: Identify the conditions from pre-launch through weapons release of the air vehicle for the specific store. Appropriate information for this column may include the following: Min-Max speed, Min-Max "G," Roll, pitch, yaw, rate of roll, and altitude range.

Applicable Loadouts: Identify by loadout number(s) the loadouts to which these conditions apply. If applicable loadouts differ for each condition (carriage vs. jettison vs. employment) then add additional rows to state loadout conditions.

Guidance for completing table 3.4.1.1-II follows:

Future Store: If the future store nomenclature is known, identify the store in this column. If the store nomenclature is unknown, enter "Unknown at the time of specification development."

Quantity: Identify the total number of future stores to be carried.

Identification Documentation: Store drawing numbers, interface control figures, interface control documentation, performance requirements, etc. should be referenced in this column.

Provisions: Identify the specific provisions that must be incorporated for stores compatibility.

REQUIREMENT LESSONS LEARNDED (3.4.1.1)

The launcher and backup structure should sustain dynamic hangfire loads, hard-landing loads, and pre-launch thrust build-up, such as when the Hellfire is a mission weapon. The suspension and release equipment should not release the weapon during a hard landing, during a 20g forward crash, or during an inadvertent thrust producing motor burn. The suspension equipment should have the capability to release a weapon in either a safed or armed condition. The rack and launcher system should provide highly repeatable performance as the accuracy of many weapons relies upon the bomb rack performance in the calculation of ballistics and targeting solutions. Bomb rack safing features should be included to provide positive means for ground crews to determine the rack is in a locked or armed condition.

The armed services have been dropping stores from air vehicles, as long as there have been combat air vehicles. Inadvertent release of stores from air vehicles has caused great losses of both military and privately owned property and therefore is unacceptable. The ability to release a weapon on demand is of critical importance. A rack or launcher that will not release a weapon on demand defeats the purpose of a fighter and attack air vehicle and erodes the pilot(s) confidence in the functionality of the total weapon system.

4.4.1.1 Store interface verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Store interface achieved	Pass/Fail	I,A	I,A	I,A, S,T	I,A, T,D	A,I, D,T

VERIFICATION DISCUSSION (4.4.1.1)

Verification of the store interface requirement should be accomplished by integrating analysis with simulations, demonstrations, and tests of the stores listed in table 3.4.1.1-I. During air vehicle developmental activities substantial data may be obtained that could be used to verify this requirement. For example, these tests might include lower-level avionics/weapon integrations tests, weapon lab tests, etc. Use of this type of data should be maximized to avoid the cost and schedule impacts of a formal demonstration.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis indicates that the mechanical, mass properties, static and dynamic, carriage characteristics (with or without store suspension equipment) and launch characteristics of each store affecting the computation of air vehicle loadout structural integrity have been established. Analysis indicates that the mechanical/pneumatic retention, jettison, releasable (e.g., drop, ejection, thrust) features associated with carriage of each store have been established. Analysis indicates that a plan of action for retrieval of unavailable future stores data is in place. Inspection of subsystem function and requirements documents indicates proper flowdown of weapon driven functions and requirements, including, but not limited to, mission planning system, carriage concepts, loading concepts, flight control requirements, avionics interface requirements, targeting requirements, survivability requirements. Analysis indicates that requirements for the compatibility of and interface between the air vehicle and the required stores (e.g., armament, pods, decoys, targets) are defined and understood and that the preliminary air vehicle design approach is considering compatibility and interface with the store types listed. Inspection of contractors planned relationships with weapon vendors indicates proper flow down of weapon interface requirements and data, weapon compatibility data and studies. Inspection of the contractor’s plan for developing, documenting and controlling the interface between the weapon and weapon system through out the weapon system life indicate a capability to satisfy this requirement (AFMC Pamphlet 63-104, section 5 or equivalent serves as the benchmark). Inspection of the contractors plan for insuring compatibility using MIL HDBK 1763 as a guide. Analysis of contractor’s processes, plans and people indicate the ability to manage armament integration and certify safety, operational suitability and effectiveness of the weapons integrated into the weapon system

PDR: Analyses of trade studies identify and establish the structural design parameters and criteria necessary to enable the air vehicle airframe to meet the structural performance requirements for the store interface. As applicable, they will cover both land and ship-based operations including take-off, catapult, flight, landing, arrestment, and ground handling. Additionally, the interrelated structural and functional analyses of the unproven store suspension equipment have been completed. All instances of requirement nonconformance discovered during the review of store interfaces have a corrective action plan. Inspection of the preliminary compatibility assessment indicates a capability to meet the stores requirements. Inspection of design documentation indicates that the design will be compatible with the stores and provide the appropriate environment for the weapons, provides the weapon system functions that allow effective, survivable, and efficient target destruction with the required weapons. Inspection of preliminary ICDs (one for each weapon) and process to be used to develop, document and control the interface between the weapons and the weapon system (AFMC Pamphlet 63-104, section 5 or equivalent serves as the benchmark) indicate. Inspection of contractor's relationships with weapon vendors indicate proper flow of weapon interface requirements and data and that the contractor team has the capability to meet the stores interface requirements.

CDR: Analysis confirms that the projected air vehicle life has been computed and the "Iron Bird" (includes structural interface for stores) tests are being conducted. Analysis and simulation of both the store interface and the store suspension equipment confirm their strength and rigidity to retain the stores throughout the air vehicle ground, flight and landing environments. Tests of the new store suspension equipment confirm repeatable release capability, and instances of requirement nonconformance have a corrective action plan. Inspection of preliminary compatibility assessments (thermal analysis and predictions, wind tunnel tests results and predictions, vibration analysis and predictions, EMI/EMC analysis and predictions, see MIL-HDBK-1763 for details) indicate that store interface compatibility will be achieved. Analysis of the air vehicle design indicates the appropriate weapon interface at the required location(s) will be provided. Inspection of ICDs confirms that the documents have been signed by both the air vehicle contractor and weapon contractor, the interfaces are being controlled, and TBDs in the documents are few.

FFR: Analysis confirms that planning is complete for ground functional tests to include fit testing, and release of droppable stores to include adequacy of safety devices to preclude release. Analysis confirms, as deemed safe within the established flight envelope, planning is complete for flight tests to demonstrate the structural safety and adequacy of installations of all stores, store suspension equipment, and associated equipment, if any. Simulated shapes of weight and moment of inertia to be used whenever service equipment is not available. Analysis, demonstrations, and ground tests confirm readiness to enter stores carriage certification. Depending on flight test phasing, stores loading and certification is commonly deferred to later phases of flight test, so may be deferred at first flight readiness review. Inspection confirms that preflight, post-flight, and all maintenance checklists are available and have been reviewed for accuracy and completeness to ensure the air vehicle interfaces properly with any store being carried in this flight test phase. Analysis confirms that safety issues associated with the interface between stores and the air vehicle have been eliminated or adequately controlled.

SVR: Analysis confirms compatibility of the store interfaces between the stores listed and the air vehicle. Analyses, demonstrations, and tests confirm that the store interfaces listed in tables 3.4.1.1-I and 3.4.1.1-II meet the store interface requirements. Analysis and inspection confirm that ICDs are agreed upon (signed) by both the air vehicle contractor and weapon contractor, the interfaces are being controlled and there are tasks in place to control the interface over the life of the weapon system (based on AFMCP 63-104 or equivalent documentation). Inspection of interface verification documentation confirms, minimally, that it is complete, and that weapon loading, carriage, and employment data are published in interim TOs.

Sample Final Verification Criteria

The store interface requirements shall be satisfied when __(1)__ analyses and demonstrations of compatability between __(2)__ and the air vehicle confirm that the interface requirements defined by __(3)__ have been satisfied.

Blank 1. Identity the type and scope of the analyses and demonstrations required to provide confidence that the requirement has been satisfied. MIL-HDBK –1763 can serve as guidance.

Blank 2. Identify the store interfaces from table 3.4.1.1-I

Blank 3. Identify the identification documentation (ICDs) listed in table 3.4.1.1-I.

Note: At this point, ICDs are agreed upon (signed) by both the air vehicle contractor and weapon contractor, the interfaces are being controlled, and there are tasks in place to control the interface over the life of the weapon system (based on AFMCP 63-104 or equivalent documentation).

VERIFICATION LESSONS LEARNED (4.4.1.1)

To Be Prepared

3.4.1.1.1 Nuclear weapon interface

The air vehicle shall carry and employ the nuclear weapons listed in table 3.4.1.1-I. The air vehicle shall interface with nuclear weapons, in accordance with table 3.4.1.1-I, to prevent such weapons from producing unintended nuclear yield. The air vehicle shall comply with the __(1)__ nuclear weapon interface requirements.

REQUIREMENT RATIONALE (3.4.1.1.1)

Air vehicles with a mission to employ nuclear stores must be capable of meeting certification requirements for nuclear store deployment. Inherent within the certification process is the ability to safely employ nuclear weapons without inadvertent or unauthorized activation.

REQUIREMENT GUIDANCE (3.4.1.1.1)

Blank 1. Complete by obtaining assistance from Headquarters, USAF/SE, AAC/WNE, and the Directorate of Nuclear Surety, Headquarters Air Force Safety Agency (HQ AFSA).

Navy air vehicle nuclear capability planning and subsequent implementation of this requirement must be coordinated with the Office of the Chief of Naval Operations to obtain current policy and direction.

REQUIREMENT LESSONS LEARNED (3.4.1.1.1)

To Be Prepared

4.4.1.1.1 Nuclear weapon interface verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Nuclear weapon interface requirements	(1)	TBD	TBD	TBD	TBD	TBD

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.4.1.1.1)

Complete the verification based upon unique program requirements and by obtaining assistance from Headquarters, USAF/SE, AAC/WNE, and the Directorate of Nuclear Surety, Headquarters Air Force Safety Agency (HQ AFSA). In light of this, verification activities of this requirement should be developed in concert with this group.

Nuclear certification is a continuous process whereby the agencies identified in this document determine if the weapons system is safe and secure, if the nuclear weapon is compatible with the carrier system, and if any operational restrictions are needed to assure its safety, security and compatibility.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Unique to program.

PDR: Unique to program.

CDR: Unique to program.

FFR: Unique to program.

SVR: Unique to program.

Sample Final Verification Criteria

Unique to program.

VERIFICATION LESSONS LEARNED (4.4.1.1.1)

To Be Prepared

3.4.1.1.2 Standard electrical interface

The air vehicle shall provide stores electrical interfaces as defined by MIL-STD-1760 class __(1)__ at __(2)__ locations. For stores without the MIL-STD-1760 capability, the air vehicle shall be compatible with the electrical interface of the store in accordance with 3.4.1.1 Store interface.

REQUIREMENT RATIONALE (3.4.1.1.2)

Use of the MIL-STD-1760 electrical interface on air vehicles is required for compatibility with the current generation of smart munitions (JDAM, JSOW, WCMD, JASSM, etc.).

REQUIREMENT GUIDANCE (3.4.1.1.2)

Blanks 1 and 2 should define the class, as defined in MIL-STD-1760, and location of interfaces at the appropriate wing, fuselage, or weapon bay locations. If a new store or air vehicle concept requires interfaces that cannot be accommodated within the existing MIL-STD-1760 interface or the growth provisions in MIL-STD-1760 (high bandwidth, fiber optic, and high voltage power provisions), this requirement may need to be tailored. Due to the large number of older stores in the inventory, most of which require unique electrical interfaces, new air vehicles must also provide a store-unique interface for each of these stores it is required to carry (see 3.4.1.1 Store interface).

MIL-HDBK-1760 provides extensive guidance on the application of MIL-STD-1760 interfaces.

REQUIREMENT LESSONS LEARNED (3.4.1.1.2)

The use of MIL-STD-1760 interfaces on an air vehicle can save significant acquisition and maintenance costs. Any unique or model-specific interface variations need to be thoroughly analyzed for their intended function. Sometimes an interface could drive undue cost to an air vehicle and it might be best to limit use of this store type on the air vehicle versus designing the interface into the air vehicle.

While this document (and MIL-STD-464) does not specifically require shields on cables, they maybe necessary in some cases to meet required EMI characteristics. It is up to the contractor to develop a design approach that meets the required performance. If shielding is used, it is important to use connector backshells designed for proper termination of the shield. Store umbilical cables generally are shielded (a full braid shield is required for MIL-STD-1760 compliant umbilicals) since the cable extends outside the aircraft skin. A cable outside the aircraft skin may require shielding because it receives no other protection from higher interference environments and lightning.

4.4.1.1.2 Standard electrical interface verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Location(s) and class of MIL-STD-1760 interfaces provided	Class Location	A	A	A	A,D,T	A,D,T

VERIFICATION DISCUSSION (4.4.1.1.2)

Verification of this requirement should be accomplished by integrating analysis with demonstrations of the store stations on the air vehicle. During air vehicle developmental activities, design data will show the wiring, connectors, and software associated with each store station. This data can be used for preliminary verification of this requirement. Analysis of the engineering data should be maximized to ensure that formal demonstrations of weapon loading and employment in flight test will be successful. The air vehicle standard electrical interface verification should include the following types of interface functions as applicable to the store: pre-launch communications from the air vehicle to an armament store (e.g., store initialization, transfer of GPS data acquired by the air vehicle, communications to assure an armament store to air vehicle safe separation interface prior to store detonation); and pre-launch communications between the store and store pod, if they exist.

Note: Verification of noncompatibility with MIL-STD-1760 store electrical interfaces should be addressed in the verification of 3.4.1.1 Store interface.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis indicates the preliminary air vehicle concept, planned usage, and weapon loadout concepts considers requirements of the air vehicle that would drive the location(s) and class of MIL-STD-1760 store interfaces. Requirements for the interface between the air vehicle and the required stores (e.g., armament, pods, decoys, targets) are defined and understood. Preliminary analysis indicates the design approach is considering interface with the store types listed.

PDR: Analysis of the air vehicle preliminary design indicates the appropriate class of MIL-STD-1760 interface at the required location(s) will be provided. Analysis of preliminary air vehicle design for the stores management system and MIL-STD-1760 class interface location(s) shows adequate power, wiring, processing, and safety provisions. Interface control documentation development properly addresses MIL-STD-1760 requirements.

CDR: Analysis of the air vehicle design confirms the appropriate class of MIL-STD-1760 interface at the required location(s) will be provided. Analysis of design for the stores management system and MIL-STD-1760 interface location(s), shows adequate power, wiring, processing, and safety provisions. Interface control documentation properly addressing MIL-STD-1760 requirements are available. Test set(s) or alternative measures for verifying each MIL-STD-1760 interface have been established.

FFR: Analysis, demonstrations, and ground tests, as needed to verify readiness to enter stores carriage certification efforts (e.g., Seek Eagle) have been accomplished. Depending on flight test phasing, stores loading and certification is commonly deferred to later phases of flight test, so may be deferred at first flight readiness review. Preflight, post-flight, and all maintenance checklists are available and have been reviewed for accuracy and completeness to ensure the air vehicle interfaces properly with any MIL-STD-1760 store being carried in this flight test phase. Analysis have been performed to confirm that all safety issues associated with the interface between stores and the air vehicle have been eliminated or adequately controlled.

SVR: All MIL-STD-1760 interfaces listed have been analyzed/demonstrated/tested to show MIL-STD-1760 compliance.

Sample Final Verification Criteria

The MIL-STD-1760 electrical interface requirements shall be verified by __(1)__ analyses, __(2)__ demonstration and __(3)__ tests.

> Blank 1. Identify the type and scope of analyses needed to confirm that the requirement has been satisfied for each MIL-STD-1760 location.
>
> Blank 2. Identify the type and scope of demonstrations needed to confirm that the requirement has been satisfied for each MIL-STD-1760 location.
>
> Blank 3. Identify the type and scope of tests needed to confirm that the requirement has been satisfied for each MIL-STD-1760 location.

VERIFICATION LESSONS LEARNED (4.4.1.1.2)

To Be Prepared

3.4.1.1.3 Store alignment

Store alignment shall be __(1)__. Store installations shall be such that removal of components or parts for boresighting is possible without needing to remove the store from the air vehicle. Boresighting provisions are __(2)__.

REQUIREMENT RATIONALE (3.4.1.1.3)

Some stores require an air vehicle to store boresighting alignment.

REQUIREMENT GUIDANCE (3.4.1.1.3)

Blank 1. Complete with store alignment line. Typically, this is such that the longitudinal axes of the stores are aligned in the pitch plane parallel to the flight path of the air vehicle in normal cruise condition to minimize drag.

Blank 2. Complete with any installed air vehicle boresighting provisions, noting performance required.

REQUIREMENT LESSONS LEARNED (3.4.1.1.3)

To Be Prepared

4.4.1.1.3 Store alignment verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Store alignment	(1)	A	A	A		A,I
Boresighting access	Boresighting access with store installed is possible (Y/N)	A	A	A		A,I
Boresighting	(2)	A	A	A		A,I

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.4.1.1.3)

Verification of the store alignment requirement should be accomplished with analysis of the design and inspection of alignment and boresight actions. During assembly, developmental test, and remove and replace activities substantial data is typically obtained that could be used to verify this requirement. Use of this type of data should be maximized to avoid the cost and schedule impacts of a formal demonstration.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analysis of design concepts indicate that requirements for stores alignment/boresighting are understood and addressed.

PDR: Analysis of preliminary design indicates adequate provisions for alignment of stores and boresighting as required. All instances of nonconformance to the requirement have a corrective action plan.

CDR: Analysis of final design confirms adequate provisions for alignment of stores and boresighting as required. All instances of nonconformance to the requirement discovered during the review of product definition have a corrective action plan.

FFR: No unique verification action occurs at this milestone.

SVR: Analysis and inspection of available data from assembly, developmental test, and remove and replace actions confirms that stores can be aligned as specified and boresighting, if required, can be accomplished without stores removal. Any known instances of nonconformance to this requirement have been corrected by product definition change.

Sample Final Verification Criteria

The stores alignment and boresighting requirements shall be satisfied when __(1)__ analyses and __(2) __ inspections confirm that stores alignment and boresighting can be accomplished when stores are loaded on the air vehicle.

> Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement has been satisfied.
>
> Blank 2. Identify the type and scope of inspections required to provide confidence that the requirement has been satisfied. Inspections should include confirmation that any known instances of nonconformance to this requirement are corrected by product definition change.

VERIFICATION LESSONS LEARNED (4.4.1.1.3)

To Be Prepared

3.4.1.1.4 Ejector unit cartridges

If an ejector unit uses explosive cartridges, the ejector unit shall be capable of using Government approved standard cartridges in accordance with __(1)__. The air vehicle to ejector unit interface shall allow weapons to be loaded prior to installing the cartridges. Cartridge retainers shall not require the use of a torque wrench for installation or removal.

REQUIREMENT RATIONALE (3.4.1.1.4)

This requirement is intended to avoid the need to design, test, qualify, procure, and logistically supply a new explosive device design, which is an expensive process, considering the safety implications. Where a new technology is available, or a new method of releasing or ejecting stores is being used, there may be overriding reasons to develop a new cartridge. In these cases, this requirement may be tailored out by the procuring activity.

Also, see 3.3.10.2.2 Energetics.

REQUIREMENT GUIDANCE (3.4.1.1.4)

Blank 1. Complete by incorporating cartridge characteristics from existing military specifications. If suitable margins are included in the design, and weapons loading technicians are trained in proper tightening techniques, the need to carry and use extra tools like torque wrenches during time-critical and safety-critical weapons loading efforts can be avoided.

REQUIREMENT LESSONS LEARNED (3.4.1.1.4)

Cartridge lessons learned are disclosed in existing military specifications. Safety and logistics issues demand that Government-approved cartridges be used whenever possible. On a new aerial target (store) program, the project engineer was advised that any unique cartridge would have to be rigorously developed in accordance with cartridge specifications. As a minimum, this meant fabricating 300 fuzes and testing them, and then fabricating 100 more for testing at the Dalgren Navy Safety Center. Any test failures would increase the number of cartridges to be tested. To forgo this type of development expense, an approved cartridge should be used.

4.4.1.1.4 Ejector unit cartridges verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Ejector cartridge type	(1)	A	A	A		A,I
Ejector cartridge installation access	Capability to install explosive cartridge when ejector unit is installed on air vehicle (Y/N)	A	A	A		A,I
Torque wrench not required	No torque wrench required to install cartridge/retainer	A	A	A		A,I

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.4.1.1.4)

Verification of the requirement for ejector unit cartridges should be accomplished by analysis of design and inspection of assembly and loading/handling actions. During assembly, developmental test, and remove and replace activities substantial data is typically obtained that could be used to verify this requirement. Use of this type of data should be maximized to avoid the cost and schedule impacts of a formal demonstration.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analysis of initial design concepts indicates ejector cartridge requirements, loading requirements, and the requirement to install ejector cartridges without the use of a torque wrench have been addressed.

PDR: Analysis of the preliminary design indicates that only ejector cartridges currently in inventory are used and they can be installed without torque wrenches with the weapons already installed on the air vehicle.

CDR: Analysis of the final design confirms that only ejector cartridges currently in inventory are used and they can be installed without torque wrenches with the weapons already installed.

FFR: No unique verification action occurs at this milestone.

SVR: Analysis and inspection of available data from assembly, developmental test, and remove and replace actions confirm that ejector cartridges can be installed with weapons mounted on the air vehicle and without the use of a torque wrench. All known instances of nonconformance to this requirement have been corrected by product definition change.

Sample Final Verification Criteria

The ejector cartridge requirements shall be satisfied when __(1)__ analyses and __(2)__ inspections confirm the use of specified ejector cartridges and that the cartridges can be installed after weapons installation without the use of a torque wrench.

Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement has been satisfied.

Blank 2. Identify the type and scope of inspections required to provide confidence that the requirement has been satisfied. Inspections should include confirmation that any known instances of nonconformance to this requirement are corrected by product definition change.

VERIFICATION LESSONS LEARNED (4.4.1.1.4)

To Be Prepared

3.4.1.2 Weapon and store loadouts

The air vehicle shall be capable of carrying and jettisoning the store loadouts identified in table 3.4.1.2-I. The air vehicle shall provide the capability to jettison internal and external stores with no damages to the air vehicle. The air vehicle shall provide for emergency and selective jettison of stores. The air vehicle shall not be capable of jettison of stores while on the ground.

TABLE 3.4.1.2-I. Weapon and store loadouts.

Loadout Number __(1)__

Store Nomenclature	Number Carried	Carriage	Emergency Jettison	Selective Jettison			Additional Information
				I	C	R	

Notes: Selective Jettison

I: Capability to selectively jettison store individually
C: Capability to selectively jettison stores in combinations
R: Capability to selectively jettison the rack, pylon, or the rack/pylon including the store(s)

REQUIREMENT RATIONALE (3.4.1.2)

The combination and number of weapons and stores that must be carried is an important factor in air vehicle design. This information is necessary to successful integration. Stores jettison is necessary for a number of reasons. Air combat air vehicle may need to reduce drag and weight to successfully engage or avoid threats. Combat damage may result in circumstances where reduction of weight and drag are essential in order to return to base safely. Base operating conditions may necessitate jettison of unexpended explosive ordnance prior to landing and/or the reduction of weight to shorten landing distances if usable runway surfaces have been degraded by threat attack.

REQUIREMENT GUIDANCE (3.4.1.2)

Repeat table 3.4.1.2-I for each store loadout to be specified.

> Blank 1. For each table 3.4.1.2-I that is created, enter an appropriate number to differentiate the various loadouts (store mix and location of each store).

Guidance for completing table 3.4.1.2-I follows:

<u>Store Nomenclature</u>**:** Enter the nomenclature of the stores to be carried in the loadout. An example of a valid entry is “MK-82 LDGP.” Entries must include stores and associated training rounds. Stores include weapons, pods, racks and other assets carried on the air vehicle.

<u>Number Carried</u>**:** Enter the quantity of each weapon and store type to be carried in the identified store loadout.

<u>Carriage</u>**:** Enter whether the weapon(s) and store(s) will be carried externally or internally for the identified loadout. If station number is known, enter this information as well.

<u>Emergency Jettison</u>**:** Emergency jettison generally occurs in circumstances of catastrophic/near catastrophic failure. Identify whether this store, for this loadout, is to be jettisoned in an emergency. Entries such as “yes,” “no,” “jettison,” “retained,” etc., are all valid. However, consistency of entries should be maintained throughout all the tables generated for this requirement.

<u>Selective Jettison</u>**:** Fill in the columns with the following information

> I: Capability to selectively jettison store individually
>
> C: Capability to selectively jettison stores in combinations, which do not degrade air vehicle safety
>
> R: Capability to selectively jettison the rack, pylon, or the rack/pylon including the store(s)

<u>Additional Information</u>**:** Enter any additional pertinent information.

REQUIREMENT LESSONS LEARNED (3.4.1.2)

To Be Prepared

4.4.1.2 Weapon and store loadouts verification

Loadout Number __(1)__

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Store carriage	Fit, see MIL-STD-1763	A	A,S	A,S, T,D		A,S, D,T
Emergency Jettison	Safe separation (see MIL-STD-1763), specified emergency jettison capability	A	A,S	A,S, T,D		A,S, D,T
Selective jettison	Safe separation (see MIL-STD-1763) specified selective jettison capability	A	A,S	A,S, T,D		A,S, D,T
Ground jettison safety	Preclusion of stores jettison while on the ground	A	A,S	A,S, T,D		A,S, D,T

VERIFICATION DISCUSSION (4.4.1.2)

To Be Prepared

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analyses indicate that weapon carriage and jettison requirements have been decomposed to lower-tier requirements and that meeting these lower-tier requirements provides the required loadout carriage and jettison.

PDR: Analyses and simulations indicates that preliminary designs provide the weapon carriage and jettison requirements. These analyses and simulations should utilize available simulation and test results from GFE and existing commercial items wherever possible.

CDR: Analyses, demonstrations, simulations and tests confirm that final designs provide weapon carriage and jettison requirements.

FFR: No unique verification action occurs at this milestone.

SVR: A combination of analysis, simulation, demonstration, and test verify the weapon carriage and jettison requirements.

Sample Final Verification Criteria

Weapons and store loadouts shall be satisfied when the __(1)__ analyses, __(2)__ simulations, __(3)__ tests, and __(4)__ demonstrations confirm that the requirements of table 3.4.1.2-I have been met.

Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement elements have been met.

Blank 2. Identify the type and scope of simulations required to provide confidence that the requirement elements have been met.

Blank 3. Identify the type and scope of tests required to provide confidence that the requirement elements have been met.

Blank 4. Identify the type and scope of demonstrations required to provide confidence that the requirement elements have been met.

VERIFICATION LESSONS LEARNED (4.4.1.2)

To Be Prepared

3.4.1.3 Gun interface

The air vehicle shall employ the gun system(s) identified in table 3.4.1.3-I. The air vehicle shall prevent inadvertent firing during ground operations, loading, downloading, and maintenance actions.

TABLE 3.4.1.3-I. Guns.

Gun Nomenclature and Description	Carriage	Rate of Fire	Magazine Size	Length of Burst/Burst Limit	Ammunition Type

REQUIREMENT RATIONALE (3.4.1.3)

A list of the guns that the air vehicle must be capable of employing is included to ensure that thorough integration planning can be accomplished. Gun operation can affect the aircrew and other aspects of the air vehicle operations. Gases and particles are ejected from the gun barrels when guns are fired and these gases and debris have been known to damage air vehicle surfaces and score canopies as well as erode the inside of the gun barrels.

REQUIREMENT GUIDANCE (3.4.1.3)

Guidance for completing table 3.4.1.3-I follows:

<u>Gun Nomenclature</u>: List all of the gun and rocket types that must be employed.

<u>Carriage</u>: Enter whether the weapon will be carried internal in the air vehicle or external in a pod. If the air vehicle must be capable of both internal and external carriage of a particular weapon, enter “internal and external pod.” Other appropriate entries include “trainable” and “turreted.”

<u>Rate of Fire</u>: Enter the rounds per minute that each gun system must be capable of firing.

Magazine Size: Enter the minimum number of rounds that must be carried by the air vehicle. Multiple requirements are offered in a. through d. for selection of the requirement(s) that are appropriate. One, more than one, or all of the following can be included.

Length of burst/burst limit: Enter the maximum allowable burst length.

Ammunition type: Enter the various types of ammunition to be fired.

REQUIREMENT LESSONS LEARNED (3.4.1.3)

When incorporating guns on the air vehicle ensure all other air vehicle performance requirements are not negatively impacted, including the following: gas affecting the air vehicle engine operation, obscuring pilot vision, creating an explosive/flammable build up of gas, adverse erosion of airframe, or adverse buildup of residue. Experience shows these areas to have caused specific air vehicle performance impacts.

4.4.1.3 Gun interface verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Ability to employ specified gun(s)	Table 3.4.1.3-1	I,A	I,A,S	I,A,S, D,T		A,D
Gun firing safety	Preclusion of gun firing while on the ground	I,A	I,A	I,A,D		A,D

VERIFICATION DISCUSSION (4.4.1.3)

To Be Prepared

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analysis indicates that interface requirements have been decomposed to lower-tier requirements and that meeting these lower-tier requirements provides the required gun interface.

PDR: Analysis and simulation indicates that preliminary designs will provide the Gun interface defined in table 3.4.1.3-I. These analyses and simulations should utilize available simulation and test results from GFE and existing commercial items wherever possible.

CDR: Analyses, demonstrations, simulations and tests confirm that final designs provide the gun interface as defined in table 3.4.1.3-I.

FFR: No unique verification action occurs at this milestone.

SVR: A combination of analysis, simulation, demonstration, and test verify the gun interface as defined in table 3.4.1.3-I.

Sample Final Verification Criteria

The gun interface requirements shall be satisfied when the __(1)__ analyses, __(2)__ simulations, __(3)__ tests, and __(4)__ demonstrations confirm that the specified guns meet all requirements.

Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement elements have been met.

Blank 2. Identify the type and scope of simulations required to provide confidence that the requirement elements have been met.

Blank 3. Identify the type and scope of tests required to provide confidence that the requirement elements have been met.

Blank 4. Identify the type and scope of demonstrations required to provide confidence that the requirement elements have been met.

VERIFICATION LESSONS LEARNED (4.4.1.3)

To Be Prepared

3.4.2 Communication, radio navigation, and identification interfaces

The air vehicle shall interface with the communication, radio navigation, and identification resources listed in table 3.4.2-I.

TABLE 3.4.2-I. Communication, radio navigation, and identification interface resources.

Resource	Characteristic	Remarks

REQUIREMENT RATIONALE (3.4.2)

This requirement establishes the communication, radio navigation, and identification interfaces required by the air vehicle to support interoperability and mission requirements. It addresses the interfaces which drive the communication, radio navigation, and identification functionality specified in the operations section of this document (see 3.1.7 Communication, radio navigation, and identification). These requirements pertain to interfaces external to the air vehicle and do not include internal communications such as between crewmembers.

REQUIREMENT GUIDANCE (3.4.2)

Guidance for completing table 3.4.2-I follows:

<u>Resource</u>: Identify the interface resource with which the air vehicle will be required to interface. Examples of items to include in resources are provided in table 3.4.2-II.

Characteristics: Identify special functional requirements. For example, identify whether a communication function is secure, nonsecure, jam resistant, analog voice, video or digital data. Other examples include 8.33 kHz channel spacing for VHF functions and FM immunity for VOR, ILS and VHF-AM functions to comply with Global Air Traffic Management (GATM) requirements.

Remarks: Include applicable specifications, standards and interface documents. Also, include any unique limitations regarding interface with this resource (e.g., capability for receive-only for VHF).

Sample list of resources. - (Example table)

Analog and Digital Communications	Radio Navigation	Identification
Ultra High Frequency-Amplitude Modulation (UHF-AM) Very High Frequency-AM (VHF-AM) VHF-Frequency Modulation (VHF-FM) High Frequency (HF) Link-16 UHF-SATCOM Super High Frequency-SATCOM MILSTAR Common Data Link (CDL) Emergency Locator Transponder VHF Data Link (GATM requirement) Integrated Broadcast Service (IBS)	VHF Omnidirectional Range (VOR) Global Positioning System (GPS) Tactical Air Navigation (TACAN) Distance Measuring Equipment (DME) UHF Automatic Direction Finding (UHF-ADF) Instrument Landing System (ILS) Microwave Landing System (MLS) Low Frequency ADF (LF-ADF)	Mark XII Identification Friend or Foe (IFF) transponder Mark XII IFF interrogator Mode S transponder, Traffic Alert and Collision Avoidance System (TCAS) Automatic Dependent Surveillance (a GATM requirement)

REQUIREMENT LESSONS LEARNED (3.4.2)

To Be Prepared

4.4.2 Communication, radio navigation and identification interfaces verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Interface with resource (a) from table 3.3.4.2-I	Interface requirements document and/or characteristic(s)	A	A	A	A,D	A,D, T
Interface with resource (b) from table 3.3.4.2-I	Interface requirements document and/or characteristic(s)	A	A	A	A,D	A,D, T
Interface with resource… from table 3.3.4.2-I	Interface requirements document and/or characteristic(s)	A	A	A	A,D	A,D, T

VERIFICATION DISCUSSION (4.4.2)

During air vehicle developmental activities, substantial data is typically obtained that could be used to verify this requirement. Use of this type of data should be maximized to minimize the cost and schedule impacts of formal demonstrations. The performance of the interface requirements defined in this requirement may also be addressed in 3.1.7 Communication, radio navigation, and identification; therefore the requirements stated herein may be verified as part of 4.1.7 Communication, radio navigation, and identification verification. The following verification activities address verification of the interface and do not address the performance of the specified interfaces. Therefore, in general, these verification activities will address confirmation of the overall interface compatibility between the air vehicle and the resource specified.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the requirements and planned usage of the air vehicle identifies factors that would tend to inhibit use of the required communication, radio navigation, and identification interfaces. Analysis indicates that the requirements for the interface between the air vehicle and the communication, radio navigation, and identification are defined and understood. Analysis indicates the design approach is considering interface to the communication, radio navigation, and identification systems listed in table 3.4.2-I.

PDR: Analysis of the air vehicle preliminary design indicates compatibility with communication, radio navigation, and identification interfaces listed in table 3.4.2-I.

CDR: Analysis of the air vehicle design confirms that compatibility with the communication, radio navigation, and identification interface requirements will be achieved. Any area of incompatibility has been thoroughly researched, and trade-offs identified.

FFR: Analyses and demonstrations confirm that flight-critical communication, radio navigation, and identification interfaces are compatible.

SVR: Analyses, tests, and demonstrations confirm air vehicle compatibility with all communication, radio navigation, and identification resource interfaces.

Sample Final Verification Criteria

The air vehicle communication, radio navigation, and identification interfaces requirements shall be verified by __(1)__ analyses, tests, and demonstrations of the interface between the air vehicle and each communication, radio navigation, and identification resource listed in table 3.4.2-I to confirm that the interface requirements defined by __(2)__ have been met.

Blank 1. Identify the type and scope of analyses, tests, and demonstrations required to provide confidence that the requirement has been satisfied.

Blank 2. Identify the interface requirement documents that must be met.

VERIFICATION LESSONS LEARNED (4.4.2)

To Be Prepared

3.4.3 Human/vehicle interface

The human/vehicle interface (HVI) consists of the aircrew/vehicle interface (AVI), the maintainer/vehicle interface (MVI) and the passenger interface (PI). To the extent practicable, aircrew and maintainers shall be provided consistent control and information formatting of all operator-to-equipment interfaces of the weapon system. To the extent practicable, operator interfaces shall be consistent from one operation and equipment interface to another. The AVI shall enable the aircrew to perform all mission elements and standard procedures. The air vehicle shall provide the PI necessary to complete any mission involving other passengers.

REQUIREMENT RATIONALE (3.4.3)

The HVI needs to provide the aircrew, maintainers, and passengers all necessary controls, displays, information and human needs to successfully complete the mission with an operationally acceptable level of workload. Additionally, crew station subsystem aircrew compatibility must be addressed at the air vehicle level for crew systems integration to be successful and to assess the functional effectiveness of the AVI and MVI. It is important that HVI requirements are routed to the subsystems that support the AVI such as avionics, flight controls, training, support systems, etc.

The maintainers may need to be able to interrogate maintenance-oriented displays from the cockpit, depending on the aircraft concept of operations. This is particularly important for deployments to austere operating bases where support equipment may not be available during the first days. This is also very useful when the aircraft is forced to land at a commercial facility that does not have platform-specific support equipment.

REQUIREMENT GUIDANCE (3.4.3)

Display control labels should be consistently located and mechanized between display pages. This includes mission planning station displays. Display menu logic should be consistently applied. Control panel and display information stereotypes should not be violated unless there is good reason to do so.

The following NATO International Standardization Agreements (STANAGs) have been established defining standard aircrew interfaces and can be used as design guidance.

STANAG No.	Title
3217	Operation of Controls and Switches at Aircrew Stations
3219	Location & Grouping of Electrical Switches in Aircraft
3224	Aircrew Station Lighting
3258	Position of Pilot Operated Navigation & Radio Controls
3329	Numerals & Letters in Aircrew Stations
3370	Aircrew Station W,C,& A Signals
3436	Colours & Markings Used to Denote Operating Ranges of A/C Instruments
3504	CRT Head Down Displays
3639	Aircrew Station Dimensional Design Factors

STANAG No.	Title
3647	Nomenclature in Aircrew Stations
3701	Aircraft Interior Colour Schemes
3705	Principles of Presentation of Information in Aircrew Stations
3800	NVG Lighting Compatibility Design Criteria
3869	Aircrew Station Control Panels
3870	Emergency Escape/Evacuation Ltg
3871	NATO Glossary of A/C Displays & Aircrew Stations Specialist Terminology & Abbreviations
3950	Helicopter Crew Seat Design
3994	Application of Human Egrg to Advanced Aircrew Systems
7041	Integrated HMDs for Rotary Wing A/C
7042	Image Intensifier Displays in A/C
7044	Mission Planning Station Interface Design
7080	Interactive Front Face
7096	Loc, Act, & Shape of Airframe Controls
7138	Aircraft Visual Display Units
7139	A/C Engine Controls, Switches, Displays, Indicators, Gauges, & Arrangements
7140	A/C Flight Instruments, Layout & Display

REQUIREMENT LESSONS LEARNED (3.4.3)

Less robust AVI development efforts have resulted in systems that were difficult to operate and seriously affected the aircrew's ability to perform the mission. A combination of man-in-the-loop (MITL) simulation and mock-ups should be used in the development of the AVI. Appropriate measures of performance should be identified for each AVI evaluation. It is also extremely important that cockpit working groups and maintainer working groups be established in order to get early user involvement in the development of the systems.

4.4.3 Human/vehicle interface verification

This verification will be accomplished in the subsequent paragraphs.

VERIFICATION LESSONS LEARNED (4.4.3)

To Be Prepared

3.4.3.1 Aircrew/vehicle interfaces

3.4.3.1.1 Aircrew anthropometrics

The air vehicle shall accommodate the aircrew population attribute range in table 3.4.3.1.1-I and table 3.4.3.1.1-II wearing required flight clothing and equipment, including, as a minimum, the following: __(1)__.

TABLE 3.4.3.1.1-I. Aircrew population anthropometrics.

Attribute*	CASE 1	CASE 2	CASE …	CASE n
Thumb tip reach				
Buttock-knee length				
Knee-height sitting				
Sitting height				
Eye height sitting				
Shoulder height sitting				
Shoulder breadth range				
Chest depth range				
Thigh circumference range				
Other(s)				

*Measured in inches

TABLE 3.4.3.1.1-II. Additional anthropometric characteristics for accommodation.

Attribute*	Measurement Range
Forearm to forearm breadth (seated)	
Hip breadth (seated)	
Shoulder to elbow length (arm flexed)	
Elbow to fingertip length (arm, flexed)	
Buttock to popliteal fossa length (leg flexed)	
Popliteal height sitting	
Boots size	
Thigh clearance (sitting thickness)	
Chest circumference	
Waist circumference	
Nude Weight	
Other(s)	

*Measured in inches

REQUIREMENT RATIONALE (3.4.3.1.1)

This requirement specifies accommodation requirements for aircrew population. The characteristics of the population need to be provided to the developer to ensure the crew station design can accommodate the intended aircrew population.

REQUIREMENT GUIDANCE (3.4.3.1.1)

Historically, DoD has specified univariate anthropometric requirements (e.g., USAF 5th to 95th percentile) based upon past male flying populations. This has led to design extremes based upon 5th or 95th percentile dimensions. Since no aircrew is all 5th or 95th dimensions, these techniques have led to nonoptimum crew station accommodation. To correct this problem, DoD has adopted a multivariate approach. This approach requires accommodation of the projected flying population based upon multiple, critical body dimensions that account for various combinations of the torso length and limb length. These combinations are described as cases. These cases, when met, will accommodate a given percentage of the projected flying population. An example would be cases 1-7 listed in the DoD Standard Aircrew Population Matrix example below, which would accommodate over 95 percent of the projected male and female flying population. Over time, these numbers will vary with changes in the characteristics of the flying populations. The projected population anthropometrics used in design should be consistent with that expected during the operational service life of the air vehicle.

Provide anthropometric characteristics of the aircrew population to ensure adequate accommodation, control/display access, and field of view. Account for special mission requirements, personal protective/survival equipment, and operational factors (e.g., environmental and threat conditions). Complete tables 3.4.3.1.1-I and 3.4.3.1.1-II with information similar to examples shown below. Keep in mind that the greater the number of dimensions that are used, the more models will be required to represent the population and the more subjects will be required to verify the accommodation. Therefore, use the minimum number of dimensions that will adequately describe the workspace you want to specify. For a crewstation position these would normally be thumb-tip reach, eye height sitting, shoulder height sitting, buttock-knee length, sitting height, and knee height sitting. Determine what portion, if not all, of the DoD standard aircrew population will be accommodated.

Blank 1. Enter item descriptions similar to the following personal equipment example list:

Anti-g Suit: CSU-13B/P with male connector (NSN 4730-00-821-2481)

Oxygen Mask: MBU-12/P with U-93A/U communications plug (NSN 5935-00-642-0626)

Flier's Gloves: GS/FRP-2

Flier's Winter Jacket: CWU-45P

Torso Harnesses: PCU-15A/P and PCU-16A/P with oxygen connector mounting bracket, PCU-56

Oxygen Connector: CRU-60/P

Flier's Helmet: HGU-55/P, HGU-68/P

Flier's Coveralls: CWU-27/P

Flier's Summer Jacket: CWU-36/P

Flier's Boots: FWU-8/P

Automatic Life Preserver: LPU-9/P, LPU-33/P

Aircrew population anthropometrics. - (Example table)

Attribute*	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7
Thumb tip reach	27.0	27.6	33.9	29.7	35.6	36.0	26.1
Buttock-knee length	21.3	21.3	26.5	22.7	27.4	27.9	20.8
Knee-height sitting	18.7	19.1	23.3	20.6	24.7	24.8	18.1
Sitting height	32.8	35.5	34.9	38.5	40.0	38.0	31.0
Eye height sitting	28.0	30.7	30.2	33.4	35.0	32.9	26.8
Shoulder height sitting	20.6	22.7	22.6	25.2	26.9	25.0	19.5
Shoulder breadth range	14.7-18.1	16.4-20.6	16.2-21.2	16.8-21.7	16.9-22.6	16.8-22.5	14.2-18.0
Chest depth range	7.4-10.9	6.9-10.6	7.2-11.3	7.1-11.0	7.3-12.1	7.4-12.2	7.2-10.2
Thigh circumference range	18.5-25.0	17.1-25.0	20.2-27.6	17.6-26.3	18.6-29.2	19.1-29.7	17.8-25.2

*Measured in inches

Additional anthropometric characteristics for accommodation. - (Example table)

Attribute*	Measurement Range
Forearm to forearm breadth (seated)	14.5 - 25.5 in.
Hip breadth (seated)	10.8 - 18.1 in.
Shoulder to elbow length (arm flexed)	11.7 - 17.2 in.
Elbow to fingertip length (am, flexed)	15.4 - 23.2 in.
Buttock to popliteal fossa length (leg flexed)	16.7 - 23.2 in.
Popliteal height sitting	13.0 - 21.3 in.
Boot size	6 – 13 (U.S.)
Thigh clearance (sitting thickness)	4.9 - 8.1 in.
Chest circumference	29.6 - 48.0 in.
Waist circumference	23.6 - 44.7 in.
Nude weight	103-245 lbs.

*Measured in inches

REQUIREMENT LESSONS LEARNED (3.4.3.1.1)

Past anthropometric assessments of aircrew accommodation using computer models have proven insufficient. Most computer models do allow the various body dimensions to be changed such that the pilot population can be accurately represented. However, impacts of clothing and pilot-mounted gear have not been adequately modeled. As a result, physical model/prototypes need to be developed. Future modeling capabilities that more accurately capture specific body motions and equipment may rectify this problem.

4.4.3.1.1 Aircrew anthropometrics verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Aircrew population accommodated	Table 3.4.3.1.1-I and table 3.4.3.1.1-II	A	A,D	D	A,D, S	D

VERIFICATION DISCUSSION (4.4.3.1.1)

The anthropometric evaluation will require a number of subjects in order to represent the required population (normally 20 or more). It is best to have at least two different subjects to represent each model to get an accurate assessment of the accommodation. This is necessary due to differences in torso, limb thickness, flexibility, etc. Computer modeling is a good, relatively inexpensive method to conduct initial evaluations. Final validation should be done in a mock-up due to the computer's inability to accurately model the Life Support System (LSS) and the pilot restraint system, and their effects on pilot mobility.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Results of analysis confirm that anthropometric requirements for the interface between the air vehicle and the aircrew are defined and understood. Analysis indicates that the design approach is considering anthropometrics, and clothing and equipment that are specified. Analysis verifies that the aircrew population is fully described by anthropometric models. Inspection of initial configuration of aircrew LSS equipment shows acceptable impacts to aircrew anthropometric accommodation.

PDR: Demonstrations, using low fidelity crew station mock-ups show representative subjects in an anthropometric evaluation with acceptable results. Crew station and anthropometric models incorporated into a computer model, and an anthropometric evaluation analyzed electronically further substantiate acceptable anthropometric design. Inspection of the LSS equipment and design shows acceptable impacts on aircrew anthropometric accommodation.

CDR: Demonstrations in a high fidelity crew station mock-up and inspections of aircrew equipment design show fully acceptable anthropometric accommodation. Subjects are evaluated while wearing the full complement of LSS equipment and possible variations (over water vs. over land, cold weather, etc.).

FFR: Results of analysis, demonstrations, and simulations confirm that all anthropometrics, clothing and equipment and air vehicle factors have been determined to be compatible and ready for first flight. Preflight, in-flight and post-flight checklists applicable to first flight checks are available and have been reviewed for accuracy and completeness to ensure the air vehicle interfaces properly with the specified aircrew anthropometrics.

SVR: Demonstrations confirm full anthropometric accommodation in the air vehicle. Subjects are evaluated while wearing the full complement of LSS equipment and possible variations (over water vs. over land, cold weather, etc.). Analysis, demonstrations, and simulations confirm that all pre-flight, in-flight, and post-flight aircrew operations can be successfully performed by aircrew personnel within the full range of anthropometric parameters defined.

Sample Final Verification Criteria

The aircrew anthropometrics requirements shall be satisfied when __(1)__ demonstrations and __(2) __simulations of the interface between specified anthropometric crew members and the air vehicle confirm that the aircrew population specified can be accommodated.

Blank 1. Identify the number of demonstrations required to provide confidence that the requirement has been satisfied. Demonstration is the best method of ensuring that the required population is accommodated. Life support gear should be worn by subjects participating in the evaluation. All LSS connections and crew restraints should be connected.

Blank 2. Identify the number of simulations required to provide confidence that the requirement has been satisfied.

VERIFICATION LESSONS LEARNED (4.4.3.1.1)

It is important that an accurate accommodation evaluation be conducted in order to assess that pilots can safely fly the aircraft. This is particularly important for high performance aircraft where G forces can adversely impact pilot reach and mobility.

3.4.3.1.2 Aircrew ingress/egress

The air vehicle shall enable the aircrew to ingress/egress the air vehicle in accordance with table 3.4.3.1.2-I.

TABLE 3.4.3.1.2-I. Ingress/egress performance.

Type Action	Conditions					Time
	Available Provisions	Number of Aircrew	Start	Stop	Special	

REQUIREMENT RATIONALE (3.4.3.1.2)

The time required for the aircrew to ingress and egress the air vehicle is an important factor in the capability of the air vehicle to respond to mission-critical elements such as alert launch, base escape, and turnaround.

REQUIREMENT GUIDANCE (3.4.3.1.2)

Guidance for completing table 3.4.3.1.2-I follows:

<u>Type Action</u>: Identify whether the action is an "ingress" or "egress" action.

<u>Available Provision</u>: Identify the support equipment and personnel available and in place to support the action identified. If none, so state.

Number of Aircrew: Identify the number of aircrew who will be required to ingress or egress the air vehicle. For single-seat fighter/attack air vehicles, the number will be one. For multiseat aircraft, the number would be equal to the total number of aircrew.

The time required for ingress will normally begin when the aircrew arrives at the entry point for the air vehicle, wearing all required personal equipment. Ingress is completed when the aircrew is seated in the air vehicle with all required personal interface attachments completed. Attachments include such connections as communication cords, oxygen and G-suit hoses, shoulder/lap/leg restraints, etc.

Start: Identify the conditions required for initiation of the ingress or egress sequence, e.g., for ingress the "start" condition might be pilot foot on the ladder. The time required for ingress will normally begin when the aircrew arrives at the entry point for the air vehicle, wearing all required personal equipment.

Stop: Identify the conditions required for completion of the ingress or egress sequence, e.g., for ingress the "stop" condition might be pilot seated in the air vehicle, attached to all required devices, and all ejection devices in the armed position. Attachments include communication cords, oxygen, G-suit hoses, and shoulder/lap/leg restraints, etc.

Special: Identify special conditions which would impact ingress or egress from the air vehicle, e.g., special protective equipment such as cold weather or Nuclear and Biological Contamination (NBC) protective equipment may be required for the aircrew to perform certain missions, allowance for the extra time required to ingress and egress while wearing this equipment should be specified. In general, personal equipment requirements and adverse weather conditions or day/night conditions might be identified in this column.

Time: Identify the required time for ingress or egress from the air vehicle. This time should be derived from alert launch, base escape, and turnaround requirements contained in the air system specification. The time could include such actions as opening/closing the canopy, climbing the ladder, etc. Egress time will normally include that time between air vehicle shutdown until the aircrew is outside the air vehicle.

For a fighter/attack type air vehicle the recommended time is 30 seconds. If special protective equipment such as cold weather or NBC protective equipment may be required for the aircrew to perform certain missions, allowance for the extra time required to ingress and egress while wearing this equipment should be specified.

REQUIREMENT LESSONS LEARNED (3.4.3.1.2)

To Be Prepared

4.4.3.1.2 Aircrew ingress/egress verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Ingress	Time	A	A,I	A,D, S,I		D,A
Egress	Time	A	A,I	A,D, S,I		D,A

VERIFICATION DISCUSSION (4.4.3.1.2)

Aircrew ingress/egress is primarily verified by demonstration. Demonstrations can be conducted with initial air vehicle, or high fidelity mock-ups that can simulate actions required. One consideration for mock-up simulations is to account for height above ground level to ensure a valid demonstration and timing.

On some air vehicles an emergency egress demonstration should be sufficient to verify this requirement as well, primarily for those cases in which emergency egress actions and procedures are identical to those in nonemergency egress situations.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analysis defines aircrew ingress/egress requirements for the air vehicle areas and related equipment.

PDR: Initial analysis indicates specified times for ingress/egress of the crew can be achieved. Inspection of lower-tier specifications and functional allocations indicates that ingress/egress requirements have been satisfactorily allocated.

CDR: Analyses of design and lower-level test data, demonstration and simulation results indicate the ability to satisfy ingress/egress requirement within the specified time limitations. Inspections of detailed task timelines verify that expected ingress/egress times can be attained.

FFR: No unique verification action occurs at this milestone.

SVR: Results of analyses of lower-level verification data, and full aircrew ingress/egress demonstrations confirm that specified ingress/egress time requirements for all specified conditions have been met.

Sample Final Verification Criteria

The aircrew ingress/egress requirement shall be satisfied when __(1)__ analyses, and __(2)__ demonstrations confirm the aircrew and passenger ingress/egress time requirement has been met for all specified operational and environmental conditions.

> Blank 1. Identify the type and scope of analyses to be conducted. Analyses types could include one or more of the following: analysis of prior air vehicle applications indicate equivalent testing has been conducted; analysis of lower-level ingress/egress testing results on new and revised equipment; and/or analysis of supporting ingress/egress test results
>
> Blank 2. Identify the type and scope of demonstrations to be conducted

VERIFICATION LESSONS LEARNED (4.4.3.1.2)

To Be Prepared

3.4.3.1.3 Emergency escape

The air vehicle shall provide the aircrew an emergency escape capability to allow safe evacuation during emergencies encountered __(1)__. The escape capability shall provide the aircrew with a safe means of escape throughout the following envelope; __(2)__. Emergency escape shall be in accordance with table 3.4.3.1.3-I.

TABLE 3.4.3.1.3-I. Emergency escape.

Type Escape	Conditions							Time	Altitude
	Airspeed	Flight Path	Attitude			Sink rate	Special		
			Pitch	Roll	Yaw				

REQUIREMENT RATIONALE (3.4.3.1.3)

The air vehicle escape system should provide the aircrew with a means for safe emergency evacuation automatically or manually during flight, emergency ground egress, and ditching. Specific air vehicle types, user or mission requirements will dictate emergency escape capabilities. System level requirement trade-offs may also be a factor. For example, large passenger/transport air vehicle unlikely to be exposed to hostilities may not require an in-flight escape capability. The cost/weight impacts for providing ejection or bail out capabilities for this type of air vehicle may prohibitively impact other mission requirements.

REQUIREMENT GUIDANCE (3.4.3.1.3)

In the context of this requirement, the term “safe” means that the air vehicle must provide the aircrew with an escape capability that allows the crew to abandon the air vehicle, within the defined performance envelope, with no injuries that will compromise their survival.

> Blank 1. Complete with the type of escape environment: in the air, on the ground, or in water. 'On the ground' and 'in the water' will always be used in blank 1. 'In the air' may or may not be used.
>
> Blank 2. Complete with the air vehicle envelope throughout which the escape capabilities shall be available, including factors such as air vehicle airspeed, air vehicle altitude, attitude and load factors. Specific conditions that will drive escape system performance and design should be identified in table 3.4.3.1.3-I. Ground or water egress capabilities should also consider potential conditions following a crash or ditching.

Guidance for completing table 3.4.3.1.3-I follows:

<u>Type Escape</u>: Identify whether the escape is automated such as ejection in the air, on the ground, or in/under water, or manual such as bailout in the air, emergency ground egress, or ditching evacuation.

Conditions: Identify air vehicle airspeed, flight path, attitude, and sink rate in which successful escape is required. Consider rotational rates, high angles of attack, and unusual attitudes that might be encountered in an emergency.

Special: Identify special conditions which would impact emergency escape from the air vehicle, e.g., special protective equipment such as cold weather or NBC protective equipment, adverse weather conditions, day/night conditions, dynamic attitude rates, G loads, and under water depths might be identified in this column.

Time: Identify the required time for escape, or to complete emergency egress from the air vehicle using the specified conditions.

Altitude: Identify the minimum altitude for successful escape, such as the altitude required to ensure that full recovery parachute inflation will be achieved after an ejection or bailout. For high altitude escape, identify the maximum altitude for successful escape.

REQUIREMENT LESSONS LEARNED (3.4.3.1.3)

The air vehicle emergency escape system typically consists of the air vehicle structure, lighting, exits, hardware, and equipment that will enable the crewmembers to escape from an air vehicle. The escape system may include exits and lighting, evacuation slides or aids, ejection seats and escape path clearance and sequencing, and escape capsules.

The aircrew needs viable survival options for emergency scenarios. The following emergency survival scenarios for escape may apply: emergency egress in flight, emergency egress on ground, (both stationary, and during takeoff/landing roll velocities), emergency egress in water, or ditching, which might occur based on intended operational use of the air vehicle.

4.4.3.1.3 Emergency escape verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Emergency escape capability for specified environment	(1) escape capabilities available	A	A	A	A,S, D	A,S, D,T
Escape envelope within specified time	(2) and table 3.4.3.1.3-I	A	A,S	A,S	A,D	A,S, D,T

*Numbers in parentheses in the Measurand column refer to numbered blanks in the requirement.

VERIFICATION DISCUSSION (4.4.3.1.3)

Emergency escape capability for specified environment

Verification of the emergency escape provisions generally require a demonstration of emergency ground egress with human subjects. In-flight bail out may initially be verified by aerodynamic analysis to ensure air vehicle separation characteristics, followed by dummy and/or human testing. Verification of emergency escape in water might consist of mock-up demonstrations, component tests of emergency exits, explosive hatches, etc., or ejection tests as applicable. Ejection capability verification will generally consist of analysis/simulation, followed by sled tests and potential in-flight ejection testing.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of air vehicle conceptual design, preliminary concept descriptions and configuration depictions indicate that the air vehicle capability for emergency escape in the specified environments is addressed.

PDR: Analysis of the air vehicle preliminary design shows that specified escape capabilities can be accommodated within the air vehicle design. Analysis of evacuation time lines, structural adequacies, and component design configurations indicate escape potential for the specified environments.

CDR: Analyses of the air vehicle detailed design confirms adequate exits or provisions for specified escape environments.

FFR: Demonstrations of emergency ground egress evacuations and simulated in-flight bailout demonstrations confirm air vehicle escape system capability for first flight. Analysis of component level testing, such as canopy jettison, emergency exit actuation, and energetic device functioning confirm specified air vehicle performance and safety. Analysis of escape system level sled tests or in-flight ejection tests on similar platforms confirm ejection system capability for the specified environments.

SVR: Analysis of component qualification testing confirms escape system performance in the specified ground, air, or water environments. Simulations confirm capabilities and define extrapolated performance at untested conditions. Demonstrations, simulations and tests with operational representative crew/passenger loads confirm specified air vehicle ground, ditching, or bailout egress capabilities.

Sample Final Verification Criteria

The air vehicle emergency escape capability for the specified air, ground or water environments shall be satisfied when __(1)__ analyses, __(2)__ simulations, __(3)__ demonstrations, and __(4)__ tests confirm specified performance is achieved.

Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement has been satisfied.

Blank 2. Identify the type and scope of simulation(s) required to provide confidence that the requirement has been satisfied. Simulations that include structural and aerodynamic considerations should be used to verify escape capabilities at conditions that may be deemed unpractical or too expensive for test.

Blank 3. Identify the type and scope of demonstration(s) required to provide confidence that the requirement has been satisfied.

Blank 4. Identify the type and scope of flight tests required to provide confidence that the requirement has been satisfied. For in-flight ejection systems, sled tests and/or in-flight ejections should be accomplished. Tests should be conducted across the escape envelope speed range and at aircrew anthropometric extremes. For ground or ditching escape, escape path clearance tests should be conducted, along with emergency evacuation demonstrations. Bailout escape should be verified by in-flight bailout testing.

Lessons Learned: To Be Prepared

Escape envelope within specified time

Escape envelope generally refers to the velocity and altitude envelope for in-flight escape. Air vehicle load factors, sideslip, rotational rates, attitude, and specific flight conditions may also be defined (table 3.4.3.1.3-I). These conditions primarily relate to in-flight escape and are verified by demonstration and test. Analyses and simulation are also used to extrapolate performance verification at conditions not readily testable. Escape envelope may also specify specific ground, ditching, or bailout conditions for escape. These conditions are generally verified by demonstration, supplemented by subsystem test and analysis.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of preliminary air vehicle design concept and configuration definitions indicate that the air vehicle will allow safe escape within the specified envelope and time requirements.

PDR: Analysis and simulations using preliminary escape system models indicate that specified envelope conditions can be met, and were used to allocate component requirements. Preliminary event and task timelines indicate escape within specified times.

CDR: Escape system design analysis, simulation models, aerodynamic analyses, and wind tunnel model data confirm specified performance and escape capability within the defined envelope. Aerodynamic characteristics defined by analyses, and/or wind tunnel models confirm that loads on seats, hatches or canopies are acceptable. Analysis and simulations of accelerations and injury hazards indicate safe escape can occur within the envelope specified. Analysis and simulation of the escape sequence indicates crew/passenger escape within the specified time.

FFR: Analysis of escape system performance (such as ejection simulations) and subsystem-level tests (such as sled tests) as well as egress demonstrations indicate that a safe escape capability is provided for that portion of the specified escape envelope applicable to initial flight.

SVR: Escape system performance analysis, escape simulations, subsystem-level tests (including ejection sled tests as applicable), and emergency egress/ditching demonstrations confirm that a safe escape capability exists for the specified envelope. Analyses, tests, and demonstrations consider effects of anthropometric extremes and environmental variables. Analysis of escape accelerations and potential injury hazards confirm acceptable risk for aircrew/passengers to achieve safe escape within the specified envelope.

Sample Final Verification Criteria

The escape capability specified in table 3.4.3.1.3-I shall be satisfied when __(1)__ analysis, __(2)__ simulations, __(3)__ demonstrations, and __(4)__ tests confirm specified performance is achieved.

> Blank 1, identify the type and scope of analysis required to provide confidence that the requirement has been satisfied. Analysis and escape system simulations should be used to verify escape capabilities at envelope conditions not tested.
>
> Blank 2, identify the type and scope of simulations(s) required to provide confidence that the requirement has been satisfied.

Blank 3. Identify the type and scope of demonstration(s) required to provide confidence that the requirement has been satisfied. Emergency ground egress/ditching demonstrations should be considered.

Blank 4. Identify the type and scope of tests required to provide confidence that the requirement has been satisfied. System level testing typically includes escape path clearance testing, sled tests, ejection or bailout tests, and drop tests. Air vehicle tests supported by lower-level testing should be used to verify performance across the envelope cited.

Lessons Learned: To Be Prepared

VERIFICATION LESSONS LEARNED (4.4.3.1.3)

See lessons learned above for "Emergency escape capability for specified environment" and "Escape envelope within specified time" requirement elements.

3.4.3.1.4 Aircrew survival and rescue

The air vehicle shall provide capability for aircrew survival and rescue that is functional and available after emergency egress in __(1)__ environments.

REQUIREMENT RATIONALE (3.4.3.1.4)

The air vehicle should provide the aircrew with a means of survival from environments expected after emergency egress. Since rescue systems are already developed in the military, the rescue provisions must interface with existing rescue practices.

REQUIREMENT GUIDANCE (3.4.3.1.4)

The survival and rescue capability supports all crewmembers for the emergency situations and environments expected to be encountered.

Blank 1. Complete environments based on mission scenarios, system usage scenarios, specified environments, and induced environments. Consider conditions such as sustained survival, and search and rescue detection when on the ground or in the water, in extreme climatic conditions of heat and cold, etc.

This requirement does not address crash loads. Crash load requirements are identified in 3.3.10.2.1 Crash worthiness . In addition, requirements associated with emergency egress from the air vehicle are identified in 3.4.3.1.3 Emergency escape.

REQUIREMENT LESSONS LEARNED (3.4.3.1.4)

To Be Prepared

4.4.3.1.4 Aircrew survival and rescue verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Aircrew survival and rescue capability	Functional and available survival and rescue capabilities	A	A	A	A,D	A,D, T

VERIFICATION DISCUSSION (4.4.3.1.4)

Verification should ensure a survival capability at the specified environments. This will primarily consist of inspections indicating system integration with qualified survival equipment, and demonstrations or tests of equipment that must operate in environmental extremes. Verification should show that the survival capabilities are accessible and will operate to allow survival within the defined environments.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analyses of allocated requirements, and initial concept descriptions indicates the incorporation of survival provisions, and accessibility and stowage of survival equipment consistent with the specified environment.

PDR: Analyses of preliminary product definition information indicates presence of survival equipment and stowage provisions adequate for the specified environments. Analysis indicates the provisions will be functional and available after emergency egress.

CDR: Analyses of product definition information indicates presence of survival equipment and stowage provisions adequate for the defined environments. Analyses indicate the provisions will be functional and available after emergency egress.

FFR: Human factors demonstrations verify accessibility and use of survival provisions. Analyses of lower-level functional tests of survival equipment verify capability in specified environments.

SVR: Analysis of lower-level testing, demonstrations, and tests confirm that this requirement has been achieved.

Sample Final Verification Criteria

The air vehicle provided capability for aircrew survival and rescue shall be verified by __(1)__ analyses, __(2)__ demonstrations, and __(3)__ tests.

Blank 1. Identify the type and scope of analyses to be performed to support verification of the requirement. For example, analysis of lower-level test results, accessibility analyses, etc.

Blank 2. Identify the type and scope of demonstrations to be performed to support verification of the requirement. For example, human factors demonstrations, emergency egress demonstrations, cockpit mock-up demonstrations, etc.

Blank 3. Identify the type and scope of test to be performed to support verification of the requirement. For example, sled tests, survivability tests, life support integration tests, etc.

VERIFICATION LESSONS LEARNED (4.4.3.1.4)

To Be Prepared

3.4.3.1.5 Controls and displays

The air vehicle shall provide the controls and displays for operation of the air vehicle and to maintain aircrew situational awareness under all conditions encountered during the mission, such that the workload is acceptable. Primary flight data shall be displayed at all times. The Primary Flight Reference (PFR) shall be in accordance with MIL-STD-1787.

REQUIREMENT RATIONALE (3.4.3.1.5)

The aircrew must be able to effectively interface with the air vehicle controls and displays to accomplish the mission. The controls and displays need to provide the aircrew all necessary information to successfully complete the mission with an acceptable level of workload.

REQUIREMENT GUIDANCE (3.4.3.1.5)

The air vehicle controls and displays should conform to a user-centered design philosophy that is optimized for the crewmember's cognitive, perceptual and physical capabilities and limitations. The interface should enable the aircrew to efficiently accomplish all functions required to achieve the mission objectives within the expected operational environment. The air vehicle controls and displays should (1) be adaptable to the crew's current needs, in response to the dynamic mission environment; (2) provide to the crew the capability to manage multiple tasks and efficiently transition from one task to another; (3) provide to the crew the capability to manage information from on-board and off-board sensors and data sources; (4) enable the crew member to monitor the activities of automated systems, assess the state of automated systems, and intervene when necessary; (5) facilitate crew member situational awareness; and (6) alert the crew to dangerous and abnormal events and conditions.

For Air Force air vehicles, endorsement of the PFR by the AF Flight Standards Agency is required. MIL-STD-1787 provides a consistent framework of requirements to support the endorsement process.

REQUIREMENT LESSONS LEARNED (3.4.3.1.5)

The number and size of controls and displays should be determined from information and control and display analyses. Required symbol and text sizing is determined by the display distance from the design eye. The methodology for determining symbol and text size is described in MIL-HDBK-87213, Electronically/Optically Generated Airborne Displays. The larger the display, the more information can be integrated to maximize situational awareness. Situational awareness is best addressed in a full mission simulation in which all aircraft subsystems, threats, and friendly players are integrated and the avionics system and pilot encounter the maximum stressors.

4.4.3.1.5 Controls and displays verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Provide controls and displays to operate the air vehicle and maintain situational awareness with acceptable aircrew workload	Availability of interface to enable crew member completion of mission tasks, aircrew workload	A	A,S	A	A,S, D	D,T, S
PFR data always displayed and in accordance with MIL-STD-1787	PFR data availability, MIL-STD-1787 compliance	A	A,S	S,D	S,D	A,T, D,S

VERIFICATION DISCUSSION (4.4.3.1.5)

Provide controls and displays to operate the air vehicle and maintain situational awareness with acceptable aircrew workload.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis indicates requirements have been allocated properly to air vehicle subsystem requirements. Analyses of program documentation indicates that the air vehicle functional, performance and workload requirements characterize a system display and control design approach that satisfies the aircrew informational needs. Results of analyses are used to define display size and information requirements. Results of analysis are used to define planned Man-in-the-loop (MITL) simulations and define how situational awareness should be assessed. Timeline analysis ascertains that all crew tasks can be completed in the time available given the conceptual controls and displays design.

PDR: Analysis indicates controls and displays are adequate to maintain vehicle control, situational awareness, and mission accomplishment. Analyses of mission profiles have been performed and result in part-task simulations being developed. Part-task simulations indicate controls and displays enable subsystem control and indicate acceptable aircrew workload.

CDR: Full mission simulation, in which all subsystems are integrated and exercised in the context of a real mission, indicates acceptable aircrew workload and adequacy of air vehicle controls and displays for all air vehicle missions.

FFR: Analyses (including analyses of lower-level tests), and demonstrations confirm flight-critical function displays and controls are suitable for conduct of first flight. Simulations confirm that workload is satisfactory for safe conduct of first flight.

SVR: Flight tests, demonstrations, and MITL simulations updated with applicable test data confirm that the controls and displays provide the information and controls necessary to successfully perform the mission with acceptable aircrew workloads.

Sample Final Verification Criteria

Control and display provisions for control of the aircraft and maintaining situational awareness with acceptable workload, under all conditions, shall be verified by __(1)__ analyses, __(2)__ demonstration, __(3)__ simulations, and __(4)__ tests.

Blank 1. Identify the type and scope of analyses to be conducted. For example, human factors analyses, workload analyses, mission profile analyses, etc.

Blank 2. Identify the type and scope of demonstrations to be conducted. For example, mock-up demonstrations, avionics integration laboratory demonstrations, human factors demonstrations, etc.

Blank 3. Identify the type and scope of simulations to be conducted. For example, part-task, MITL, full mission, etc.

Blank 4. Identify the type and scope of test to be conducted. For example, dedicated flight tests, or piggyback test, etc.

PFR data always displayed and in accordance with MIL-STD-1787.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis indicates that the controls and displays and operational concept define how many displays (HUD, HDD, HMD, etc.) will be utilized as PFRs and in which mission segments they will be used.

PDR: Analysis of information display requirements by mission phase defines displays which will provide PFR data for each mission phase. Part-task simulation indicates PFR functionality and acceptability in accordance with MIL-STD-1787.

CDR: Full mission MITL simulation, and demonstrations indicate PFR data is displayed at all times in all mission phases and in accordance with MIL-STD-1787. Product definition information indicates that PFR information display at all times is incorporated in design.

FFR: MITL simulations, and demonstrations in an avionics integration lab, using flight representative displays and avionics, confirm that the PFR data is displayed at all times and is in accordance with MIL-STD-1787 for first flight operations.

SVR: Analyses, flight tests, demonstrations, and MITL simulations updated with applicable test data confirm PFR data is displayed at all times in all mission phases and in accordance with MIL-STD-1787.

Sample Final Verification Criteria

Continuous display of PFR data and conformance to MIL-STD-1787 shall be verified by __(1)__ analyses, __(2)__ demonstration, __(3)__ simulations, and __(4)__ tests.

Blank 1. Identify the type and scope of analyses to be conducted. For example, display analyses, mission profile analyses, etc.

Blank 2. Identify the type and scope of demonstrations to be conducted. For example, mock-up demonstrations, avionics integration laboratory demonstrations, human factors demonstrations, etc.

Blank 3. Identify the type and scope of simulations to be conducted. For example, MITL, full mission, etc.

Blank 4. Identify the type and scope of test to be conducted. For example, dedicated flight tests, or piggyback test, etc.

VERIFICATION LESSONS LEARNED (4.4.3.1.5)

With the advent of multifunction displays and advanced, integrated avionics there have been instances in which mission data is displayed on all aircraft displays at the expense of basic flight data. The first and foremost job of the pilot is to fly the aircraft. When the basic flight information is not available it is easy for the pilot to lose situational awareness and not recognize a dangerous flight condition. In terms of controls and display development programs have experienced the problem of the real software not operating in the same manner as the pilots were shown in simulation. This has caused costly redesign and/or many deficiency reports to be filed during flight test.

Operational pilots should be used as subject matter experts. Objective and subjective data should be collected to verify satisfactory workload.

3.4.3.1.6 Warnings, cautions and advisories

The air vehicle warnings, cautions, and advisories (WCA) functions shall comply with the requirements of MIL-STD-411, Aircrew Station Alerting Systems.

REQUIREMENT RATIONALE (3.4.3.1.6)

This requirement is to ensure the aircrew is provided adequate and timely information to control and react to degradation or complete loss of critical functions.

REQUIREMENT GUIDANCE (3.4.3.1.6)

To Be Prepared

REQUIREMENT LESSONS LEARNED (3.4.3.1.6)

To Be Prepared

4.4.3.1.6 Warnings, cautions and advisories verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
MIL-STD-411 WCAs	Compliance with MIL-STD-411 WCAs	A	A,I, S	S,A	A,D, T	A,D, T

VERIFICATION DISCUSSION (4.4.3.1.6)

MIL-STD-411 and JSSG handbook 2010-5 provide detailed requirements for alerts. Verification of the WCAs requirement should be accomplished by analysis of the air vehicle design and demonstration and test of the integrated caution and warning air systems. Analysis and demonstration should be used to determine responsiveness to aircrew interrogation and the ability to distinguish between signals. During air vehicle developmental activities, substantial data is typically obtained that could be used to verify this requirement.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of design concept indicates that WCAs necessary for the platform are identified. Analysis of initial crew station design concept documentation shows that all WCA messages appear in a consistent location and that dedicated warning lights have been located properly.

PDR: Analysis indicates a WCA priority scheme has been developed. Inspection of air vehicle design documentation and preliminary engineering drawings depicts system definition and display location. Simulation of both visual and auditory display design indicates WCA design requirements will be met.

CDR: Results of full mission simulations, which exercise and evaluate WCAs as introduced during routine and high workload mission segments, confirm operational effectiveness of the design. Analysis of the air vehicle design confirms compatibility of the warnings, cautions and advisories requirements with all defined aircrew operations. Analysis of lower-level tests and demonstrations confirm interrogation performance capability, nonintrusiveness of advisory signals, timeliness of warning and caution signals and the ability of the aircrew to distinguish between all provided signals.

FFR: Analysis, demonstrations, and test (system functional and ground) of the air vehicle confirm that warnings, cautions, and advisories functions are operational and appropriate for conduct of first flight.

SVR: Analysis, demonstrations, and air vehicle tests confirm that all warnings, cautions, and advisories functions are operational and distinguishable.

Sample Final Verification Criteria

The warnings, cautions and advisories (WCA) requirement shall be satisfied when __(1)__ analysis, __(2)__ demonstrations, and __(3)__ tests verify compliance with MIL-STD-411.

> Blank 1. Identify the type and scope of analysis required to provide confidence that the requirement has been satisfied.
>
> Blank 2. Identify the type and scope of demonstrations required to provide confidence that the requirement has been satisfied.
>
> Blank 3. Identify the type and scope of ground and flight tests required to provide confidence that the requirement has been satisfied.

VERIFICATION LESSONS LEARNED (4.4.3.1.6)

To Be Prepared

3.4.3.1.7 Interior vision

The air vehicle shall provide the aircrew with the interior visual capabilities necessary to perform missions specified herein. All cockpit/crew station displays and controls shall be readable in the full range of anticipated ambient lighting conditions, including day/night.

REQUIREMENT RATIONALE (3.4.3.1.7)

This requirement ensures the aircrew has proper interior visual capabilities to perform mission tasks.

REQUIREMENT GUIDANCE (3.4.3.1.7)

When required by the mission, all air vehicle visual capabilities, both external and internal, should be fully compatible with night vision imaging systems (NVIS).

REQUIREMENT LESSONS LEARNED (3.4.3.1.7)

Interior vision is extremely important to air vehicle operation. Stick and throttle design and placement are primary causes of obstruction to pilot vision of controls and displays. This is less of a problem for side stick controllers. Lighting range is also a prime consideration in any cockpit design. Lights should be bright enough to be visible at high altitudes and dim enough at night to allow dark adaptation for pilot exterior vision.

4.4.3.1.7 Interior vision verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Interior vision	Interior vision necessary for the aircrew to perform the mission(s) specified	A	A,S, D	A,I, D	D	A,D

VERIFICATION DISCUSSION (4.4.3.1.7)

Verifications of the interior vision requirements should be accomplished by integrating results of early development analysis, inspection, and simulation with demonstrations at the later stages.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis indicates that interior vision requirements for displays and controls for all crew positions, which support specified mission operations, have been established.

PDR: Analysis of the preliminary air vehicle design indicates that interior vision requirements have been allocated to the appropriate air vehicle elements. Analysis of preliminary product definition information for equipment identifies visual capability and indicates that any associated technical risks have been addressed and design tradeoffs presented for review. Analysis of vision plots, computer simulations, and demonstrations in a mock-up indicate that controls do not obstruct vision of critical displays. Analysis indicates that illumination requirements and levels for all controls, displays, and visual information have been addressed to support all missions, including use of night vision devices if required.

CDR: High fidelity mock-up demonstrations indicate that controls and any pilot-mounted equipment do not obstruct critical interior vision. Analysis and inspection of the air vehicle design and lower-level test data results indicate acceptable interior vision conditions under varying environmental conditions. Analysis of subsystem-level testing demonstrates acceptable illumination levels.

FFR: Demonstrations confirm that the air vehicle interior visibility conditions including internal lighting are supportive of first flight requirements.

SVR: Analyses (including analyses of flight test data) and demonstrations of interior visibility provisions confirm the ability of the aircrew and air vehicle to perform specified missions. Analysis of subsystem tests and the lighting mock-up confirm illumination locations and levels, as well as compatibility with other systems such as night vision devices and life support equipment.

Sample Final Verification Criteria:

The interior vision requirement, including readability of cockpit controls and displays in all day/night lighting conditions, shall be verified when __(1)__analyses and __(2)__ demonstrations confirm visual capabilities necessary to perform specified air vehicle missions.

> Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement has been met. Analysis types could include one or more of the following: analysis of lower-level interior vision testing results on new and revised equipment; and/or analysis of supporting interior vision test results.
>
> Blank 2. Identify the type and scope of demonstrations required to provide confidence that the requirement has been met. Typically, demonstrations would be done in a lighting mock-up and during ground and flight testing.

VERIFICATION LESSONS LEARNED (4.4.3.1.7)

It is important that any mock-ups accurately reflect control placement so that vision assessments can be accurately conducted. For example, some air vehicles have had problems with the center-pull control of the ejection seat obstructing the center pedestal displays.

3.4.3.1.8 Exterior vision

The air vehicle shall provide the aircrew with the exterior visual capabilities necessary to perform missions specified herein.

REQUIREMENT RATIONALE (3.4.3.1.8)

This requirement ensures that the aircrew will be provided sufficient exterior visual capabilities to perform missions specified herein. External vision requirements are different for transport and fighter aircraft.

REQUIREMENT GUIDANCE (3.4.3.1.8)

For aerial refueling operations, external visual cues (including markings, lights, etc.) may be required for the air vehicle to assist the aircrew in successfully and safely conducting their duties during the aerial refueling process. For instance, the air vehicle requirement may include refueling mast illumination light(s).

REQUIREMENT LESSONS LEARNED (3.4.3.1.8)

To Be Prepared

4.4.3.1.8 Exterior vision verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
External vision	External vision necessary for the aircrew to perform the mission(s) specified	A	D,A, S	D,A, S	D	A,D

VERIFICATION DISCUSSION (4.4.3.1.8)

Verifications of the exterior vision requirements should be accomplished by integrating results of early development analysis, inspection, and simulation with demonstrations at the later stages. For example, exterior marker, and lighting aids for aerial refueling operations should be analyzed, computer simulated, inspected and demonstrated for their effectiveness.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis indicates that exterior vision requirements, which support specified mission operations, have been established.

PDR: Analysis indicates that exterior vision requirements have been allocated to the appropriate air vehicle elements. Analysis of preliminary product definition information for equipment identifies visual capability, and indicates that any associated technical risks have been addressed and design tradeoffs presented for review. Visual plot analyses and computer simulations indicate that the design approach is appropriate for addressing the exterior vision requirement.

CDR: Demonstrations in a high fidelity mock-up indicate that the external vision required to perform the missions specified will be attained. Analyses of the design indicates appropriate exterior vision provisions for specified mission(s). Analysis of equipment product definition information identifies visual capability, and indicates that any associated technical risks have been addressed and design tradeoffs presented for review. Computer and mock-up simulation indicate the ability to achieve specified mission(s).

FFR: Demonstrations of exterior visibility capability confirm readiness for first flight.

SVR: Analyses (including analyses of flight test data) and demonstrations of exterior visibility provisions confirm the ability of the aircrew and air vehicle to perform specified missions.

Sample Final Verification Criteria

The exterior vision requirement shall be verified when __(1)__analyses and __(2)__ demonstrations confirm visual capabilities necessary to perform specified air vehicle missions.

Blank 1. Identify the type and scope of analyses to be conducted. Analysis types could include one or more of the following: analysis of lower-level exterior vision testing results on new and revised equipment, and/or analysis of supporting exterior vision test results.

Blank 2. Identify the type and scope of demonstrations to be conducted.

VERIFICATION LESSONS LEARNED (4.4.3.1.8)

To Be Prepared

3.4.3.2 Maintainer/vehicle interface

The air vehicle shall be capable of being maintained by the population of personnel with characteristics and skills representative of the job type and skill code shown in table 3.4.3.2-I and who have received system unique training and appropriate certification.

TABLE 3.4.3.2-I. Skill codes/job types of maintainers.

Job Type Name	Skill Code	Job Type Reference Source

REQUIREMENT RATIONALE (3.4.3.2)

In order to permit operation and maintenance by qualified personnel the skills of the anticipated maintainer population should be specified. This requirement specifies the flight line air vehicle maintenance and operator skills.

REQUIREMENT GUIDANCE (3.4.3.2)

Guidance for completing table 3.4.3.2-I follows:

<u>Job Type Name:</u> Enter each of the appropriate job types available for maintenance of the air vehicle. (e.g., avionics technician, jet engine mechanic, hydraulics technician, etc.).

<u>Skill Code:</u> Enter the appropriate code. (e.g., Air Force specialty code (AFSC), Navy enlisted classification (NEC), military occupational specialty (MOS), etc.).

<u>Job Type Reference Source:</u> Enter the name of the document that describes the skill code (e.g., NAVPERS 18068D).

REQUIREMENT LESSONS LEARNED (3.4.3.2)

To Be Prepared

4.4.3.2 Maintainer/vehicle interface verification

Requirements Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Air vehicle maintainable with personnel with the skill codes specified	Air vehicle maintenance performed with specified skilled personnel	A	A	A		A,D

VERIFICATION DISCUSSION (4.4.3.2)

Verification of the maintainer/vehicle interface requirement should be accomplished by examining the skill level and codes required of the maintenance personnel to service and repair the air vehicle. The personnel required to maintain the air vehicle will have a combination of experience and training that relate to the air vehicle. A mix of specialty codes is normally required to offer full service to the air vehicle.

This requirement provides maintainer interface information that must be considered in developing all air vehicle maintenance requirements and verifications. The verification approach defined below assumes that the air vehicle maintainer/vehicle interface performance should be verified via the specific verifications specified elsewhere.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis indicates that maintainer/vehicle interface skill definitions are understood and are addressed in other air vehicle maintenance requirements and flowed to lower-level requirements.

PDR: Analyses of preliminary air vehicle design indicates that the specified mix of skill codes is being considered and is capable of maintaining the air vehicle.

CDR: Analyses of final design confirms that the specified mix of skill codes is capable of maintaining the air vehicle.

FFR: Maintainer/vehicle interface is not a factor that relates to the FFR of the air vehicle. Typically, maintenance for the first flight is performed by the air vehicle developer.

SVR: Analyses incorporating data from lower-level demonstrations and maintenance actions performed, and air vehicle demonstrations confirm that the air vehicle is capable of being maintained by the skill code specialties specified.

Sample Final Verification Criteria

__(1)__ analyses and __(2)__ demonstrations confirm the air vehicle can be maintained by personnel with the job type and skill codes specified in table 3.4.3.2-I.

> Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement has been satisfied.
>
> Blank 2. Identify the type and scope of demonstrations required to provide confidence that the requirement has been satisfied.

VERIFICATION LESSONS LEARNED (4.4.3.2)

Various factors are all considered in the selection of the proper skills required to maintain the air vehicle. These include level of maintenance specified, degree of built-in prognostics and diagnostics, level of detail in the technical manuals, and the degree of contractor maintenance involvement. Verification of these skills takes a multitude of actions and normally should be accomplished over a long testing period in which the government performs the maintenance or at least aids the contractor during this period of time.

3.4.3.2.1 Air vehicle states

The air vehicle shall facilitate or enable the maintainer to transition the air vehicle between the following three principal states:

a. Air vehicle power off and air vehicle secured;

b. Air vehicle in maintenance or servicing mode. In this state the air vehicle may not be fully powered; and

c. Air vehicle in fully operational mode including associated servicing and associated maintenance tasks to be accomplished while in fully operational state such as the integrated combat turn and those of routine maintenance activity.

REQUIREMENT RATIONALE (3.4.3.2.1)

This requirement will ensure the maintainer will be capable of transitioning the air vehicle between all required states experienced during maintenance and operations.

REQUIREMENT GUIDANCE (3.4.3.2.1)

To Be Prepared

REQUIREMENT LESSONS LEARNED (3.4.3.2.1)

To Be Prepared

4.4.3.2.1 Air vehicle states verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Air vehicle to maintainer interface for transitioning air vehicle between principal states	Capability for maintainer to transition air vehicle between: Power OFF and air vehicle secured (Y/N) Power ON for maintenance or service (Y/N) Fully operational (Y/N)	A	A	A	A	A,D

VERIFICATION DISCUSSION (4.4.3.2.1)

Verification of the requirement for air vehicle states should be accomplished by integrating analysis with demonstrations of the air vehicle state transitions required during maintainer operations. During air vehicle developmental activities, substantial data is typically obtained that could be used to verify this requirement. Use of this type of data should be maximized to avoid the cost and schedule impacts of a formal demonstration.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis indicates that requirements for air vehicle states are defined and understood. Analysis indicates the design concept considers all air vehicle states transition requirements in support of maintenance and servicing operations.

PDR: Analysis of the air vehicle preliminary design indicates that the air vehicle states can be effectively transitioned by the maintainer in support of maintenance and servicing operations.

CDR: Analysis of the air vehicle design indicates that the air vehicle states can be transitioned by the maintainer in support of maintenance and servicing operations.

FFR: Air vehicle states transition in support of maintainer operations is not typically a factor for FFR since maintenance for the first flight is usually performed by the air vehicle developer. Analysis confirms air vehicle state transitions to be performed for first flight are supportive of first flight maintenance and servicing requirements.

SVR: Analysis and demonstration confirms that the air vehicle states can be transitioned by the maintainer in support of all maintainer operations.

Sample Final Verification Criteria

The air vehicle states requirement shall be satisfied when __(1)__ analyses and __(2)__ demonstrations confirm that the air vehicle can be transitioned by the maintainer between the specified states.

> Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement element has been met.
>
> Blank 2. Identify the type and scope of demonstrations required to provide confidence that the requirement element has been met.

VERIFICATION LESSONS LEARNED (4.4.3.2.1)

To Be Prepared

3.4.3.2.1.1 Maintainer/aircrew communication

The air vehicle shall provide a means of establishing intelligible communication between the air vehicle and maintainers during ground and shipboard deck operations. Such communication capability shall allow the maintainer free movement about the area of the air vehicle without causing hazard, disorientation or otherwise detracting from the maintainer’s capability.

REQUIREMENT RATIONALE (3.4.3.2.1.1)

This requirement ensures the maintainer will be capable of communicating with the air vehicle during maintenance and servicing activities.

REQUIREMENT GUIDANCE (3.4.3.2.1.1)

To Be Prepared

REQUIREMENT LESSONS LEARNED (3.4.3.2.1.1)

To Be Prepared

4.4.3.2.1.1 Maintainer/aircrew communication verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Air vehicle to maintainer communication capability	Communication capability is ▪ Intelligible (Y/N) ▪ Allows free maintainer movement (Y/N) ▪ Hazard free (Y/N)	A	A	A		A,D

VERIFICATION DISCUSSION (4.4.3.2.1.1)

Verification of the maintainer/aircrew communication requirement should be accomplished through analysis and demonstration of specified maintenance personnel to aircrew communications as various maintenance actions are performed. During air vehicle developmental activities, substantial data is typically obtained that could be used to verify this requirement. Use of this type of data should be maximized to avoid the cost and schedule impacts of a formal demonstration.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of design concept indicates that maintainer/aircrew communication requirements are understood, and are addressed and flowed to lower-level requirements.

PDR: Analysis of the preliminary design indicates that the specified maintainer/aircrew communications capability is supportive of the maintainer to air vehicle functions for ground and/or shipboard operations and allows free and hazard free maintainer movement.

CDR: Analysis of final design confirms that the specified maintainer/aircrew communications are intelligible and allow a full range of hazard free maintainer movement that is required for the performance of all maintainer functions.

FFR: Air vehicle to maintainer communications is not a factor that relates to FFR, since typically, maintenance for the first flight is performed by the air vehicle developer. Analysis confirms air vehicle to maintainer communications are functional to support first flight.

SVR: Analyses incorporating data from lower-level demonstrations, and demonstrations of maintainer functions performed during ground and shipboard operations, confirm that the air vehicle maintenance function is fully supported by the air vehicle maintainer/aircrew communications.

Sample Final Verification Criteria

The maintainer/aircrew communication requirement shall be satisfied when __(1)__ analyses and __(2)__ demonstrations confirm that the maintainer/aircrew communications fully meet the requirements of intelligibility and the need for hazard free maintainer movement.

Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement has been satisfied.

Blank 2. Identify the type and scope of demonstrations required to provide confidence that the requirement has been satisfied.

VERIFICATION LESSONS LEARNED (4.4.3.2.1.1)

To Be Prepared

3.4.3.2.1.2 Air vehicle stabilization

The maintainer shall be able to stabilize the air vehicle and shall be provided a means for confirming that the air vehicle is stable.

REQUIREMENT RATIONALE (3.4.3.2.1.2)

This requirement establishes that the air vehicle should be capable of being stabilized, that is held securely in place to preclude motion during maintenance and servicing operations and should provide indication to all affected maintenance crew that the air vehicle is in such secured state. Said secured state includes motion of air vehicle and its appendages in both the horizontal and vertical planes.

REQUIREMENT GUIDANCE (3.4.3.2.1.2)

To Be Prepared

REQUIREMENT LESSONS LEARNED (3.4.3.2.1.2)

To Be Prepared

4.4.3.2.1.2 Air vehicle stabilization verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Stabilization provisions	Stabilization capability provided (Y/N)	A	A	A	D	A,D
Stabilization indication	Means of confirming stabilization provided (Y/N)	A	A	A	D	A,D

VERIFICATION DISCUSSION (4.4.3.2.1.2)

Verification of the air vehicle stabilization requirement should be accomplished by integrating analysis with demonstrations of operation and compatibility of the stabilization provisions with the air vehicle and related maintenance actions. During air vehicle developmental activities, substantial data is typically obtained that could be used to verify this requirement. Use of this type of data should be maximized to avoid the cost and schedule impacts of a formal demonstration.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements specified in the verification table.)

SRR/SFR: Analysis of the conceptual design of the air vehicle indicates that planned maintenance concept and any unique requirements of the air vehicle that would tend to inhibit the required stabilization state requirements are defined and understood. Preliminary analysis indicates the design approach is considering all maintenance state requirements.

PDR: Analysis of the preliminary air vehicle design indicates that the air vehicle stabilization design is compatible with the requirements of the maintainer actions.

CDR: Analysis confirms the air vehicle design is compatible with the Air Vehicle Stabilization requirement. Any areas of incompatibility that dictate a unique design have been thoroughly researched, and results of trade study decisions are presented for review.

FFR: Demonstrations of pre-flight, post-flight, and all developer maintenance actions checklists which are required for conduct of first flight confirm the air vehicle provides the specified stability and stability indications.

SVR: Analysis of the design, and operational demonstrations of air vehicle stabilization provisions confirm the air vehicle stabilization, and indications of air vehicle stabilization, are compatible with all specified maintainer actions.

Sample Final Verification Criteria

The aircraft stabilization requirements shall be satisfied if __(1)__analyses and __(2)__operational maintainer demonstrations confirm that the stabilization requirements have been met.

> Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement has been satisfied.

Blank 2. Identify the type and scope of demonstrations required to provide confidence that the requirement has been satisfied. Include the essential maintenance actions that must be verified by demonstration, in lieu of analysis.

VERIFICATION LESSONS LEARNED (4.4.3.2.1.2)

To Be Prepared

3.4.3.2.1.3 Maintainer/vehicle interface authorization

The air vehicle shall authorize the maintainer access to the air vehicle for the purposes of servicing and/or maintenance in accordance with the authority granted said maintainer.

REQUIREMENT RATIONALE (3.4.3.2.1.3)

This requirement is to ensure the air vehicle can interface with the maintainer in such a fashion to ensure only authorized personnel have access to the air vehicle.

REQUIREMENT GUIDANCE (3.4.3.2.1.3)

This requirement may need to be expanded to address limiting access to specific maintainers to perform specific jobs. In other words, a maintainer only gets access to those portions of the air vehicle necessary to perform authorized maintenance or servicing task. This may also necessitate an independent air vehicle interface to some element of the support system that tracks jobs that need to be done on the air vehicle and the access authorizations of individual maintainers.

REQUIREMENT LESSONS LEARNED (3.4.3.2.1.3)

To Be Prepared

4.4.3.2.1.3 Maintainer/vehicle interface authorization verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Maintainer to vehicle access control	Maintainer access with granted authority (Y/N)	A	A	A		A,D

VERIFICATION DISCUSSION (4.4.3.2.1.3)

Verification of the requirement for maintainer/vehicle interface authorization should be accomplished by integrating analysis with demonstrations of the air vehicle to maintainer interface controls. During air vehicle developmental activities, substantial data is typically obtained that could be used to verify this requirement. Use of this type of data should be maximized to avoid the cost and schedule impacts of a formal demonstration.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the air vehicle design concept indicates that air vehicle to maintainer interface authorization requirements have been addressed.

PDR: Analysis of the air vehicle preliminary design indicates the access control functionality addresses the full range of maintainer interface requirements.

CDR: Analysis of the air vehicle design indicates the access control functionality addresses the full range of maintainer interface requirements. Any area of incompatibility has been thoroughly researched, and results of trade study decisions are presented for review.

FFR: No unique verification action occurs at this milestone.

SVR: Analysis and demonstrations of maintainer air vehicle interface confirm air vehicle authorization for access control and compatibility with all maintainer access requirements.

Sample Final Verification Criteria

The maintainer air vehicle interface authorization requirement shall be satisfied when __(1)__ analyses and __(2)__demonstrations confirm interface and access control.

> Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement element has been met.
>
> Blank 2. Identify the type and scope of demonstrations required to provide confidence that the requirement element has been met.

VERIFICATION LESSONS LEARNED (4.4.3.2.1.3)

To Be Prepared

3.4.3.2.1.4 Diagnostic function interface

The air vehicle shall provide the maintainer a means of confirming that the proper series of tasks required to power-on the air vehicle to a fully operational state, and power-off the air vehicle to a secure state have been accomplished. Additionally, the air vehicle shall present to the maintainer the data necessary to service the air vehicle between flights. This data shall include the nature and content of the consumable to be restored, removed, or added prior to enabling the air vehicle to resume operation.

REQUIREMENT RATIONALE (3.4.3.2.1.4)

This requirement ensures that the maintainer can safely apply power to the air vehicle, that the air vehicle is properly shutdown prior to servicing, and that all servicing related conditions of the air vehicle are presented to the maintainer.

REQUIREMENT GUIDANCE (3.4.3.2.1.4)

When developing this requirement, consideration should be given to ensuring complete data is presented to the maintainer in a logical sequence that enables proper start-up, shutdown, and servicing of the air vehicle.

REQUIREMENT LESSONS LEARNED (3.4.3.2.1.4)

Many electronics require proper shutdown in order that they start-up in the proper mode. Sometimes an out of sequence shutdown occurs that requires avionics to be reset prior to start-up.

4.4.3.2.1.4 Diagnostic function interface verification

(Note: The verifications of 3.4.3.2.1.4.1 Power-off transition, 3.4.3.2.1.4.2 Power-on transition, and 33.4.3.2.1.4.3 Servicing indications are also included in this paragraph.)

Requirement Elements	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Power-on	Safe to power-on sequence indicators displayed	A	A	A	A	A,D
Power-off	Steps to power-off sequence indicators displayed	A	A	A	A	A,D
Servicing indications	Status of critical systems displayed and levels of consumables displayed	A	A	A	A	A,D

VERIFICATION DISCUSSION (4.4.3.2.1.4)

Verification of the Diagnostic Function Interface requirement should be accomplished by integrating analysis with demonstrations of the indicators provided by the air vehicle. During air vehicle development activities, the methodology and design details are presented that indicate the degree to which indicators are prevalent and the sequence of events that take place during the power-on, power-off, and servicing phases of the air vehicle mission.

Key Development Activities

Key activities include, but are not limited to the following efforts for any given milestone.

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: No unique verification action occurs at this milestone.

PDR: Sequence of tasks to power on, power off and service the air vehicle have been initially identified and a means to provide these tasks and their status at the maintenance interface are included in the preliminary design.

CDR: Sequence of tasks to power on, power off and service the air vehicle have been identified and a means to provide these tasks and their status at the maintenance interface are included in the design.

FFR: No unique verification action occurs at this milestone.

SVR: That diagnostics interface properly indicates the status of the power-on and power-off transitions and the servicing requirements under all air vehicle conditions, which can impact said transitions or servicing, should be demonstrated.

Sample Final Verification Criteria

__(1)__ analyses and demonstrations shall be performed to verify that the air vehicle diagnostics interface properly indicates the status of the power-on and power-off transitions and the servicing requirements under all air vehicle conditions, which can impact said transitions or servicing. Servicing indicators shall be presented to the maintainer in unambiguous terms and verified through __(2)__ demonstrations.

Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement elements have been satisfied.

Blank 2. Identify the type and scope of demonstrations required to provide confidence that the requirement elements have been satisfied.

VERIFICATION LESSONS LEARNED (4.4.3.2.1.4)

To Be Prepared

3.4.3.2.1.4.1 Power-off transition

During the transition from a power-on to a power-off/secure state of the air vehicle, the maintainer shall be presented data indicating that all hardware elements are ready for shutdown, no external utility devices are connected to the air vehicle, and power-off has been accomplished. If, for any reason, the described transition cannot be accomplished, indication of such shall be presented to the maintainer and direction shall be provided so that the secure state of the air vehicle can be achieved and confirmed.

REQUIREMENT RATIONALE (3.4.3.2.1.4.1)

This requirement is to ensure the maintainer is provided with the data necessary to execute power-off transition.

REQUIREMENT GUIDANCE (3.4.3.2.1.4.1)

To Be Prepared

REQUIREMENT LESSONS LEARNED (3.4.3.2.1.4.1)

To Be Prepared

4.4.3.2.1.4.1 Power-off transition

Verification for this requirement is included with 3.4.3.2.1.4 Diagnostic function interface.

3.4.3.2.1.4.2 Power-on transition

During the transition from a power-off/secure state to a power-on, fully operational state, the maintainer shall be presented data indicating the power-on sequence (where the maintainer is required to control all or any part of the sequence), the presence of external utility devices, and the presence or absence of any configuration elements which create a hazard, and the condition of each function as it achieves operational status. If, for any reason, the described transition cannot be accomplished, indication of such shall be presented to the maintainer and direction shall be provided so that the power-on state of the air vehicle can be achieved and confirmed.

REQUIREMENT RATIONALE (3.4.3.2.1.4.2)

This requirement is to ensure the maintainer is provided with the data necessary to execute power-on transition.

REQUIREMENT GUIDANCE (3.4.3.2.1.4.2)

To Be Prepared

REQUIREMENT LESSONS LEARNED (3.4.3.2.1.4.2)

To Be Prepared

4.4.3.2.1.4.2 Power-on transition verification

Verification for this requirement is included with 3.4.3.2.1.4 Diagnostic function interface.

3.4.3.2.1.4.3 Servicing indications

The air vehicle shall provide the maintainer that data necessary to service the air vehicle between flights and at power-on. Said data presentation shall be unambiguous and shall provide the nature and content of the consumable to be restored, removed, or added prior to enabling the air vehicle to resume operation. Additionally, the air vehicle shall provide data, which defines the functional state of the vehicle, and if degraded modes or loss of function conditions exist, the data describing functional loss or degradation and the discrepant equipment(s) or component(s) shall be presented.

REQUIREMENT RATIONALE (3.4.3.2.1.4.3)

To ensure the maintainer is provided with the data necessary to accomplish servicing.

REQUIREMENT GUIDANCE (3.4.3.2.1.4.3)

To Be Prepared

REQUIREMENT LESSONS LEARNED (3.4.3.2.1.4.3)

To Be Prepared

4.4.3.2.1.4.3 Servicing indications verification

Verification for this requirement is included with 3.4.3.2.1.4 Diagnostic function interface.

3.4.3.2.1.5 Servicing interfaces

The air vehicle shall be capable of being serviced by __(1)__ percentile females through the __(2)__ percentile males utilizing __(3)__.

REQUIREMENT RATIONALE (3.4.3.2.1.5)

The requirement will ensure the air vehicle is designed to be serviced by the maintenance population and will provide the maintainer with feedback regarding servicing status. The air vehicle should be designed to be maintainable by the widest segment of the population as possible. Standing height is normally the anthropometric measure that is specified as other related measures, i.e., reach, can be found in the Air Force Research Laboratory anthropometric database.

REQUIREMENT GUIDANCE (3.4.3.2.1.5)

Blanks 1 and 2. Typically complete blank 1 with 5^{th} and blank 2 with 95^{th}.

Blank 3. Complete with appropriate support equipment listed in 3.4.9 Support equipment interface or ‘no external support equipment as the maintenance concept dictates. This requirement may be modified if there is a need to monitor the servicing process.

REQUIREMENT LESSONS LEARNED (3.4.3.2.1.5)

Where the design of the aircraft requires connections of any auxiliary equipment such as intercoms, auxiliary power units, and/or portable refueling panels, an indication should be presented to the maintainer that the connection is made and should convey identification, feedback and status of the fuel transmission to the maintainer without the assistance of the fuel servicing equipment operator, or from any person acting in the capacity of fuel service equipment operator. If fire suppression equipment is required to be located within the area of fuel servicing operations, the maintainer should be provided a means of identifying to the fuel transmitting function that the equipment has been provided. The control to be used for that function should preclude the onset of fuel transmission until the maintainer has so authorized.

If the air vehicle requires that gases or liquids be used in pressure-operated equipment to expel other gases from storage containers, actuators, or for purging tubes and lines, the maintainer should be provided with a means of observing and controlling the transmissions at the point of service on the aircraft. The maintainer should be provided a go/no go indication, by some means, that gas/fluids servicing of any kind or for any reason has satisfactorily transpired. A similar requirement should exist for the transmission of all other aircraft fluids, i.e., hydraulic/environmental fluids, for which the maintainer will have the servicing responsibility. Exterior access servicing ports, which must be accessed before and/or after each sortie, should be covered by doors or panels designed for access manual or actuated, in less than (TBD) seconds/minutes. The number and diversity of panel/door fasteners should be the minimum required to comply with air vehicle requirements for stress, bonding, pressurization, shielding, thermal temperature, and safety and should not require special tools for access. The type of fluids to be used, the frequency of servicing and the procedures should be specified and indicated by some means to the maintainer on demand,

and within the time frames for aircraft turnarounds as required herein. Such indication should not require the maintainer to interpret fluid levels feedback beyond a go/no go presentation.

If inflation of aircraft tires is to be performed by the maintainer, the on-equipment service point should be designed so that servicing can only be initiated from the least hazardous position in or about the area. The crew chief/maintainer must be provided a means of establishing 1) the amount and type of servicing required, and 2) acceptable completion of servicing vis a vis go/no-go symbology. The interface between the tire and the inflation service should enable hands-free operation, should not require interpretation beyond the go/no go indication, and should be obvious in low ambient light and in high ambient noise (up to 100 dB(A)).

4.4.3.2.1.5 Servicing interfaces verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Capability of air vehicle servicing by the specified population	Service performed, given (1), (2), (3)	A	A	A,S, D		A,S, D

*Numbers in parentheses in the Measurand column refer to numbered blanks in the requirement.

VERIFICATION DISCUSSION (4.4.3.2.1.5)

To Be Prepared

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis indicates that the specified population and support equipment have been addressed in the maintenance concept for air vehicle and flowed down to lower-level elements. Analysis indicates consideration has been given to any protective gear the maintainers will be wearing.

PDR: Analyses indicate that servicing is achievable for the air vehicle given the specified maintainer population and support equipment. Analysis indicates consideration has been given to any protective gear the maintainers will be wearing.

CDR: Analyses and simulation indicate that servicing is achievable for the air vehicle given the specified population and support equipment considering any protective gear the maintainers will be wearing. Analyses of product definition information indicates equipment compatibility with the specified maintainer population and air vehicle configuration. Demonstrations with mock-ups or initial components, if required, indicate compatibility with the air vehicle.

FFR: No unique verification action occurs at this milestone. Typically, the developer services the air vehicle for first flight.

SVR: Analyses (including analyses of normal servicing during flight test), simulations and demonstrations confirm servicing is achievable for the air vehicle given the specified maintainer population (including required protective gear) and specified support equipment.

Sample Final Verification Criteria

The capability of the air vehicle to be serviced by the specified maintainer population and support equipment shall be verified by __(1)__ analyses, __(2)__ simulation, and __(3)__ demonstration.

Blank 1. Identify the type and scope of analyses to be conducted. For example, dimensional analyses, human factors analyses, etc.

Blank 2. Identify the type and scope of simulations to be conducted. For example, three dimensional full scale modeling.

Blank 3. Identify the type and scope of demonstrations to be conducted. For example, mock-up demonstrations, maintainability demonstrations, human factors demonstrations, etc.

VERIFICATION LESSONS LEARNED (4.4.3.2.1.5)

To Be Prepared

3.4.3.2.1.5.1 Stores loading

Stores stations shall be directly accessible to the __(1)__ percentile females through the __(2)__ percentile males of the maintenance personnel population __(3)__ the use of stands, ladders, or step stools, and who may be wearing CBR or cold weather protective clothing. The maintainer shall be provided a means of precluding accidental arming/firing of munitions during the uploading activity. Single point safing for both electrical and mechanical arming systems shall be provided and an indication shall be presented to the maintainer that the safed condition has been obtained. Such indication shall be an unambiguous go/no-go type visually detectable from __(4)__ feet by the unaided, but visually corrected, __(5)__ percentile male/female maintainer in low ambient light conditions and wearing chemical biological protection or cold weather protective gear. Removal and installation of fuses on loaded stores shall be possible.

REQUIREMENT RATIONALE (3.4.3.2.1.5.1)

This requirement is to ensure the air vehicle is designed to enable stores loading, safing and alignment by maintenance personnel.

REQUIREMENT GUIDANCE (3.4.3.2.1.5.1)

Blanks 1 and 2. Typically complete blank 1 with 5th and blank 2 with 95th.

Blank 3. Complete with "with" or "without" as the maintenance concept dictates.

Blanks 4 and 5. Typically complete blank 4 with 100 and complete blank 5 with 5th.

REQUIREMENT LESSONS LEARNED (3.4.3.2.1.5.1)

To Be Prepared

4.4.3.2.1.5.1 Stores loading verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Store station accessibility	(1), (2)	I,A	A	A	A	A
Preclude accidental arming/firing of munitions/single point safing	Means for precluding accidental arming/firing of munitions	I,A	A	A	A,T	D
Unambiguous go/no-go indication	(4), (5)	I,A	A	A	A,D	D

*Numbers in parentheses in the Measurand column refer to numbered blanks in the requirement.

VERIFICATION DISCUSSION (4.4.3.2.1.5.1)

Computer modeling should be used early in the development process to ensure that stores loading can be successfully accomplished. Computer modeling will show whether clearances are adequate for warfighter access and vision, as well as any limitations for support equipment.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Critical stores loading tasks have been identified. Incorporation of computer modeling of maintainer anthropometric models and stores loading tasks has been planned for analysis. Analysis indicates the unambiguous go/no-go capability has been included in the planning.

PDR: Stores loading tasks have been analyzed using initial computer modeling with the maintainer anthropometric data and indicates that the maintainer can access all store stations and safing points. Analysis of initial design data indicates that single point safing capability will be provided to the maintainer and that the go/no-go indication will be visible to the maintainer population specified. FMECA should include analysis of the single point safing capability.

CDR: Stores loading tasks have been analyzed using updated computer modeling with the maintainer anthropometric data and confirms that the maintainer can access all store stations and safing points. Computer models include maintainer anthropometric data with the maintainer in the appropriate protective gear. Analysis of updated design data confirms that single point safing capability will be provided to the maintainer and that the go/no-go indication will be visible to the maintainer population specified. FMECA should include analysis of the single point safing capability.

FFR: Analysis of computer modeling confirms that maintainer can access all store stations and safing points and that the go/no-go indication is visible. Stores loading tasks have been successfully demonstrated on the actual aircraft prior to first flight of the aircraft that is used for stores carriage/separation testing. Analysis/testing confirms that the safing capability is functional.

SVR: Analyses of design and development data (including results from flight test programs) confirm that any known instances in which store stations and safing points are inaccessible to maintenance personnel have been corrected by product definition change. Capability for maintenance personnel to safe munitions during the loading process is confirmed via demonstration. Visibility of the go/no-go indication to the maintenance population is confirmed via demonstration.

Sample Final Verification Criteria

The stores loading requirement shall be satisfied when __(1)__ analyses, __(2)__ simulations, and __(3)__ demonstrations confirm specified performance is achieved.

Blank 1. Identify the type and scope of analyses to be conducted. For example, analysis shall be performed to confirm that all known instances in which stores stations are inaccessible to the maintainer population have been eliminated.

Blank 2. Identify the type and scope of simulations to be conducted.

Blank 3. Identify the type and scope of demonstrations to be conducted. For example, demonstrations of the single point safing capability confirm that the maintainer can preclude accidental arming/firing of munitions, and the presence of an unambiguous go/no-go indication that is visible to the maintainer population.

VERIFICATION LESSONS LEARNED (4.4.3.2.1.5.1)

F-22 weapons loading demonstrations in the main bays showed that weapons bay lighting was required due to the close quarters in the bays and the proximity of the bay doors to the ground.

Sneak circuit analysis has been a successful method for verifying the functionality of the single point safing capability.

Demonstration has been required on past developmental programs for critical stores loading tasks when computer models could not adequately emulate the restrictions to mobility and vision that warfighter protective gear imposes and where equipment is located close together or where visual access has been severely limited (or blind).

3.4.3.2.1.5.2 Certifying the air vehicle for flight

The air vehicle shall provide the maintainer a means of confirming that the proper series of tasks required to restore the air vehicle to a mission-ready status as a consequence of turnaround, start-up, or following corrective action, have occurred prior to its release for launch. The air vehicle shall permit the maintainer to input the relevant data points required by the flight log, and to receive verification from the air vehicle that the air vehicle is prepared for flight. The maintainer shall be able to perform the function of confirming the air vehicle is ready for flight through some means that does not require entry into the cockpit. The ready for flight indication shall be stored aboard the air vehicle at all times and be available at the maintenance interface.

REQUIREMENT RATIONALE (3.4.3.2.1.5.2)

This requirement ensures the maintainer can confirm that the air vehicle is ready for flight after servicing and/or repair, and retains evidence of such confirmation with both the air vehicle and on-ground maintenance resources.

REQUIREMENT GUIDANCE (3.4.3.2.1.5.2)

When developing this requirement, consideration should be given to ensuring the maintenance interface will enable the maintainer to confirm the air vehicle ready for flight in time to support the turnaround and alert time requirements specified elsewhere in the specification.

REQUIREMENT LESSONS LEARNED (3.4.3.2.1.5.2)

To Be Prepared

4.4.3.2.1.5.2 Certifying the air vehicle for flight verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Mission ready status provided to maintainer	Mission ready status data available	A	A	A	A,D	A,D
Air vehicle enables maintainer to confirm that air vehicle is ready for flight without entry into cockpit	Ready for flight indication provided external to cockpit	A	A	A	A	A,D
Ready for flight confirmation record retained on aircraft and available at maintenance interface	Ready for flight confirmation record available	A	A	A	A	A,D

VERIFICATION DISCUSSION (4.4.3.2.1.5.2)

Verification of this requirement should be accomplished by integrating analysis with demonstrations of the method the maintainer utilizes to ensure and document that the air vehicle is ready for flight (all corrective actions taken, preventive maintenance performed, servicing accomplished, etc.).

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Mission profiles, maintenance concept, and any unique requirement of the air vehicle that would tend to create a lengthy time for confirming the air vehicle is ready for flight are defined. Requirements for recording and displaying the data necessary to confirm the air vehicle ready for flight are understood.

PDR: Analysis of the preliminary air vehicle design indicates compatibility with the requirement to enable the maintainer to confirm the air vehicle is ready for flight without entry into the cockpit. Preliminary analysis indicates that the air vehicle will enable retention of the ready for flight confirmation record.

CDR: Analysis of the final air vehicle design confirms the design is compatible with the requirement to enable the maintainer to confirm the air vehicle is ready for flight without entry into the cockpit. Analysis confirms that the air vehicle will enable retention of the ready for flight confirmation record. Any lengthy or unusual ready for flight procedures have been thoroughly researched, and trade-offs.

FFR: Analysis and demonstration confirms that data required for the air vehicle is ready for flight is provided at the maintenance interface and that the ready for flight confirmation record is retained and available both on aircraft and at the maintenance interface.

SVR: All appropriate analyses and demonstrations have been accomplished that confirm the air vehicle is capable of presenting to the maintainer the data required to confirm the air vehicle is ready for flight, the data is available both on the air vehicle and at the maintenance interface, and the ready for flight confirmation does not have to take place in the cockpit. Demonstration has been accomplished that a record of ready for flight confirmation is available both on air vehicle and at the maintenance interface.

Sample Final Verification Criteria

__(1)__ analyses and __(2)__ demonstration shall be performed to verify that the air vehicle enables the maintainer to confirm the mission ready status of the air vehicle and that the maintainer can input/access data on air vehicle flight readiness without entry into the cockpit. The retention of the ready for flight confirmation record both on the air vehicle and at the maintenance interface shall be verified by __(3)__ demonstrations.

> Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement elements have been satisfied.
>
> Blanks 2 and 3. Identify the type and scope of demonstrations required to provide confidence that the requirement elements have been satisfied.

VERIFICATION LESSONS LEARNED (4.4.3.2.1.5.2)

To Be Prepared

3.4.3.2.1.6 Maintenance interface

3.4.3.2.1.6.1 Accessibility

The air vehicle shall provide for maintenance technicians wearing CBR or cold weather protective clothing to be able to remove, replace and/or repair removable components, assemblies and subassemblies without compromising the effectiveness of the protective gear being worn. The air vehicle shall enable removal of any flight line replaceable item without disassembly of the primary load bearing structure. The air vehicle shall provide the maintainer with unobstructed physical and visual access to any indicators or data ports on equipment items requiring maintenance actions.

REQUIREMENT RATIONALE (3.4.3.2.1.6.1)

This requirement will ensure maintenance personnel have adequate access to safely perform maintenance task(s).

REQUIREMENT GUIDANCE (3.4.3.2.1.6.1)

To Be Prepared

REQUIREMENT LESSONS LEARNED (3.4.3.2.1.6.1)

To Be Prepared

4.4.3.2.1.6.1 Accessibility verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Air vehicle is maintainable while wearing CBR or cold weather protective clothing	Pass/Fail	A	A,I, S	A		A,S, D
Removal of flight line replaceable items without disassembly of the primary load bearing structure	Pass/Fail	A	A	A,S		A,S, D
Unobstructed physical and visual access to any indicators or data ports on equipment items requiring maintenance actions	Pass/Fail	A	A	A,S		A,S, D

VERIFICATION DISCUSSION (4.4.3.2.1.6.1)

Accessibility incremental verification is achieved through a structured set of efforts/tasks designed to provide the necessary level of insight into the attributes of the design, and the design refinement process. Key activities include, but are not limited to, accessibility analysis/modeling based on frequency of access (scheduled maintenance activities, hardware durability and life estimates, reliability predictions, inspection and operations related activities) and maintenance time (based on a time line analysis performed for major tasks) to include human factors lift restrictions. The verification of adequate clearances and large enough grasping areas is a major factor in assuring that the system will be capable of meeting its required availability requirements with the assigned maintenance personnel in protective attire. The ability to model systems in three dimensions and check for fit has progressed to the point that simulations and modeling is becoming an increasingly viable method of verifying this requirement. During assembly, developmental test, and remove and replace activities substantial data is typically obtained that could be used to verify this requirement. Use of this type of data should be maximized to avoid the cost and schedule impacts of a formal demonstration.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analysis of the design concept indicates that: accessibility requirements have been addressed; the maintenance tasks are understood; and subsystem requirements are allocated to enable maintenance accomplishment. Analysis of the design concept indicates that appropriate features are incorporated to enable maintenance without damage to protective gear. Inspection of air vehicle analyses and specifications indicate that accessibility, repair and repair/replacement with maintenance protective gear has been factored into the systems engineering process. Consensus has been reached on methods used to verify/validate accessibility at program milestones. Verification demonstration methods and acceptance criteria based on the verification methods established are incorporated into the design process, schedules, facilities requirements, manpower needs, and other programmatic imperatives.

PDR: Analyses and inspections of the preliminary design and lower-tier specifications indicate applicable lower-tier requirements have been derived. Analyses of the preliminary design indicate that the maintenance accessibility requirement will be met. Simulation models and analyses have been updated to assess interfaces (i.e., edges, space, lighting), equipment for maintenance accomplishment, and changes in reliability, accessibility, and integrity. Accessibility analysis is updated to include subcontractor information.

CDR: Analyses and inspections of detailed design information and updated lower-level test/simulation/demonstration data confirm the specified accessibility requirements are met. Analyses of the final design using accessibility analysis/modeling/simulation to assess the interfaces/equipment/access frequency necessary to allow maintenance to accomplish their mission. Accessibility analysis/modeling confirms the latest updates to reliability, maintainability, integrity, and maintenance concepts are included.

FFR: No unique verification action occurs at this milestone.

SVR: Analysis of maintenance actions, modeling/simulations, and demonstrations confirm that the accessibility requirements have been met.

Sample Final Verification Criteria

The accessibility requirement shall be satisfied when __(1)__ analyses, __(2)__ simulations, and __(3)__ demonstrations confirm specified performance is achieved.

> Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement has been satisfied.

Blank 2. Identify the type and scope of simulation(s) required to provide confidence that the requirement has been satisfied. Simulations may rely on computer modeling to confirm accessibility into most of the areas of the air vehicle due to the expense of demonstrating all maintenance actions.

Blank 3. Identify the type and scope of demonstrations required to provide confidence that the requirement has been satisfied. Demonstration provides the best assessment of the maintenance crew's ability to perform their mission. This also allows for the range in population of maintenance personnel to be assessed for accomplishment of tasks without damage. Due to time and cost, it may be necessary to identify the critical maintenance tasks for demonstration.

VERIFICATION LESSONS LEARNED (4.4.3.2.1.6.1)

Accessibility incremental verification does not occur through any one test or demonstration but rather through the results of efforts/tasks structured to provided increased insight into the attributes of the design. This is accomplished through a series of efforts and combined through analysis to ensure insight at the appropriate levels for management of the design refinement and acquisition process.

The level of detail expected in accessibility analysis varies with the milestone, phase of program, complexity of item/system, and the rate of change of technology. Accessibility analysis, throughout the program, must show the design is compatible with requirements based on design, access frequency, maintenance concepts, numbers of maintainers, etc. If this is not true, immediate action must be taken to address the shortfall and determine acceptable alternatives, including the possible reduction in requirements (all other impacts of such changes must be well understood before making recommendations to reduce requirements).

3.4.3.2.1.6.1.1 Mounting, installation and alignment

The air vehicle shall preclude improper mounting, installation, and/or alignment during installation of replacement items. The air vehicle shall provide installations that enable components that appear to be the same but which are, in fact, functionally different, to be readily distinguishable in the installed state.

REQUIREMENT RATIONALE (3.4.3.2.1.6.1.1)

This requirement will ensure that maintenance personnel properly install or remove components.

REQUIREMENT GUIDANCE (3.4.3.2.1.6.1.1)

To Be Prepared

REQUIREMENT LESSONS LEARNED (3.4.3.2.1.6.1.1)

To Be Prepared

4.4.3.2.1.6.1.1 Mounting, installation and alignment verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Proper mounting, installation, and/or alignment	No improper installation		A	A		I
Functionally different items	Readily identifiable		A	A		I

VERIFICATION DISCUSSION (4.4.3.2.1.6.1.1)

During assembly, developmental test, and remove and replace activities substantial data is typically obtained that could be used to verify this requirement. Use of this type of data should be maximized to avoid the cost and schedule impacts of a formal demonstration.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: No unique verification action occurs at this milestone.

PDR: Analysis indicates preliminary design incorporates features that will preclude the improper mounting, installation, and/or alignment of items during installation or replacement. Analysis of the preliminary design indicates components that appear to be the same but which are, in fact, functionally different, will be readily distinguishable in the installed state. All instances of nonconformance to the requirement discovered during the review of product definition have a corrective action plan.

CDR: Analysis confirms final design incorporates features that will preclude the improper mounting, installation, and/or alignment of items during installation or replacement. Analysis of the final design confirms components that appear to be the same but which are, in fact, functionally different, will be readily distinguishable in the installed state. All instances of nonconformance to the requirement discovered during the review of product definition have a corrective action plan.

FFR: No unique verification action occurs at this milestone.

SVR: Inspection of available data from assembly, developmental test, and remove and replace actions confirms that improper mounting, installation, and/or alignment of items during installation or replacement does not occur, and components that appear to be the same but which are, in fact, functionally different, can be readily distinguishable in the installed state. All known instances of nonconformance to this requirement have been corrected by product definition change.

Sample Final Verification Criteria (4.4.3.2.1.6.1.1)

The mounting, installation and alignment requirement shall be satisfied when ___(1)___ inspections confirm that the required performance has been met.

Blank 1. Inspections might include examination of available data from assembly, developmental tests, remove and replace actions, and other maintainer interface actions.

VERIFICATION LESSONS LEARNED (4.4.3.2.1.6.1.1)

To Be Prepared

3.4.3.2.1.6.1.2 Adjustment controls

Wherever adjustments on the air vehicle are required, the air vehicle shall provide feedback to the maintainer for control of the adjustment. Adjustment controls with a limited degree of motion shall have stops with adequate strength to prevent damage by a force __(1)__ times greater than the resistance to movement within the range or not less than __(2)__ inch pounds torque for dials or not less than __(3)__ pounds force applied at the end of a lever for a slide or lever adjustment device.

REQUIREMENT RATIONALE (3.4.3.2.1.6.1.2)

This requirement ensures that controls and adjustments are sufficiently robust so as to control adjustment and preclude maintainer-induced damage.

REQUIREMENT GUIDANCE (3.4.3.2.1.6.1.2)

Blank 1. Enter a minimum of 100.

Blanks 2 and 3. Complete based on the anthropometric data describing the maintainer population.

REQUIREMENT LESSONS LEARNED (3.4.3.2.1.6.1.2)

Controls internal to the air vehicle should be located to preclude inadvertent contact with dangerous voltages or other hazards. If emergency shut-off switches are dictated, they should be located or protected to preclude accidental engagement.

4.4.3.2.1.6.1.2 Adjustment controls verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Adjustment feedback	Indication present		A	A		I,A
Adjustment limit stops	Structural integrity of stop (1), (2), (3)		A	A		I,A

*Numbers in parentheses in the Measurand column refer to numbered blanks in the requirement.

VERIFICATION DISCUSSION (4.4.3.2.1.6.1.2)

During assembly, developmental test, and remove and replace activities, substantial data is typically obtained that could be used to verify this requirement. Use of this type of data should be maximized to avoid the cost and schedule impacts of a formal demonstration. Further the structural integrity of the mechanical stops can be demonstrated as an integral part of vendor qualification or product testing.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: No unique verification action occurs at this milestone.

PDR: Analysis of preliminary design indicates that provisions are present for adjustment feedback and adequate structural integrity of adjustment limit stops.

CDR: Analysis of final design confirms that there is feedback to the maintainer of all adjustments required. Analysis of results from vendor qualification or product testing, as applicable, confirm adequate structural integrity of any mechanical stops.

FFR: No unique verification action occurs at this milestone.

SVR: Inspection, of available data from assembly, developmental test, and remove and replace actions, confirms that there is adequate adjustment feedback to the maintainer and all limit stops have adequate structural integrity. All known instances of nonconformance to this requirement have been corrected by product definition change. Analysis of lower-level requirement verification activities.

Sample Final Verification Criteria

The adjustment controls requirement shall be satisfied when ___(1)___ inspections confirm that the required performance has been met.

> Blank 1. Inspections might include examination of available data from assembly, developmental tests, remove and replace actions, and other maintainer interface actions.

VERIFICATION LESSONS LEARNED (4.4.3.2.1.6.1.2)

To Be Prepared

3.4.3.2.1.6.1.3 Weight, lift and carry limitations and identification

The weight limitations for air vehicle replaceable items shall be __(1)__. Lift and carry limitations and lifting point identification shall be provided in accordance with __(2)__.

REQUIREMENT RATIONALE (3.4.3.2.1.6.1.3)

This requirement ensures that the air vehicle can be maintained within the expected ergonomic characteristics of the maintainer population while minimizing damage induced by dropping, misalignment or other faulty installation.

REQUIREMENT GUIDANCE (3.4.3.2.1.6.1.3)

Complete blanks 1 and 2 with the appropriate requirements for one person and multi-person lift or carry and labeling of lifting restrictions and lifting points. A source for details regarding these requirements is MIL-STD-1472, paragraphs 5.9.11.3 through 5.9.11.3.9.

REQUIREMENT LESSONS LEARNED (3.4.3.2.1.6.1.3)

To Be Prepared

4.4.3.2.1.6.1.3 Weight, lift and carry limitations and identification verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Weight limitations	(1)	A	A	A		I
Lift and carry limitations and lifting point identification	(2)	A	A	A		I

*Numbers in parentheses in the Measurand column refer to numbered blanks in the requirement.

VERIFICATION DISCUSSION (4.4.3.2.1.6.1.3)

During assembly, developmental test, and remove and replace activities, substantial data is typically obtained that could be used to verify this requirement. Use of this type of data should be maximized to avoid the cost and schedule impacts of a formal demonstration. Further, the ability of maintainers to lift and carry replaceable units can be evaluated by the joint reliability/maintainability evaluation team.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to each of the requirement elements.)

SRR/SFR: Analysis of design concepts indicate maintenance actions have been considered in determining weight, and lift and carry requirements for replaceable items.

PDR: Analysis of preliminary design indicates that provisions are present for lifting and carrying and labeling the replaceable units. Analysis of preliminary design indicates that replaceable items comply with the weight limitations specified.

CDR: Analysis of final design indicates that provisions are present for lifting and carrying and labeling the replaceable units. Analysis of final design confirms that replaceable items comply with the weight limitations specified.

FFR: No unique verification action occurs at this milestone.

SVR: Inspection of available data from assembly, developmental test, remove and replace actions, and the Joint Reliability/Maintainability Evaluation Team confirms that replaceable units comply with specified weight limitations, are labeled with lift and carry limitations, and provisions for lifting and carrying units are present. All known instances of nonconformance to this requirement have been corrected by product definition change.

Sample Final Verification Criteria

The weight, lift and carry limitations and identification requirement shall be satisfied when ___(1)___ inspections confirm that the required performance has been met.

Blank 1. Inspections might include examination of available data from assembly, developmental tests, remove and replace actions, and other maintainer interface actions.

VERIFICATION LESSONS LEARNED (4.4.3.2.1.6.1.3)

To Be Prepared

3.4.3.3 Passenger interfaces

To Be Prepared

3.4.4 Transportability

The __(1)__ shall be __(2)__ transportable by __(3)__ without damage that would degrade operational capability. The transported air vehicle and any removed subassembly shall meet the dimensional, towing, lifting, tie down, clearance, access, pressurization, temperature, vibration, and load limit constraints of the specified transport method(s), as specified in __(4)__.

REQUIREMENT RATIONALE (3.4.4)

This requirement is applicable to air vehicles intended to be air, land, or sea transportable. Typically, this requirement is applied to small air vehicles or subassemblies that can be configured to fit within the confines of larger cargo air vehicles, on road vehicles, or on ship. It is needed to ensure that the air vehicle and any of its required spares or support equipment can be transported via the most economical as well as via the fastest means available.

The mobility concept should include the need for the air vehicle and its subassemblies to be transportable via other cargo air vehicles and/or by available ground transport modes or sea vessels. Small air vehicles can be made transportable via larger air vehicle, rotary wing air vehicles, over the road, or by ship through partial disassembly or minor breakdown. Larger air vehicles are not usually transportable intact, but major components such as engines and wings can be removed for shipment as needed. All air vehicle components and equipment as required to support deployment or repair activities should be transportable by multiple methods as dictated by the mobility concept.

REQUIREMENT GUIDANCE (3.4.4)

Blank 1. Complete by noting air vehicle configuration or appropriate subassembly, typically the “air vehicle,” “XXX system,” or air vehicle subcomponent (such as engine, wing, etc.).

Blank 2. Enter the desired modes of transport such as land, air, or sea.

Blank 3. Complete with the mode identifier such as truck, rail car, cargo aircraft, helicopter, ship, etc. The mode identifier may also include the type of aircraft, ship, rail car, etc. See MIL-STD-1366 for additional guidance (example: “The F-XX air vehicle with wings removed shall be air transportable in a C-5 aircraft, ground transportable using commercial or US Military vehicles on improved roadways, and sea transportable on LASH Lighter Ships.”).

Blank 4. Complete with the appropriate interface documentation/specification, such as MIL-STD-1366 or MIL-HDBK-1791. For air vehicles requiring multiple modes of transportation, a table may be appropriate.

If applicable for external air transport, the air vehicle may require provisions for lifting attachment and transportability by rotary wing air vehicles. During design and development, the upper weight limit and to some extent the overall size of the air vehicle must be considered in respect to the external lift and payload capacity of current rotary wing air vehicles (i.e., helicopters).

REQUIREMENT LESSONS LEARNED (3.4.4)

Designing for transportability requires interface compatibility with a wide variety of cargo air vehicle, land equipment, and ship characteristics. Systems built without consideration for modes of transport become a burden when they must be moved other than under their own power. Nonflyable air vehicles often require removal of wings, engines, empennage, and sometimes more extensive breakdown to be able to move on surface roads and fit even on large cargo airlifters. High replacement parts such as engines or propellers must be transportable by cost-effective methods to include the support equipment and maintenance stands required for removal/installation. Air vehicles with one-piece, nonremovable wings or with engines that cannot be transported on their installation trailers become long-term logistics problems that could have been avoided early on.

4.4.4 Transportability verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Transportable	Method (3) without degradation of operational capability	A	A	A,I		A,I, D,T

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.4.4)

Transportability verification should be accomplished through a combination of analyses, inspections, demonstration, and test as necessary for a positive determination that the item can be configured or packaged for efficient and safe transport by the required modes.

Key Development Activities

Key development activities should include, but are not limited to, the following:

SRR/SFR: Analysis of the design concept indicates that the item and related systems can be configured into packages that meet the limits of size and weight for the chosen modes of transport. Analysis of item and support concepts indicate that allowances are made for hoisting and handling in addition to tiedown of the item. Analysis of material selection and packaging concepts should be considered to show that the transport environment will not induce damage.

PDR: Analysis of preliminary design indicates that transportability considerations, including the size and weight limitations, as well as handling concepts, for the transport modes chosen, have been addressed.

CDR: Analysis of final design confirms that transportability considerations, including the size and weight limitations, as well as handling concepts, for the transport modes chosen, have been addressed. Analysis of material selection and packaging confirms that the transport environment will not induce damage.

FFR: No unique verification action occurs at this milestone.

SVR: Analysis, inspections, and demonstrations confirm that the item can be configured for the transport role. When appropriate, results of testing of restraint provisions confirm that structural capability exists. Analysis of design and development data, including results from support of the flight test program, confirm that item is transportable in a manner consistent with operational concepts.

Sample Final Verification Criteria

The transportability requirement shall be satisfied when __(1)__ analyses, __(2)__ inspections, __(3)__ demonstrations, and __(4)__ tests confirm that the item can be transported by the specified mode of transport without degrading the overall operational capability of the item.

> Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement elements have been satisfied.
>
> Blank 2. Identify the type and scope of inspections required to provide confidence that the requirement elements have been satisfied.
>
> Blank 3. Identify the type and scope of demonstrations required to provide confidence that the requirement elements have been satisfied.
>
> Blank 4. Identify the type and scope of tests required to provide confidence that the requirement elements have been satisfied.

VERIFICATION LESSONS LEARNED (4.4.4)

The increased use of composite structures, design considerations for stealth, weight reduction measures, advanced aerodynamics, and modern construction techniques favor larger components with fewer joints. This can easily lead to air vehicle designs that cannot be reduced in size while remaining mobile. Often these same construction techniques also lead to an air vehicle without any means for applying restraint needed for shipment. When such aircraft become operational, there is no economical method to move the airframe when it becomes unflyable.

3.4.4.1 Preparation for transport

The air vehicle shall be capable of being prepared for transport in __(1)__ mode by a crew of __(2)__ trained members within a time period of __(3)__ utilizing __(4)__ ground handling equipment.

REQUIREMENT RATIONALE (3.4.4.1)

This requirement is applicable to small air vehicles that are not capable or intended for self movement in an expeditious manner (typically by air) as a part of the operational concept or for routine deployment. The requirement is needed to ensure that the air vehicle and any of its required spares or support equipment can be made ready for transport in an economical as well as timely manner.

REQUIREMENT GUIDANCE (3.4.4.1)

Blank 1. Typically, complete the blank with the modes defined in 3.4.4 Transportability.

Blank 2. Complete with the maximum number of crew programmed to support this aspect of the operation.

Blank 3. Specify the time period allowed in hours or parts thereof.

Blank 4 should be used to scope the amount and type of support equipment used. Support equipment that is not normally required for routine maintenance (e.g., large cranes) may be excluded by specifying which equipment is allowed.

REQUIREMENT LESSONS LEARNED (3.4.4.1)

Systems built without consideration for ease of configuration for transport become a burden when they must be prepared for shipment under austere conditions. Removal of wings, engines, and other parts should be planned for ease of operation when required to configure the air vehicle for shipment on the specified transport mode(s). Minimizing the required crew, time, and support equipment allowed will help ensure operational mobility is designed into the vehicle with less impact on the supporting infrastructure.

4.4.4.1 Preparation for transport verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Time to prepare for transport in mode (a)	(3)	A	A	A		A,D
Time to prepare for transport in mode (b)	(3)	A	A	A		A,D
Time to prepare for transport in mode (…)	(3)	A	A	A		A,D

*Numbers in parentheses in the Measurand column refer to numbered blanks in the requirement.

VERIFICATION DISCUSSION (4.4.4.1)

Preparation for transport verification should be accomplished through a combination of analyses, inspections, demonstrations, and tests as necessary for a positive determination that the item can be prepared for timely, and efficient transport by the required modes.

Key Development Activities

Key development activities should include, but are not limited to, the following:

SRR/SFR: Analysis of the design concept indicates that the item can be configured within the time constraints of the requirement.

PDR: Analysis of the preliminary design indicates that the time to prepare the vehicle can be achieved within the constraints of personnel and support equipment.

CDR: Analysis of the final design confirms that the time to prepare the vehicle can be achieved within the constraints of personnel and support equipment.

FFR: No unique verification action occurs at this milestone.

SVR: Analysis and/or demonstrations confirm that the time to prepare the vehicle can be achieved within the constraints of personnel and support equipment.

Sample Final Verification Criteria

This preparation for transport requirement shall be satisfied when __(1)__ analyses, and __(2)__ demonstrations confirm that the air vehicle can be prepared for transport in the required time with the specified personnel and support equipment.

Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement elements have been satisfied.

Blank 2. Identify the type and scope of demonstrations required to provide confidence that the requirement elements have been satisfied.

VERIFICATION LESSONS LEARNED (4.4.4.1)

Smaller air vehicles, especially unmanned types, require a means that allows timely and economic deployment. Preparation for transport should be achievable with a minimum of crewmembers and equipment and with a timeline consistent with the operational concept.

3.4.5 Cargo and payload

3.4.5.1 Cargo handling

The air vehicle shall provide cargo handling capabilities as specified in table 3.4.5.1-I.

TABLE 3.4.5.1-I. Cargo handling capabilities.

Mission Scenario	Cargo Handling Equipment	Cargo Restraint Equipment	Cargo Loading Aids	Special Mission Equipment	Operator Interface

REQUIREMENT RATIONALE (3.4.5.1)

This requirement is needed for air vehicles intended to transport cargo items as a primary or secondary mission. This requirement should define the scope of cargo missions and the mission equipment needed for the air vehicle to load and unload the required cargo items under the operational mission concepts. This requirement should also address the specific mission equipment needed to satisfy the safety of flight requirements for transported cargo.

REQUIREMENT GUIDANCE (3.4.5.1)

Guidance for completing table 3.4.5.1-I follows:

Mission Scenario: Identify the mission conditions under which the air vehicle will operate, (i.e., strategic airlift, tactical assault, austere bare base, etc.). Strategic airlift implies long range missions between main bases with unlimited runways, routine load factors, adequate materials handling ground equipment (mhe), etc. Tactical airlift implies shorter range missions into less complete airfields with limited mhe. Austere bare base may involve extreme load factors, little or no mhe, rapid onload/offload conditions, etc. Airdrop of cargo or personnel would involve dropping the items during low speed flyover of the objective and must be identified as to type, weight, quantity, etc.

Cargo Handling Equipment: Identify the on board mission equipment needed to perform onload/offload of the cargo. For example, the air vehicle may need some type of conveyors and guide rails for carrying palletized cargo and accomplishing airdrop missions. Some of the conveyors may need to employ omni-directional rollers to permit pallets to be moved longitudinally and laterally during onload/offload. The air vehicle may need a load bearing cargo ramp and ramp toes to permit drive on loading of vehicles.

Cargo Restraint Equipment: Identify the built in features and on board equipment to be used for securing the cargo to meet restraint requirements for flight. A level of risk must be assumed to establish restraint criteria. High levels of restraint must be weighed against increased workload and structural impact plus the concept for restraint of cargo items not having the same level of structural capability. For a compatible interface with existing infrastructure, the air vehicle may employ straps, chains, and an indent/detent system within the roller guide rails or separately attached to the cargo floor structure.

Cargo Loading Aids: Identify any special cargo onload/offload aids needed such as a winch, powered conveyors, overhead hoist, elevator, stabilizing struts, ramp extensions, antiskid floor treatment, lighting, etc.

Special Mission Equipment: Identify any special mission equipment needed. Typical special mission equipment may include airdrop anchor cables, deflector doors, special lighting, parachute release devices, troop seating, reconfiguration capability, overboard vents, electrical outlets, etc.

Operator Interface: Identify the controls and displays needed for operation of the systems by the specified crew complement. Indicate the number and capability of the crewmember to be used for each mission scenario.

REQUIREMENT LESSONS LEARNED (3.4.5.1)

The scope of the cargo mission significantly influences the overall design and layout of the air vehicle. In addition it affects matters such as size and location of cargo doors, strength of floor, and loading methodology. The conditions under which cargo is to be loaded/unloaded will also drive the design of the air vehicle. Generally, air vehicle with autonomous loading capability will be capable of bringing cargo into any airfield, but with inherent penalties in weight and drag.

Increasingly, crew costs have driven the users to require single loadmaster operation. While reducing workload, this often results in increased complexity for operating the systems. Most cargo category air vehicle are equipped with a wide assortment of mission hardware to enable the individual air vehicle to perform a variety of cargo related missions. Nearly all subsystems must have a backup capability to enable completion of the primary mission.

Interface with the existing infrastructure will force similarities in the materials handling system aboard the airframe. Cargo handling mission equipment is often a compromise designed for multipurpose usage in conjunction with the overall layout of the cargo compartment. For example, the guidance rails, locks and conveyor systems for accommodating logistics platforms can also be used for airdrop missions. However, this same equipment can also interfere with rolling stock or troop transport missions and must be made removable or stowable for these alternate uses.

4.4.5.1 Cargo handling verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Air vehicle capability to handle specified cargo for each mission scenario	Pass/Fail	A	A	A,D, S	A,I, D	A,D, S,T
Air vehicle provides required physical/functional interface with cargo for each mission scenario	Yes/No	A	A	A,D, S	A,I, D	A,D, S,T

VERIFICATION DISCUSSION (4.4.5.1)

Cargo handling verification should be accomplished through a combination of analyses, simulation, demonstration, and test as necessary for a positive determination that the cargo handling abilities provide for the efficient and safe loading and transport by the required modes.

Key Development Activities

Key development activities should include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analysis of the design concept indicates that all required types of cargo are considered and under what conditions. Analysis of onload/offload methodology for each type of cargo identifies and incorporates the requirement for special onload/offload aids or special mission equipment. Inspection indicates restraint criteria are established and used as design requirements.

PDR: Analysis of the preliminary design indicates that the air vehicle is designed to onload/offload the required cargo in a manner consistent with the operational requirements and that design considerations for meeting the size and weight of individual items is evident. Analysis indicates that the requirements for cargo and payload handling equipment have been identified and included in the equipment list, with unique capabilities indicated for each component. Analysis indicates that the interface with the operator and the air vehicle (power requirements, displays, control functions, etc.) have been identified.

CDR: Analysis of the structural forces involved in onload/offload and flying each cargo component confirm they are within allowable operating limits. Onload/offload demonstrations on a full size mock-up or computer modeling simulations confirm the required capability. Analysis and simulation with mock-ups or other visual tools confirm that the air vehicle will be equipped with the necessary cargo handling equipment and that it is consistent in design philosophy with the operational concept. Simulation of controls and displays for operating the cargo onload/offload equipment and for stowage or reconfiguration confirms compliance with human factor considerations.

FFR: Analysis, inspection and demonstration of all required sub-components confirm them as airworthy and compatible with the required cargo items. Functional operation of all required air vehicle cargo systems has been demonstrated.

SVR: Analyses of design test data confirms that the cargo transport missions can be readily accomplished by the air vehicle design and equipment installations. Cargo handling of various sample payloads has been successfully demonstrated. Test results and demonstrations confirm performance to specified levels under worst-case scenarios. The operational scenario for all cargo handling missions has been successfully simulated. All cargo handling hardware has been successfully utilized. Analysis and demonstrations of operator workload and time requirements for cargo handling confirm that required performance can be attained.

Sample Final Verification Criteria

The cargo handling requirement shall be satisfied when __(1)__ analyses, __(2)__ simulations, __(3)__ demonstrations, and __(4)__ tests confirm that the air vehicle provides specified cargo handling capabilities.

> Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement elements have been satisfied.
>
> Blank 2. Identify the type and scope of simulations required to provide confidence that the requirement elements have been satisfied. Types of simulations might include mock-up or virtual.
>
> Blank 3. Identify the type and scope of demonstrations required to provide confidence that the requirement elements have been satisfied. Demonstrations might include evaluation of operator workload or time required to accomplish various tasks.
>
> Blank 4. Identify the type and scope of testing required to provide confidence that the requirement elements have been satisfied.

VERIFICATION LESSONS LEARNED (4.4.5.1)

As most cargo mission air vehicle are long lived, operational concepts and requirements are often outgrown, with subsequent adverse impact on future mobility planning. Given the scarcity of development of these type air vehicles, it is extremely important that the operational concept be far sighted, that the variety of mission requirements be all-inclusive, and that the verifications at both system and subsystem levels be thorough. With systems tracking and component verification of cargo handling capability from the outset, problems caused by inadequate equipment and design oversights can be readily avoided.

3.4.5.2 Cargo weight and balance

The air vehicle shall be capable of the following weight and balance computations at various weight and c.g. (center of gravity) conditions when loaded with cargo: __(1)__. The air vehicle shall not require redistribution of cargo in order to determine weight and center of gravity.

REQUIREMENT RATIONALE (3.4.5.2)

Weight and balance computation is a necessity for safe and efficient operation of the cargo-capable air vehicle.

REQUIREMENT GUIDANCE (3.4.5.2)

Refer to SAWE Recommended Practice No.7 section titled "Balance Computer Design Data" for guidance. Cargo compartment markings are discussed in 3.3.6.2 Marking of cargo compartments.

> Blank 1. Enter types of weight and balance computations, including, but not limited to, ramp weight, take-off weight, critical weight and c.g. combinations, payload drop, and landing weights.

REQUIREMENT LESSONS LEARNED (3.4.5.2)

In the past, computers such as circular slide ruler, “slip stick,” hand held programmable calculators, laptops, onboard computers, and palm computers have been used to provide the data or form necessary for this crew task. Hand computation takes too long to compute and errors tend to occur.

4.4.5.2 Cargo weight and balance verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Provide weight and balance computation capability	Weight and c.g. determined for (1)	A	A	A		A,T

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.4.5.2)

Weight and balance of cargo type air vehicles must be calculated prior to each flight and filed with the flight clearance form. Verification of the requirement consist of assuring that the program elements are in place to provide for the computation; verifying the contractor’s approach to the problem is adequate; performing an analysis to show the design adequately calculates the air vehicle weight and balance and checks the flight- and ground-critical limitations; and practical test to assure the analysis is correct and supports the user needs.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the design concept indicates that the cargo weight and balance computation capability is provided.

PDR: Analysis of the preliminary design indicates that the cargo weight and balance computation capability is provided.

CDR: Analysis of the detailed design confirms that the cargo weight and balance computation capability is provided and that it addresses all critical conditions (i.e., max weight, most forward/aft c.g., etc.).

FFR: No unique verification action occurs at this milestone.

SVR: Analyses confirms the algorithms correctly calculate the weight and c.g. for all critical conditions (i.e., max weight, most forward/aft c.g., etc.). Analysis confirms that all critical conditions are addressed in the weight and c.g. computation capability. Ground test confirm that the completed weight and c.g. computations are consistent with measured values.

Sample Final Verification Criteria

The cargo weight and balance computation capability shall be verified by __(1)__ analyses __(2)__ tests.

Blank 1. Identify the scope and type of analyses to include whether the algorithms correctly address all critical conditions.

Blank 2. Identify the scope and type of test to include whether the algorithms correctly calculate the weight and c.g. for all critical conditions.

VERIFICATION LESSONS LEARNED (4.4.5.2)

In the case of a particular aircraft, the “Beta” testing was rushed and the program did not test adequately for the allowable load. The program adequately added the weight and moment but did not calculate the worst-case condition correctly. The same program did not warn the user of the program of exceeding maximum zero fuel weight limits.

3.4.6 Refueling and defueling interfaces

3.4.6.1 Ground/shipboard refuel/defuel

3.4.6.1.1 Ground refueling interfaces

The air vehicle shall be capable of ground refueling as specified in table 3.4.6.1.1-I.

TABLE 3.4.6.1.1-I. Ground refueling interfaces.

Refueling Equipment	Refuel System Type	Refueling Interface Description	Refueling Interface Standards	Operating Pressure Range	Maximum Surge Pressure	Maximum Flow Rate	Conditions

REQUIREMENT RATIONALE (3.4.6.1.1)

Air vehicle refueling is required to facilitate operational and mission needs. Defining the air vehicle refueling interfaces has a significant impact on air vehicle design considerations associated with refueling points, routing of fuel lines, and physical connections. Proper refueling interface definition can also have a significant impact on air vehicle interoperability.

REQUIREMENT GUIDANCE (3.4.6.1.1)

Guidance for completing table 3.4.6.1.1-I follows:

Refueling Equipment**:** Identify the type of equipment that will be utilized to refuel the air vehicle at all deployment and operational locations, i.e., fuel truck or fuel pits.

Refuel System Type**:** Classify the type of refueling equipment as either "Pressure Refueling" or "Gravity Refueling."

Refueling Interface Description**:** Identify the characteristics of the physical interface to the refueling system. The following table contains sample information:

Type Designation	Military Standard Number	Outlet Configuration	Pressure Regulation
D-1	MS29520	45° Elbow	None
D-1R	MS29520	45° Elbow	55 psi
D-2	MS29520	Straight	None
D-2R	MS29520	Straight	55 psi

The physical interface could also be characterized via detailed drawings.

Refueling Interface Standards**:** Identify military or NATO standards associated with the refueling equipment. The following is a sample list of standards:

ISO 45	Aircraft Pressure Refueling Connections
ISO 46	Aircraft Fuel Nozzle Grounding Plugs and Sockets
ISO 102	Gravity Filling Orifices
NATO STANAG 2946	Forward Area Refueling Equipment
NATO STANAG 2947	Technical criteria for a Closed-Circuit Refueling System
NATO STANAG 3105	Pressure Refueling Connections and Defueling for Aircraft
NATO STANAG 3212 (ASSE)	Diameters for Gravity Filling Orifices
NATO STANAG 3294 (ASSE)	Aircraft Fuel caps and Fuel Cap Access Covers
NATO STANAG 3847	Helicopter In-Flight Refueling (HIFR) Equipment
NATO STANAG 3681	Criteria for Pressure Fueling/Defueling of Aircraft
NATO STANAG 3682	Electrostatic Safety Connection Procedures

The following are military applicable documents:

MIL-N-5877E	Military Specification, Nozzle, Pressure Fuel Servicing
T.O. 00-25-172	Ground Servicing of Aircraft and Static Grounding/Bonding
NAVAIR NATOPS 00-80T-109	Aircraft Refueling Manual

Operating Pressure Range**:** Identify the operating pressure range of the refueling equipment with which to be interfaced. The pressure range included in this column should be the regulated normal operating range the air vehicle would encounter during refueling operations (i.e., 30-55 psi).

Maximum Surge Pressure: Identify the maximum surge pressure that the air vehicle will be subjected to when interfacing with the specified fueling equipment. Fuel surge pressures include, but are not limited to those generated by the pump start-up, air vehicle or fueling system valve closures, or inadvertent disconnects.

Maximum Flow Rate**:** Identify the maximum flow rate (usually expressed in gallons per minute (gpm)) to which the air vehicle will be exposed when interfacing with the refueling equipment, i.e., 600 gpm.

Conditions**:** Identify any conditions or restraints that would be implemented when interfacing with the refueling equipment. Conditions may include engines running or not running, no electric power available, wings folded, or other unusual configurations. Conditions should also address specific techniques (e.g., hover in-flight refueling, closed circuit refueling, single point refueling, etc.) employed during refueling operations with the cited refueling equipment.

REQUIREMENT LESSONS LEARNED (3.4.6.1.1)

NATO STANAGs that address refueling interfaces are of particular importance when developing an air vehicle designed for interoperability with other nations. The latest version of the STANAGs should be reviewed in order to assess exceptions made during United States government coordination.

A single point refueling capability forward of the main landing gear and accessible from ground level is highly desirable for air vehicles. The single point refueling capability will ensure rapid refueling, and ease of servicing.

Hot refueling (engine(s) running) capability is mission oriented in support of rapid turnaround requirement. Aircraft are hot refuel through their regular single point fueling adapters. Location of the adapter in relation to aircraft hot exhaust components and hot brakes should be considered early in the design concept.

Helicopter In-Flight Refueling (HIFR) is performed to extend a helicopter’s on-station time. The Closed Circuit Refueling (CCR) nozzle is commonly used for HIFR. These nozzles can fit onto Army helicopters adapters, but they regulate pressure to 45 psig in contrast to the standard 15 psig Army requirement. Emergency breakaway is initiated when 450 +/- 50 pounds of straight tensile pull is exerted on the automatic breakaway coupling. Nearly all U.S. Navy and Marine Corps HIFR capable helicopters are outfitted with a CCR nozzle connection for HIFR while the helicopters of other NATO countries use a Single Point Refueling nozzle (SPR).

Fuel velocity entering the tanks and in line fuel velocity should be considered to minimize static charge generation. In general a maximum of 30 feet per second (ft/sec) (20 ft/sec preferred) should be considered an acceptable fuel line velocity. A maximum recommended tank entry velocity is 10 ft/sec.

4.4.6.1.1 Ground refueling interfaces verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Air vehicle is capable of ground refueling using equipment specified	Pass/Fail	I,A	A	A,I,T	A,T	A,D

VERIFICATION DISCUSSION (4.4.6.1.1)

Verification of the requirements for ground refueling interfaces is based on initially defining the numerable characteristics associated with the air vehicle ground refueling process. Then, plan and implement a set of verifications for each group of features or properties that comprise each of the ground refueling characteristics. Essentially, the verifications should be accomplished by integrating a series of inspections and analyses followed by demonstration(s) whenever it appears that there is moderate (or higher) risk of achieving the requirement. During other air vehicle developmental activities, substantial data is typically obtained that could be used to verify the requirements. Use of this type of data should be maximized to avoid the cost and schedule impacts of a formal demonstration.

Verification of the ground refueling interface requirements should be accomplished by at least the following types of processes:

a. Examining techniques used to acquire and install the design characteristics that are driven by pre-established international standards (e.g., NATO STANAGs);

b. Analyzing the design procedures (e.g., computer imaging of ground refueling location attributes and clearance envelopes, and design analysis of venting provisions);

c. Analyzing the planned basing and operational conditions (e.g., the available refueling equipment and the 5-minute hot refueling turnaround associated with fighter aircraft);

d. Testing unique features and functional provisions;

e. As risk indicates, demonstrating ground refueling functional capabilities, and

f. Ground test to demonstrate receiver surge pressures are below the proof pressure capability.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Inspection and analyses of the preliminary ground refueling design concepts indicate that requirements for the interfaces between the air vehicle and the ground refueling provisions are defined and understood. Analysis indicates that the preliminary design approach has considered all features related to each of the numerable interface characteristics that apply to the listed requirements for achieving the ground refueling interfaces.

PDR: Analysis of the air vehicle preliminary design indicates compatibility with specified ground refueling interfaces, and that preliminary lists of unique and international standardization items are available. Analysis indicates test planning, including resource requirements, for unique ground refueling provisions and moderate-to-high risk items have been identified and are consistent with ground refueling interface verification practices.

CDR: Analysis of the final air vehicle design confirms compatibility with the ground refuelng interface requirements. Analysis confirms that any area of incompatibility has been thoroughly researched and testing of lower-level unique provisions have been satisfactorily completed. Inspection confirms that interface control documents, if any, have been negotiated and provisions have been provided.

FFR: Analysis and ground tests confirm the ground refueling interfaces that impact first flight are compatible.

SVR: Analysis and demonstration confirm air vehicle ground refueling interfaces are compatible with the specified requirements and any known instances of nonconformance to the interface requirements have been corrected by product definition change.

Sample Final Verification Criteria

The air vehicle ground refueling interfaces shall be verified by __(1)__ analyses and __(2)__ demonstrations of the interface between the air vehicle and the supporting refueling equipment to confirm that the interface requirements have been met.

> Blank 1. Identify the type and scope of analyses required to confirm all the ground refueling interfaces are compatible with the air vehicle.
>
> Blank 2. Identify the type and scope of demonstrations required to confirm all the ground refueling interfaces are compatible with the air vehicle.

VERIFICATIONS LESSONS LEARNED (4.4.6.1.1)

Surge pressure is generally defined as a transient pressure rise or fall in fluid pressure, usually as a result of operation of fuel system valves. During the air vehicle surge pressure testing, sufficient pressure measurement points should be provided in the system to characterize the surge pressure wave in the system. The following are applicable reference documents: ARP 1665, “Definition of Pressure Surge Test and Measurement Methods for Receiver Aircraft.”; and AS 1284, “Standard Test Procedure and Limit value for Shutoff Surge pressure of Pressure Fuel Dispensing Systems.”

The time to refuel is dependent on the time required to refuel the slowest or the largest tank on the air vehicle. The maximum refueling capacity should be verified by analysis and test on the air vehicle. The starting condition for the refueling must be specified. A starting condition of 10 percent of maximum fuel weight (at normal ground attitude) distributed in a manner resulting from normal use of the system is recommended.

3.4.6.1.2 Defueling interfaces

The air vehicle shall be capable of being defueled as specified in table 3.4.6.1.2-I.

TABLE 3.4.6.1.2-I. Defueling interfaces.

Defueling Equipment	Defueling Interface Description	Defueling Interface Standards	Conditions

REQUIREMENT RATIONALE (3.4.6.1.2)

Air vehicle defueling is required for operational and maintenance considerations such as fuel tank maintenance, transporting the air vehicle, changing tires, etc. Emergency defueling may be required when it is critical to quickly reduce the weight of the air vehicle to hoist or relocate it.

REQUIREMENT GUIDANCE (3.4.6.1.2)

Guidance for completing table 3.4.6.1.2-I follows:

<u>Defueling Equipment</u>: Identify the type of equipment that will be utilized to defuel the air vehicle at all deployment and operational locations, i.e., fuel truck or fuel pits.

<u>Defueling Interface Description</u>: Identify the characteristics of the physical interface to the defueling system. A drawing or military standard number are appropriate entries for this column.

<u>Defueling Interface Standards</u>: Identify military or NATO standards associated with the cited defueling equipment.

<u>Refueling Interface Standard</u>: Identify military or NATO standards associated with the refueling equipment.

The following is a sample list of standards:

ISO 45	Aircraft Pressure Refueling Connections
ISO 46	Aircraft Fuel Nozzle Grounding Plugs and Sockets
ISO 102	Gravity Filling Orifices
NATO STANAG 2947	Technical criteria for a Closed-Circuit Refueling System
NATO STANAG 3105	Pressure Refueling Connections and Defueling for Aircraft
NATO STANAG 3212 (ASSE)	Diameters for Gravity Filling Orifices
NATO STANAG 3681	Criteria for Pressure Fueling/Defueling of Aircraft
NATO STANAG 3682	Electrostatic Safety Connection Procedures

The physical interface could also be characterized via detailed drawings.

The following are military applicable documents:

AFTO 00-25-172	Ground Servicing of Aircraft and Static Grounding/Bonding
NAVAIR NATOPS 00-80T-109	Aircraft Refueling Manual

Conditions: Identify defueling conditions which would impact the air vehicle defuel interface such as availability of electrical equipment or hydraulic support equipment; engines running; flat tires or wheel struts; collapsed landing gear; etc.

REQUIREMENT LESSONS LEARNED (3.4.6.1.2)

This is an operational and interface requirement. Certain maintenance actions on the air vehicle require the fuel to be removed from the air vehicle's fuel subsystem prior to conducting the maintenance action. For tactical and ship-based air vehicles, it is highly desirable to have a single point defueling capability that utilizes the same servicing location that is used for refueling. The capability to quickly defuel an aircraft that is disabled on a runway or shipboard landing area, regardless of its physical attitude, is essential to ensure the ability to clear the landing area and allow other air vehicles to safely land.

Since there are a number of different defueling interface types, the clearance envelope for connection of each should be specified to permit efficient and easy connection to the air vehicle. Identify the required clearance envelope for each of the defueling interfaces.

The minimum flow rate required to meet operational and emergency defuel time requirements should be considered during design of the defuel capability. The flow rate should be derived from system safety requirements, capabilities of the defueling equipment and the maintainability requirements. The required defueling rate should be accomplished by suction from the defueling ground equipment assisted by the air vehicle pumps. It should be able to defuel each tank with any single failure in the system.

If the air vehicle will be used in a forward arming and refueling point (FARP or FARRP) operations, it is important to define the conditions that the exercise will be conducted (e.g., engines/props running, APU running, loading or unloading of cargo, rearmament, other concurrent maintenance actions). The reservoir that the fuel will be defueled into should be specified (bladder cell, truck vehicle, aircraft), and the intended location of each reservoir relative to the air vehicle. If the FARP/FARPP operations include off-loading fuel to other air vehicles, identify what concurrent operations will be performed on these air vehicles during the FARP/FARPP process (e.g., engines running, rearmament). The single-point refueling and aerial refueling subsystems have been successfully used to support FARP/FARPP requirements.

Any restriction on the defueling operations should be specified. The defueling system design should take into consideration that failures can occur which may prevent defueling of the tank. Ensure the latest version of the NATO STANAG document, and any exceptions that may have been included and for which consensus has been reached as part of the US government coordination are included in the air vehicle design.

4.4.6.1.2 Defueling interfaces verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Air vehicle is capable of defueling with the equipment specified	Pass/Fail	I,A	A	A,T	A,T	A,D

VERIFICATION DISCUSSION (4.4.6.1.2)

Verification of the requirements for defueling interfaces is based on defining the variable characteristics associated with the air vehicle defueling process (e.g., ground and/or ship basing and each related clearance envelope), and the standard features (e.g., NATO STANAGs). Then a set of verifications can be structured for each group of features or properties that comprise the defueling characteristics. Essentially, the verifications should be accomplished by a series of analyses followed by a demonstration dependent upon the degree of risk. Other air vehicle developmental activities generally result in substantial data that could be used to verify the defueling interface requirements. Use of this type of data should be maximized to avoid the cost and schedule impacts of a formal demonstration.

Verification of the defueling interface requirements should be accomplished by at least the following types of processes: (a) inspections of standards to assure design characteristics driven by pre-established international standards (e.g., NATO STANAGs) are available, (b) analyzing the design procedures (e.g., computer imaging of ground refueling location attributes and clearance envelopes, and design analysis of venting provisions), (c) analyzing the planned basing and air vehicle operational conditions to assure defueling provisions are compatible with basing defueling capacities, (d) testing unique features and functional provisions, and (e) demonstrating defueling functional capabilities.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Inspection and analyses of the defueling design concepts indicate that requirements for the interfaces between the air vehicle and the defueling provisions are defined and understood. Analysis indicates that the preliminary design approach has considered all conditions or properties related to each of the numerable interface features that apply to the established interface characteristics for achieving the defueling interfaces.

PDR: Analysis of the air vehicle preliminary design indicates compatibility with specified defueling interfaces, and that the equipment identified on the lists of unique and international standardization items are available. Test planning, including resource requirements, for defueling provisions and moderate-to-high risk items has been identified and are consistent with defueling interface verification practices.

CDR: Analysis of the final air vehicle design confirms compatibility with the defueling interface requirements. Analysis confirms that any area of incompatibility has been thoroughly researched and testing of lower-level, unique provisions has been satisfactorily completed.

FFR: Analysis and ground tests confirm defueling interfaces that impact first flight are compatible.

SVR: Analysis and demonstration confirm air vehicle defueling interfaces are compatible with the specified requirements and any known instances of nonconformance to the interface requirements have been corrected by product definition change.

Sample Final Verification Criteria

The air vehicle defueling interfaces shall be verified by __(1)__ analyses and __(2)__ demonstrations of the interface between the air vehicle and the supporting refueling equipment to confirm that the interface requirements have been met.

Blank 1. Identify the type and scope of analyses required to confirm all the defueling interfaces are compatible with the air vehicle.

Blank 2. Identify the type and scope of demonstrations required to confirm all the defueling interfaces are compatible with the air vehicle.

VERIFICATION LESSONS LEARNED (4.4.6.1.2)

The ground refuel test procedures should specify the quantity and distribution of fuel on the air vehicle. System design should preclude negative pressures in the tanks during the defueling process. The air vehicle negative pressure generated during defueling should by verified by analysis and ground test.

Defueling of crashed air vehicle is desired in order to reduce hazards and to lighten the weight of the air vehicle for removal. The capability to defuel with a damaged refueling adapter should be verified by analysis.

3.4.6.2 Aerial refueling interfaces

3.4.6.2.1 Receiver interfaces

The air vehicle shall be capable of aerial refueling with tanker aircraft in accordance with table 3.4.6.2.1-I. The receiver air vehicle shall provide the following visual cues to tanker air vehicles that must be observable by the tanker aircrew:__(1)__.

TABLE 3.4.6.2.1-I. Receiver Interface requirements.

Category	Interface Requirement
Tanker Air Vehicles	
Tanker Air Vehicle Subsystem Type	
Interface Definition	
Tanker Induced Structural Loads	
Tanker Aerial Refueling Flight Envelope	
Operating Conditions	
Procedure	
Interface Clearance Envelope	
Delivered Fuel Type	
Delivered Fuel Pressure and Flow Rate	
Receiver Maximum Refuel Amount	
Max Receiver Refuel Time	
Tanker Visual Cues	
Minimum Tanker to Receiver Separation Distance	
Minimum Receiver to Receiver Separation Distance	

REQUIREMENT RATIONALE (3.4.6.2.1)

The objective of a receiver during aerial refueling is to receive its required fuel amount from the tanker in the most expedient and safe manner possible. When the air vehicle is required to be aerial refueled, the targeted tanker aerial refueling interface(s) must be identified to determine the design requirements of the receiver aerial refueling interface in order to be compatible with the desired tanker aerial refueling interface.

REQUIREMENT GUIDANCE (3.4.6.2.1)

Blank 1. Enter a description of the visual cues to be provided by the receiver air vehicle, which should include lighting, markings, and other visual cues.

In the event that there are more characteristics desired at the tanker/receiver interface, add columns to the table as required.

Guidance for completing table 3.4.7.2.1-I follows:

<u>Tanker Air Vehicles:</u> Specify the targeted tanker air vehicles with which the receiver will be required to operate. Examples would include KC-10, KC-135, or KC-130.

<u>Tanker Air Vehicle Subsystem Type:</u> Identify the tanker aerial refueling subsystem. Examples would include centerline boom, centerline drogue, and/or wing drogue subsystem(s).

<u>Interface Definition</u>: Identify the documentation that defines the physical dimensions of the interface component for the tanker aerial refueling subsystem. An example would be Military Standard (MS) drawing 27604, Nozzle – Universal Aerial Refueling Tanker Boom.

<u>Tanker Induced Structural Loads</u>: Identify the maximum loads, which will be transferred from the tanker aerial refueling, interface to the air vehicle. The loads will be dependent upon the

tanker subsystem type, the handling quality/stability of the interface for the tanker subsystem, as well as tanker air vehicle type. Include loads experienced due to inadvertent contacts of the interface with the structure surrounding the receiver's interface area.

Tanker Aerial Refueling Flight Envelope: Identify the tanker air vehicle aerial refueling flight envelope. The envelope should be defined in terms of airspeed and altitude. The resultant receiver flight envelope must be a subset of the overall receiver flight envelope specified elsewhere within this document (see 3.1.1.1.1 Aerial refueling envelope).

Operating Conditions: Identify environmental conditions under which the aerial refueling operation must be performed. Conditions would include day/night, all lunar angles while in flight, and turbulent air. Also, the induced environmental conditions from section 3.2 Environment encountered during the aerial refueling process must be identified. Induced conditions would include electromagnetic coupling interactions between the tanker and the receiver(s).

Procedure: Some air vehicles may require specific procedures for refueling operations. This column should list any unique or required refueling procedures required by the receiver air vehicle. Examples would include NATO STANAG 3971 or Allied Tactical Publication (ATP), 56. If other procedures are required, ensure they address all factors associated with aerial refueling operations. The procedures should address day versus night operations (with and without night vision goggles), employment versus deployment scenarios, tanker/receiver rendezvous methods, communication techniques under various threat levels for detection/intercept, tanker/receiver formation techniques under various under single/multiple tanker and single/multiple receiver combinations, and tanker/receiver contact process under single/multiple combinations. An example of procedures used to complete the table would include AFTO 1-1C-1-20, Aerial Refueling Procedures with USAF HC/MC-130 tankers (wing and drogue subsystems). See 3.1.1.1.1 Aerial refueling envelope.

Interface Clearance Envelope: Identify the receiver refueling interface clearance envelope. An example would be that interface may not exceed the envelope dimensions specified in NATO STANAG 3447 (ASSE) for the probe interface.

Delivered Fuel Type: Identify the fuel types that the tanker air vehicle is able to transfer. This column should include all deviations from the fuel specification requirements. This requirement should be developed in concert with section 3.4.11 Fuel designation .

Delivered Fuel Pressure and Flow Rate: Identify the maximum fuel delivery pressure that the tanker air vehicle will deliver (including single failures within the tanker's pressure regulation system). An example would be that the pressure at the refueling probe/receiver-coupling interface shall not exceed 55 psig. This requirement should include all pump start-up surge pressures associated with the tanker vehicle. This value should be determined in conjunction with flow rate. Recommend providing delivered fuel flow rate versus delivered fuel pressure curve.

Receiver Maximum Refuel Amount: Identify the maximum refuel capacity for the receiver air vehicle. This can be expressed in terms of pounds of fuel or gallons of fuel, or in terms of percentage of total fuel tank volume. Typically, this is not 100% of the maximum fuel tank capacity, because of design factors such as ullage space, unusable fuel, structural and stability limitations, etc.

Maximum Receiver Refuel Time: Identify the maximum refuel time that is required by the air vehicle. This column has a direct relationship to fuel flow rate, fuel flow pressure, and maximum refuel amount and should be developed in concert with these parameters. This parameter should include time from initial connection (if multiple reconnects are required, the time would still be initiated at the initial connection), refuel to the maximum refuel amount, and disengage from the tanker air vehicle. This requirement is primarily required if the fuel pressure/flow rate delivery curves are not available for the specific tanker aerial refueling subsystem and a maximum refuel time is a key performance parameter within the user's requirements for the air vehicle.

Tanker Visual Cues: Identify the visual cues, including the specific exterior lighting associated with the tanker aerial refueling interface provided on each tanker, that are required to be observed by a receiver crew member during the aerial refueling process.

Minimum Tanker to Receiver Separation Distance: Identify the minimum distance permitted between the tanker air vehicle and receiver air vehicle (excluding interface area). This distance would be the minimum distance between the tanker and receiver at the pre-contact, contact, fuel transfer, and disconnect positions.

Minimum Receiver to Receiver Separation Distance: Identify receiver separation distance required for simultaneous aerial refueling operations. This distance would be the minimum distance between any multiple receivers at the pre-contact, contact, fuel transfer, and disconnect positions.

REQUIREMENT LESSONS LEARNED (3.4.6.2.1)

The requirement for the air vehicle to be able to be aerial refueled as a receiver typically has been a derived requirement based on the mission range(s) for the air vehicle, the air vehicle's performance capability (range), and the forward basing concept for the air vehicle. The requirement may also come from the user's ORD. Identification of the targeted tanker aerial refueling subsystem(s) should be based on inputs from the ORD, aeroperformance capability of the air vehicle, aerial refueling envelope of the targeted tanker aerial refueling subsystem(s), and the mission(s) of the air vehicle.

The identified tanker aerial refueling subsystem(s) will dictate many of the design requirements for the air vehicle as a receiver. For example, the targeted tanker aerial refueling subsystem(s) will determine the type of receiver aerial refueling subsystem(s) installed on the air vehicle, i.e., receptacle versus probe subsystem, and the number of receiver aerial refueling subsystems, i.e., single subsystem versus dual subsystem. The identified tanker aerial refueling subsystem(s) will also dictate the aerial refueling envelope that the air vehicle and its receiver aerial refueling subsystem(s) will have to operate within to be compatible with each targeted tanker aerial refueling subsystem. The identified tanker aerial refueling subsystem(s) can also dictate the aerial refueling procedures that must be used which can impact the air vehicle and its receiver aerial refueling subsystem(s) design. The location of each targeted tanker aerial refueling subsystem on the tanker platform can dictate the location of each receiver aerial refueling subsystem installed on the air vehicle.

As the aerial refueling subsystem performance capabilities can vary drastically from each type of tanker aircraft, the identification of the targeted tanker aerial refueling subsystem(s) should be specific to tanker platform (model, series, and country/service) and the tanker aerial refueling subsystem(s) installed on the tanker platform. For example, specifying that a receiver shall be compatible with a USAF KC-10 is not adequate since the USAF KC-10 is dual subsystem equipped; i.e., it has a boom subsystem and drogue subsystem. In addition, specifying that a receiver shall be compatible with a USAF KC-10 drogue aerial refueling subsystem is not sufficient since some USAF KC-10 aircraft can be multipoint equipped; i.e., it will have a centerline drogue aerial refueling subsystem and some can have wing aerial refueling pod subsystems also. The centerline drogue subsystem and the wing pod subsystems have different performance capabilities that would dictate what receivers can or can not be aerial refueled by them.

Ensure all targeted tanker aerial refueling subsystems are identified by using an ORD that has been coordinated by the user command(s) for the air vehicle and the respective tanker command(s) that the air vehicle will operate with when aerial refueling. In addition, examine any MOUs/MOAs that may exist between the DoD services and/or with other allied countries regarding tanker support.

Due to inadequate lighting provisions on a new receiver air vehicle, the USAF KC-135 tanker fleet had to add a Tail-Mounted-Flood Light on its vertical tail to assist illuminating the new receiver's receptacle during night aerial refueling operations. This was a costly modification to the KC-135 tanker fleet to attain aerial refueling compatibility with the new receiver.

The U.S. Government has agreed to comply with NATO STANAG 3971, without reservation or exception. As such, all new receiver air vehicles with an aerial refueling subsystem, must be able to conduct aerial refueling operations per NATO STANAG 3971 procedures.

The NATO STANAG 3971 contains a list of Points Of Contact (POC) for current allied tankers. When aerial refueling support is to be provided to, or obtained from, allied air vehicles; these POCs should be contacted to determine if any unique changes/exceptions to the aerial refueling procedures in the document are required to be compatible with their air vehicles. An allied country may have agreed to the STANAG with reservations and/or concurred with the document for <u>future</u> air vehicles but took exception for existing air vehicles at the time of coordination.

New receiver air vehicles must be able to refuel using the procedures that have been established for each tanker aerial refueling subsystem on the fielded tanker. Each tanker and each tanker aerial refueling subsystem can have unique procedures associated with them. The aerial refueling procedures with USAF KC-135 tankers (boom and drogue subsystems) are provided in AFTO 1-1C-1-3. Aerial refueling procedures with USAF KC-10 tankers (boom and drogue subsystems) are provided in AFTO 1-1C-1-33. Aerial refueling procedures with USAF HC/MC-130 tankers (wing drogue subsystems) are provided in AFTO 1-1C-1-20. Aerial refueling procedures with US Navy/USMC tanker assets are provided in NAVAIR NATOPS 00-80T-110 Air-to-Air Refueling Manual.

Receiver air vehicles should not require the tanker aircrew or aerial refueling subsystem to adopt to special procedures. For example, the number of tanker aerial refueling pumps being used to transfer fuel should remain constant during the aerial refueling process. In the past, some receivers have required the tanker to limit the number of pumps used to initially transfer the fuel due to fuel pressure transients. Once a steady state flow condition was obtained, the tanker was then able to increase the number of aerial refueling pumps used to transfer the fuel. Similarly, requiring the tanker to reduce the number of aerial refueling pumps being used near the end of the fuel transfer process to alleviate fuel surge pressures should also be avoided.

When identifying the induced environmental conditions, ensure that during the aerial refueling operation (particularly when the tanker and receiver(s) are engaged) electromagnetic compatibility of the equipment onboard each air vehicle is maintained and that there are no unintentional electromagnetic interactions on any air vehicle caused by the flight operations of another air vehicle in the aerial refueling process. Transmissions on HF communication are a particular concern during aerial refueling operations because the wavelength involved can cause resonant interaction between the air vehicles participating in the aerial refueling process. Electromagnetic compatibility on any air vehicle may be compromised and arcing is possible across poor electrical bonds.

The airspeed/altitude envelope that existing tanker aerial refueling subsystems are able to operate varies from subsystem to subsystem. There are multipoint drogue tankers which have a wing pod subsystem that has an airspeed/altitude operational envelope quite different from their centerline hose reel subsystem. As such, the airspeed/altitude envelope for each new receiver aerial refueling subsystem being developed should be made as large as possible to maximize operational utility of the subsystem and mission flexibility for the air vehicle.

Tanker stability varies from platform to platform. Similarly, the stability of a tanker aerial refueling subsystem interface varies from platform to platform and from subsystem to subsystem. Each receiver has its own inherent stability characteristics that can be altered when placed behind a tanker. Receiver stability behind a tanker will differ from tanker platform to tanker platform and from tanker subsystem to tanker subsystem. As such, the minimum separation distance(s) must be specified for each particular aerial refueling subsystem on each particular tanker platform.

Separation distances have been specified as definite lengths (feet) and have be defined in relative proportion of receiver air vehicle wingspans. For example, the minimum separation distance between adjacent receiver air vehicles in simultaneous, multipoint refueling operations has been specified to equal at least ¼ the wing span of the largest winged receiver air vehicle that can be in the simultaneous, multipoint refueling operation when the receiver air vehicles are in any position within the fuel transfer range for the particular tanker aerial refueling subsystems.

For tanker drogue subsystems, it is critical to address this requirement, particularly when the target receiver air vehicle(s) include(s) rotary-wing (helicopter) receivers. For such receivers, it is important that there is adequate clearance between the trailing aerial refueling hose and the rotary blade(s) of the helicopter receiver such that the rotary blade(s) does(do) not strike the aerial refueling hose during the aerial refueling process. Particular concern for adequate clearance should be upon the approach to contact, initial contact, and fuel transfer positions associated with drogue aerial refueling subsystem. One critical design parameter that can affect the clearance between the trailing aerial refueling hose and the rotary blade(s) of a helicopter receiver is the hose trail angle (catenary curve) for the given airspeed/altitude conditions. Another critical design parameter is the hose response capability (hose reel drogue subsystems) at initial receiver contact and when an engaged receiver maneuvers about within the operating envelope for the given drogue aerial refueling subsystem.

Obstructions can cause hang-up of the tanker subsystem interface that would prevent it from mating with the receiver subsystem interface. Obstructions can also cause damage to the either aerial refueling subsystem interface which can result in damage to the interface such that mating is not possible and/or uncontrollable fuel leakage occurs. In addition, obstructions in and around the aerial refueling subsystem interface areas can become damaged and/or broken off resulting in a loss of capability to other air vehicle subsystems and/or becoming a source of FOD to the receiver air vehicle. Obstructions that have been identified in previous air vehicles include external air data sensors, external temperature sensors, raised structural fasteners, and antennae.

The U.S. Government has agreed to comply with NATO STANAG 3447 (ASSE), without reservation or exception. As such, all new aerial refueling subsystems must meet NATO STANAG 3447 (ASSE) with regard to clearance around the interface(s).

The USAF and USMC C-130 tanker's drogue design for helicopter aerial refueling (Low Speed Drogue) is larger than the minimum clearance envelope specified in STANAG 3447 for probe aerial refueling subsystem installations. As such, receiver air vehicles requiring compatibility with the USAF and/or USMC tankers equipped with their Low Speed Drogue must allow for extra clearance around the probe installation.

The receiver probe subsystem interface (probe nozzle) must comply with the dimensional requirements of NATO STANAG 3447 (ASSE) in order to be physically compatible with the existing tanker drogue subsystem interfaces. Again, since the U.S. Government has agreed to comply with NATO STANAG 3447 (ASSE), without reservation or exception, all new probe subsystem interfaces must meet NATO STANAG 3447 (ASSE). The receiver receptacle subsystem interface must comply with NATO STANAG 3447 (ASSE) once those interface requirements have been incorporated into the document.

Though the KC-135 and KC-10 boom nozzles are different designs, they both conform to the dimensional requirements of MS27604. Replacement boom nozzles for the KC-135 have been evaluated, which provided an Independent Disconnect capability to the KC-135 boom subsystem, but the physical dimensions of these nozzles were still required to comply with MS27604 to ensure compatibility with existing receiver receptacles.

Probe nozzles qualified to MIL-PRF-25161 and allied (UK and French) manufactured probe nozzles comply with the dimensional requirements of NATO STANAG 3447 (ASSE). There are design features between the various probe nozzles that affect the level of functional compatibility with the currently fielded tanker drogue aerial refueling subsystems.

During design of the receiver air vehicle, an adequate target area must be provided to the "static" aerial refueling interface in order that the "dynamic" aerial refueling interface can successfully achieve a contact and engagement with the "static" interface. Inadequate interface target area can impact the total time to successfully complete aerial refueling operations. Target area is typically applicable to the interface area for a receptacle aerial refueling subsystem on receivers and a drogue aerial refueling subsystem on tankers. These two interfaces typically are the "static" interface for the aerial refueling process while their counterpart interfaces (boom nozzle and probe nozzle) are the "dynamic" interfaces. During aerial refueling procedures, the "dynamic" interface is the one that is moved to achieve a contact and engagement with the "static" interface. In boom-receptacle aerial refueling procedures, the tanker's boom nozzle is moved to the receiver's receptacle to effect an engagement. In probe-drogue aerial refueling procedures, the receiver's probe nozzle is typically moved to the tanker's drogue/coupling to attain an engagement. In air vehicles with multiple aerial refueling subsystems, it may be necessary to apply separate target areas to each subsystem and identify a unique target area for subsystem interface.

Following any type of disconnect, it must be possible for the tanker and receiver to effect another contact, if required, to successfully meet mission requirements. The shorter the duration, the faster the cycle time between successive contacts of the tanker subsystem with the receiver subsystem. From a fuel pressure standpoint, a time of three seconds has been required for the fuel pressure to relieve back down to head pressure after the tanker's coupling disconnects from the receiver's probe. For tanker drogue subsystems, the specified time must account for the hose extension time to its full trail position following an inadvertent disconnect of the receiver probe from the coupling from the inner most position within the fuel transfer envelope for the subsystem.

If there is a receptacle subsystem, to be compatible with the KC-135 and KC-10 centerline boom subsystem, the receptacle installation must be designed to withstand an ultimate tension (pullout) load of 14,000 pounds divided by cosine A, where the angle A may vary throughout a 30 degree cone measured about the receptacle bore centerline with the load applied at the boom nozzle ball joint. The receptacle installation must also withstand an ultimate compression load of 20,000 pounds applied at the boom nozzle ball joint, with the ball joint angle anywhere within a 34 degree cone measured about the receptacle bore centerline. The receptacle installation must also be designed for limit tension and compression loads of 9000 pounds divided by cosine C, where the load is applied at the boom nozzle ball joint and the angle C may vary for 0 to 17 degrees. The slipway of the receptacle installation must also be designed to withstand ultimate impact loads of 2000 pounds laterally and 5000 pounds vertically. If there is a probe subsystem, the specified loads are dependent upon the drogue aerial refueling subsystem(s) identified for operational compatibility. If the KC-135 Boom-Drogue-Adapter (BDA) subsystem is a targeted subsystem, the air vehicle’s probe mast and its attachment and support structure must withstand limit loads of 1000 pound tension force in combination with a 3000 pound radial load and a 2000 pound compression load acting singly at the probe nozzle. When aerial refueling from a hose reel subsystem, the air vehicle’s probe mast and its attachment and support structure must withstand limit loads of 1000 pound tension load in combination with a 1000 pound radial load, and a 2000 pound compression load acting singly at the probe nozzle. Ultimate loads should be 133 percent of the limit loads. Impact loads onto the probe nozzle should be based upon the loads produced by each targeted tanker drogue subsystem when the probe nozzle contacts the drogue/coupling at angular positions up to 15° 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.

The above loads are in addition to any aerodynamic/gust loads that may be imparted on the structure of the air vehicle, its aerial refueling subsystem and the aerial refueling interface 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 lines of the subsystem/interface must be considered. All loading conditions must be applied to the support structure to which the aerial refueling subsystem/interface attaches.

The design loads recommended above for a receptacle subsystem are based on a limit load imposed by the KC-135 and KC-10 boom subsystem resulting from an emergency pullout (tension disconnect or brute force disconnect). An emergency pullout is the process of pulling the nozzle out of the receptacle against the force of the locked receptacle toggle latches. The maximum force permitted to accomplish this disconnect is 9412 pounds with the receptacle at –65° F and with the boom nozzle average retract velocity up to 10 feet per second.

For receiver receptacle subsystems, the area around the receptacle can be subjected to inadvertent boom strikes during the aerial refueling process. In the past, it has been recommended that a minimum distance of 12 inches around the perimeter of the receptacle be designed to withstand ultimate impact loads of 705 pounds laterally and 1800 pound vertically.

For receiver probe subsystems, the area around the probe nozzle and probe mast can be subjected to inadvertent strikes by the drogue/coupling during the aerial refueling process. Since there are design differences in the various tanker drogue aerial refueling subsystems that affect the level of impact loads experienced by the receiver, the receiver air vehicle should be designed to withstand the “worst case” drogue aerial refueling subsystem of the targeted tanker(s) from the stand point of impact loads. The specified impact loads should be based on receiver closure rate velocities up to 10 feet per second and at the maximum airspeed of the aerial refueling envelope for that “worst case” drogue subsystem. The location and type of probe installation, along with other system requirements (e.g., low observables), will dictate the size of the area around the probe nozzle/probe mast that must be designed to withstand inadvertent strikes by the drogue/coupling.

When aerial refueling from the KC-135 BDA subsystem, due to its short and nonretracting hose features, the area of inadvertent strike and magnitude of impact loads must consider those created and imparted by the hose. After contact, the hose of the BDA assumes a “C” shape and the hose can spin and flip from side to side. For nose-mounted probe installations, such a scenario could result in inadvertent strikes onto the nose and forward fuselage structure of the receiver air vehicle.

When not restricted by low observable or other mission requirements, receptacle aerial refueling subsystems have typically had lead-in and outline markings at the receptacle area on the air vehicle. Any item near the receptacle interface clearance area should also be marked to assist the boom operator in avoiding an inadvertent boom strike onto this item during the engagement/disengagement phase of the aerial refueling process.

Some tanker boom and receiver receptacle aerial refueling subsystems permit a secure voice communication capability once the tanker’s boom nozzle is properly engaged within the receiver’s receptacle. This design approach only allows communication to one receiver air vehicle during the contact/fuel transfer phase of the aerial refueling process.

One form of required data communication between tanker and receivers is identification of the receiver by tail number for the tanker’s fuel accounting/billing requirements. In boom/receptacle aerial refueling operations, one method used to communicate such data has been to identify the receiver’s tail number near/around the receptacle so that it is clearly visible to the boom operator. However, for probe-equipped receivers using a tanker’s centerline drogue aerial refueling subsystem, the tail number may have to be verbally communicated to the tanker by the receiver. Other possible required data communication may include the specific amount of fuel accepted by each receiver.

There may be mission requirements in which voice/data communication is required throughout the entire aerial refueling sequence; i.e., from rendezvous, formation, pre-contact, contact/fuel transfer, reformation). There also may mission requirements in which simultaneous voice/data communication is required between the tanker and multiple receivers throughout the aerial refueling process. Voice/data communication system(s) must be electromagnetically compatible with flight operation of the air vehicles involved in the aerial refueling operation.

The fuel specifications identify what the requirements are for the fuel at procurement. Once the fuel has been handled through the fuel delivery system (pipeline, storage tanks, hydrant tanks, refuel trucks, etc.), certain properties of the fuel can change prior to the introduction into the air vehicle. Once inside an air vehicle, the fuel properties can change again such that the fuel may no longer meet all of its original specification requirements. This feature must be recognized when transferring fuel from a tanker air vehicle to a receiver air vehicle. The receiver air vehicle may be accepting fuel that no longer meets its procurement specification requirements and may have different properties than that same fuel originally delivered on the ground.

If a tanker air vehicle uses its fuel for thermal management, and that fuel can be transferred to a receiver, the delivered fuel temperature from the tanker to the receiver may be incompatible for use in the receiver's aerial refueling/fuel subsystem, particularly if the receiver also uses its fuel for its own air vehicle thermal management. This requirement should also be applied to receiver air vehicles if reverse aerial refueling capability is a mission requirement.

Receiver aerial refueling subsystems are designed assuming a predetermined fuel delivery pressure at the aerial refueling interface from the tanker. If the fuel delivery pressure from the tanker is significantly lower than what the receiver's aerial refueling subsystem was designed for, the fill rate into the receiver will be different than what is expected for the receiver. In addition, a significantly lower delivery pressure could affect the fill sequence into the receiver, which could impact the center of gravity of the receiver as it aerial refuels. If the fuel delivery pressure from the tanker is significantly higher than what the receiver's aerial refueling subsystem was designed for, the result can be higher surge pressures being experienced within the receiver's aerial refueling subsystem than what is expected. These higher surge pressures could possibly exceed the proof pressure of the receiver's aerial refueling subsystem, which could lead to fuel leaks, and/or component damage within the receiver's aerial refueling subsystem.

The fuel delivery rates/pressures must consider the maximum delivery rate and delivery pressure possible for the given tanker/receiver combination, whether the limitation for delivery rate/pressure may be a tanker subsystem limitation or a receiver subsystem limitation.

Fuel surge pressures include, but are not limited to, those generated by pump start-up, tanker/receiver valve closures, and tanker/receiver disconnects (normal operational disengagements and inadvertent, fuel-flowing disengagements). These types of transient pressures are typical during the aerial refueling process; i.e., no subsystem failures within either the tanker or any receiver aerial refueling subsystem.

Proof pressure limitations must include positive and negative pressures.

In multipoint aerial refueling operations (i.e., a tanker having more than one aerial refueling subsystem and has at least two receivers simultaneously refueling), it is important to consider pressure transients generated by the refuel process to one receiver being able to propagate to the refueling process of another receiver. Where tanker subsystem designs permit such an occurrence, the resultant level of fuel surge pressures within the engaged receiver aerial refueling subsystem can be higher than those experienced during single receiver refueling due to a cumulative effect.

When applicable, consider those fuel surge pressures generated during reverse aerial refueling procedures. When acting as the tanker in reverse aerial refueling, the surge pressures generated by, and experienced by, the receiver subsystem can be higher than those encountered during normal aerial refueling operations.

Single failures of fuel pressure regulation mechanisms within the air vehicle’s aerial refueling subsystem include any pressure regulator, whether it is installed in a component (e.g., coupling), part of a subassembly (e.g., pod), or is installed within the air vehicle’s basic fuel/aerial refueling subsystem. Single failures of surge alleviation mechanisms include surge boots, surge accumulators, surge dampeners, etc.

4.4.6.2.1 Receiver interfaces verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Capability to be refueled in accordance with table 3.4.6.2.1-I	Pass/Fail (for each tanker)	A,S	A,S	A,S,		A,S, D,T
Visual cues	(1)	A,S	A,S	A,S,		A,S, D,T

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.4.6.2.1)

Verification of the requirements for the aerial refueling receiver interfaces is based on initially identifying the known characteristics of the identified tanker(s) with which the receiver air vehicle must interface. Then, verification of the receiver interfaces, dimensions and operating parameters requires the evaluation of each interface requirement between the air vehicle receiver and tanker(s). The verifications should be accomplished by integrating a series of analyses followed by simulations, tests and demonstrations to evaluate each of the interface requirements.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analyses and simulation of receiver to tanker interface including physical, functional and procedural characteristics (e.g., mandatory STANAGs requirements and mandatory Joint Service characteristics) of the identified tanker(s) indicates the receiver aerial refueling interfaces are defined and agreed upon. Analyses of the receiver interfaces (e.g., clearance envelopes, communications, receptacle and probe loads, desired fuel transfer time, fuel flow rate and fuel operating pressure, surge pressures and visual cues) with the identified air vehicle tankers are defined and agreed upon. Aerial refueling risks have been defined and needed trade studies have been defined or initiated.

PDR: Analysis of the provisions for aerial refueling interfaces of the receiver and the preliminary design for the tanker to receiver interfaces has been completed. Structural analyses of the loads transferred from the tanker to the receiver have been evaluated and are within required limits. Receiver fuel system characteristics including fuel line sizing, operating pressure, surge pressure, flow rates, simulation and analysis of lower-level component and iron bird testing are completed or scheduled.

CDR: Analysis of the completed design provisions, simulations and lower-level tests of the receiver aerial refueling system design confirms compatibility with the specified requirements and STANAGs for achieving the tanker interfaces. Any area of incompatibility has been thoroughly assessed and additional testing of areas of concern have been completed. Interface control documents, if any, have been fully negotiated, completed and provided.

FFR: No unique verification action occurs at this milestone.

SVR: Simulations, demonstrations, analyses and testing confirm that the receiver aerial refueling interfaces have been achieved.

Sample Final Verification Criteria

The air vehicle receiver interface requirements shall be satisfied when __(1)__ analyses, __(2) simulations, __(3)__ demonstrations, and __(4)__tests confirm the capability to refuel and provide specified visual cues.

Blank 1. Identify the type and scope of analyses required to confirm the receiver air vehicle has met all of the requirements and is capable of interfacing with the specified tanker(s).

Analyses should include, but are not limited to, aerodynamic and structural loading of the aerial refueling equipment and attachment structure throughout the specified operating envelope. Clearance of the receiver's aerial refueling interfaces should be evaluated including clearance with multiple receivers if applicable. Analyses of receptacle-equipped receivers should include structural analysis of boom induced loads including tension disconnects. Probe equipped receivers should perform a probe load analysis. Analyses of fuel line sizing to achieve desired flow rate, pump sizing with consideration for pressure drops and line losses, and system proof pressure capabilities should be performed. Ventilation analysis for vapor dilution should be conducted for all phases of the mission including, but not limited to, static or low-speed ground operations, high altitude/low air density, and other unique conditions.

Blank 2. Identify the type and scope of the simulations required to confirm the receiver air vehicle has met all of the requirements and is capable of interfacing with the specified tanker(s).

Blank 3. Identify the type and scope of receiver aerial refueling ground and flight demonstrations required to confirm the receiver air vehicle has met all of the requirements and is capable of interfacing with the specified tanker(s).

Demonstrations should include, but are not limited to, receiver handling qualities with the specified tankers in the aerial refueling position throughout the altitude, airspeed and gross weight ranges of both the tanker and receiver. Bow wave effects of the receiver on a boom or drogue system should be evaluated. For rotary ring aircraft, rotor to hose clearance should be evaluated throughout the range of airspeed and associated catenary curves. Demonstration and evaluation of the receiver's visual cues to the tanker should be evaluated including status lights, markings and other visual indicators. Demonstration should include refueling capability in day versus night operations (with and without night vision goggles), turbulence and other adverse weather. Verification that there is no electromagnetic interference between the tanker and specified receivers should be accomplished.

Blank 4. Identify the scope and type of aerial refueling ground and flight tests required to confirm the receiver air vehicle has met all of the requirements and is capable of interfacing with the specified tanker.

Tests should include structural load evaluation of the aerial refueling probe/receptacle loads that should include tension disconnects. Fuel pressure and flow rate testing should be first performed during ground tests for operating, surge and proof pressures. Fuel surge pressures generated during rapid closure of level control valves should be evaluated on the ground throughout the range of expected fuel flows. Flight tests should measure fuel flow rates, operating pressure and surge pressures throughout all phases of the aerial refueling process.

VERIFICATION LESSONS LEARNED (4.4.6.2.1)

To Be Prepared

3.4.6.2.2 Tanker interfaces

The air vehicle shall interface with receiver aircraft in accordance with tables 3.4.6.2.2-I and 3.4.6.2.2-II. The tanker air vehicle shall provide the following visual cues to the aircrew on the receiver air vehicles:__(1)__.

TABLE 3.4.6.2.2-I. Tanker interface requirements.

Category	Interface Requirement
Receiver Air Vehicles	
Receiver Air Vehicle Subsystem Type	
Interface Definition	
Tanker Induced Structural Loads Allowed	
Receiver Aerial Refueling Flight Envelope	
Operating Conditions	
Procedure	
Interface Clearance Envelope	
Receiver Fuel Type	
Receiver Fuel Pressure (Min/Max/Damage Threshold)	
Receiver Flow Rate	
Receiver Maximum Refuel Amount	
Max Receiver Air Vehicle Fuel Up Time	
Receiver Proof Pressure Limit	
Receiver Visual Cues	

TABLE 3.4.6.2.2-II. Receiver combinations.

Total Simultaneous Receivers	Receiver Combinations	Minimum Tanker to Receiver Separation Distance	Minimum Receiver to Receiver Separation Distance	Number of Off-Load Occurrences Per Tanker Sortie

REQUIREMENT RATIONALE (3.4.6.2.2)

The objective of a tanker during aerial refueling is to transfer as much fuel as possible to the receiver(s) in the most expedient and safe manner possible. When the air vehicle has a tanker mission, the targeted receiver fleet system capabilities and the specific operational conditions must be identified to determine the design requirements of the air vehicle and its tanker aerial refueling interface(s) in order to be compatible with the desired receiver(s).

REQUIREMENT GUIDANCE (3.4.6.2.2)

Blank 1. Complete with a description of the visual cues to be provided by the tanker air vehicle, which should include lighting, markings, and other visual cues.

In the event that there are more characteristics desired at the tanker/receiver interface, add columns to the table as required.

Guidance for completing table 3.4.6.2.2-I follows:

<u>Receiver Air Vehicles</u>: Specify the targeted receiver air vehicles that the tanker will be required to support. Examples would include F-16, F/A-18, A-10.

<u>Receiver Air Vehicle Subsystem Type</u>: Identify the receiver aerial refueling subsystem. Examples would include receptacle or probe subsystem(s).

<u>Interface Definition</u>: Identify the documentation that defines the physical dimensions of the interface component with the receiver aerial refueling subsystem.

<u>Tanker Induced Structural Loads Allowed</u>: Identify the maximum load, which the tanker can induce on the receiver aerial, refueling, interfaces. This is a not to exceed value. An example of loads would be that the tanker cannot induce a load on the receiver probe in excess of 1000 lb tensile force in combination with a 3000 lb radial load and 2000 lb compression load acting on a receiver probe nozzle. Include loads experienced due to inadvertent contacts of the interface with the structure surrounding the receiver's interface area.

<u>Receiver Aerial Refueling Flight Envelope</u>: Identify the receiver air vehicle aerial refueling flight envelope. The envelope should be specified in terms of airspeed and altitude. See 3.1.1.1.1 Aerial refueling envelope.

<u>Operating Conditions</u>: Identify environmental conditions under which the aerial refueling operation must be performed. Conditions would include day/night, all lunar angles while in flight, and turbulent air. Also, the induced environmental conditions from section 3.2 Environment that are encountered during the aerial refueling process must be identified.

Induced conditions would include electromagnetic coupling interactions between the tanker and the receiver(s).

Procedure: Some air vehicles may require specific procedures for refueling operations. This column should list any unique or required refueling procedures required by the receiver air vehicle. Examples would include NATO STANAG 3971 or Allied Tactical Publication (ATP) 56. If other procedures are required, ensure they address all factors associated with aerial refueling operations. The procedures should address day versus night operations (with and without night vision goggles), employment versus deployment scenarios, tanker/receiver rendezvous methods, communication techniques under various threat levels for detection/intercept, tanker/receiver formation techniques under various under single/multiple tanker and single/multiple receiver combinations, and tanker/receiver contact process under single/multiple combinations. For drogue subsystems, the procedures must address any limitations on receiver closure rates to achieve a successful contact and any limitations on receiver movement relative to the tanker during the fuel transfer process after probe nozzle/coupling engagement. See Aerial Refueling Envelope paragraph.

Interface Clearance Envelope: Identify the receiver refueling interface clearance envelope. Typically, the tanker-refueling interface would be designed such that it is capable of fitting the smallest receiver interface clearance envelope. An example would be that interface may not exceed the envelope dimensions specified in NATO STANAG 3447 (ASSE) for the probe interface~~.~~

Receiver Fuel Type: Identify the fuel types that the receiver air vehicles are able to accept (designated primary and alternate fuels). This column should include all deviations from the fuel specification requirements.

Receiver Fuel Pressure: Identify the fuel delivery pressure that characterizes receiver air vehicle capabilities. Pressures should be expressed in terms of minimum acceptable, maximum allowable, and the threshold above which damage occurs due to fuel transfer pressures. An example would be that the minimal allowable pressure is 30 psig, the maximum allowable pressure is 50 psig, and the threshold above which damage occurs is 70 psig.

Receiver Flow Rate: Identify the receiver fuel flow rate information. This information is usually in the form of fill sequence chart depicting maximum fuel rate versus time. These charts will assist in the determination of the number of refuel points and transfer rate for tanker to meet each of the receivers refuel time requirements.

Receiver Maximum Refuel Amount: Identify the maximum refuel capacity for the receiver air vehicle. This can be expressed in terms of pounds of fuel or gallons of fuel, or in terms of percentage of total fuel tank volume. Typically, this is not 100% of the maximum fuel tank capacity, because of design factors such as ullage space, unusable fuel, structural and stability limitations, etc.

Maximum Receiver Air Vehicle Refuel Time: Identify the maximum refuel time that is required by the air vehicle. This column has a direct relationship to fuel flow rate, fuel flow pressure, and maximum refuel capacity and should be developed in concert with these parameters. This parameter should include time from initial connection (if multiple reconnects are required, the time would still be initiated at the initial connection), refuel to the maximum refuel amount, and disengage from the tanker air vehicle.

Receiver Proof Pressure Limit: Identify the proof pressure limit for the aerial refueling plumbing of each receiver. Transient and steady state fuel pressures that occur within the receiver's aerial refueling system during the fuel transfer sequence must not exceed this limitation.

Receiver Visual Cues: Identify the visual cues provided on each receiver air vehicle that are required to be observed by a tanker crew member during the aerial refueling process. Visual cues include the specific exterior lighting, markings, and other visual indicators associated with the receiver aerial refueling interface. Include dissertation and/or standardized aerial refueling lighting

Guidance for completing table 3.4.6.2.2-II follows:

Total Simultaneous Receivers: Identify the total number of simultaneous receivers, which will be aerial refueled by the tanker air vehicle. For example: one (the one air vehicle would be a B-52) or 4 (of a distribution of F-18s and F-15s). Insert the number in table 3.4.6.2.2-II. If the number of simultaneous receivers is specified in the Air System Specification, then the total number and combination of receivers will probably be a direct flowdown requirement.

Receiver Combinations: Identify the anticipated air vehicle combinations to be aerial refueled by the air vehicle (for example, a combination of 2 F-18s and 2 F-15s).

Minimum Tanker to Receiver Separation Distance: Identify the minimum distance permitted between the tanker air vehicle and receiver air vehicle (excluding interface area). This distance would be the minimum distance between the tanker and receiver at the pre-contact, contact, fuel transfer, and disconnect positions.

Minimum Receiver to Receiver Separation Distance: Identify receiver separation distance required for simultaneous aerial refueling operations. This distance would be the minimum distance between any multiple receivers at the pre-contact, contact, fuel transfer, and disconnect positions.

Number of Off-Load Occurrences Per Tanker Sortie: Specify the number of times per tanker sortie that this refueling condition occurs. In conjunction with the off-load capacity per receiver and number of receivers per flight, this will size the total off-load capacity per tanker. Note: this is total off-load capacity per mission (an installed-performance requirement).

REQUIREMENT LESSONS LEARNED (3.4.6.2.2)

If the air vehicle has a tanker mission, identification of the targeted receiver air vehicle should be based on inputs from the ORD, and possibly the mission(s) of the air vehicle and its aeroperformance capabilities. If the air vehicle has a general support tanker mission, there is an existing MOU between the U.S. Navy and the USAF (10 Jul 81) which states that all general support tankers will be equipped with both tanker aerial refueling subsystems, i.e., boom and drogue subsystem. The MOU further states that each tanker aerial refueling subsystem will operate independently from the other tanker aerial refueling subsystem(s) and will be capable of refueling the targeted receiver air vehicles throughout the receiver's normal aerial refueling envelope. The MOU also specifies that specialized mission tankers (e.g., carrier-based tankers and helicopter-dedicated tankers) need only be compatible with their planned receiver air vehicle.

The identified receiver fleet will dictate many of the design requirements for the air vehicle as a tanker. For example, the targeted receiver fleet will determine the type of tanker aerial refueling subsystem(s) installed on the air vehicle, i.e., boom versus drogue subsystem, and the number of tanker aerial refueling subsystems installed; i.e., single subsystem versus dual subsystem, and the configuration of each tanker aerial refueling subsystem installed;

i.e., single-point versus multipoint/redundant points. The identified receiver fleet will also dictate the aerial refueling envelope that the air vehicle and its tanker aerial refueling subsystem(s) will have to operate within to be compatible with each targeted receiver aerial refueling subsystem. The identified receiver fleet can also dictate the aerial refueling procedures that must be used which can impact the air vehicle and its tanker aerial refueling subsystem(s) design. The physical size of each targeted receiver platform can dictate the number and location of each tanker aerial refueling subsystem installed on the air vehicle. The targeted receiver fleet will also dictate what type of fuel(s) the air vehicle must be able to carry and off-load as a tanker to the receiver(s). The targeted receiver mission(s) can dictate the allowable time the aerial refueling process for a receiver or a cell of receivers may be. As such, predetermined aerial refueling times within the receiver mission(s) can impact the air vehicle tanker design with regards to number and location of each tanker aerial refueling subsystem and the fuel off-load rate for each tanker aerial refueling subsystem.

As the aerial refueling subsystem performance capabilities can vary drastically from each type of receiver air vehicle, the identification of the targeted receivers should be specific to aircraft model, series, and country/service to account for differences among receiver air vehicles. For example, different series within a given model can have a different location for their aerial refueling subsystem(s) that could impact tanker/receiver clearances during the aerial refueling process. In addition, different design features can be incorporated into a model series' aerial refueling subsystem(s), e.g., probe strength, which could dictate different performance requirements for the air vehicle's tanker aerial refueling subsystem(s).

Ensure all targeted receiver air vehicles are identified by using an ORD that has been coordinated by the user command(s) for the air vehicle and the respective receiver command(s) that the air vehicle will operate with when aerial refueling. In addition, examine any MOUs/MOAs that may exist between the DoD services and/or with other allied countries regarding tanker support.

The U.S. Government has agreed to comply with NATO STANAG 3971, without reservation or exception. As such, all new tanker air vehicles with an aerial refueling subsystem must be able to conduct aerial refueling operations per NATO STANAG 3971 procedures.

New tanker air vehicles and their tanker subsystems should be able to aerial refuel fielded receiver air vehicles using procedures consistent with the receiver air vehicle’s existing aerial refueling procedures. The USAF has defined aerial refueling procedures with each receiver air vehicle. These procedures are contained within a series of TOs numbered 1-1C-1-XX (XX designates a unique number for each receiver air vehicle, e.g., AFTO 1-1C-1-35 is for the C-17). Aerial refueling procedures for the U.S. Navy/USMC receivers are provided in individual aircraft NATOPS manuals and NAVAIR NATOPS 00-80T-110 Air-to-Air Refueling Manual.

The NATO STANAG 3971 contains a list of points of contact (POC) for current allied receivers. When aerial refueling support is to be provided to, or obtained from, allied air vehicles, these POCs should be contacted to determine if any unique changes/exceptions to the aerial refueling procedures in the document are required to be compatible with their air vehicles. An allied country may have agreed to the STANAG with reservations and/or concurred with the document for future air vehicles but took exception for existing air vehicles at the time of coordination.

For tanker drogue aerial refueling subsystems, it is important that the aerial refueling procedure(s) identify the limitations and restrictions associated with the receiver’s closure rate (relative to the tanker) to achieve a successful engagement of the probe nozzle with the drogue coupling and the receiver's maneuvering rate (relative to the tanker) once engaged.

When identifying the induced environmental conditions, ensure that during the aerial refueling operation (particularly when the tanker and receiver(s) are engaged) electromagnetic compatibility of the equipment onboard each air vehicle is maintained and that there are no unintentional electromagnetic interactions on any air vehicle caused by the flight operations of another air vehicle in the aerial refueling process. Transmissions on HF communication are a particular concern during aerial refueling operations because the wavelength involved can cause resonant interaction between the air vehicles participating in the aerial refueling process. Electromagnetic compatibility on any air vehicle may be compromised and arcing is possible across poor electrical bonds.

The airspeed/altitude envelope that existing receiver aerial refueling subsystems are able to operate varies from subsystem to subsystem. Each receiver has its unique airspeed/altitude envelope that it is able to operate its aerial refueling subsystem(s). As such, the airspeed/altitude envelope for each new tanker aerial refueling subsystem being developed should be made as large as possible to maximize operational utility of the subsystem and mission flexibility for the air vehicle.

Tanker stability varies from platform to platform. Similarly, the stability of a tanker aerial refueling subsystem interface varies from platform to platform and from subsystem to subsystem. Each receiver has its own inherent stability characteristics that can be altered when placed behind a tanker. Receiver stability behind a tanker will differ from tanker platform to tanker platform and from tanker subsystem to tanker subsystem. As such, the minimum separation distance(s) must be specified for each particular aerial refueling subsystem on each particular tanker platform taking into account these various stability parameters.

Separation distances have been specified as definite lengths (feet) and have be defined in relative proportion of receiver air vehicle wingspans. For example, the minimum separation distance between adjacent receiver air vehicles in simultaneous, multipoint refueling operations has been specified to equal at least ¼ the wing span of the largest winged receiver air vehicle that can be in the simultaneous, multipoint refueling operation when the receiver air vehicles are in any position within the fuel transfer range for the particular tanker aerial refueling subsystems.

For tanker drogue subsystems, it is critical to address this requirement, particularly when the target receiver air vehicle(s) include(s) rotary-wing (helicopter) receivers. For such receivers, it is important that there is adequate clearance between the trailing aerial refueling hose and the rotary blade(s) of the helicopter receiver such that the rotary blade(s) does(do) not strike the aerial refueling hose during the aerial refueling process. Particular concern for adequate clearance should be upon the approach to contact, initial contact, and fuel transfer positions associated with drogue aerial refueling subsystem. One critical design parameter that can affect the clearance between the trailing aerial refueling hose and the rotary blade(s) of a helicopter receiver is the hose trail angle (cantenary curve) for the given airspeed/altitude conditions. Another critical design parameter is the hose response capability (hose reel drogue subsystems) at initial receiver contact and when an engaged receiver maneuvers about within the operating envelope for the given drogue aerial refueling subsystem.

Obstructions can cause hang-up of the tanker subsystem interface that would prevent it from mating with the receiver subsystem interface. Obstructions can also cause damage to either aerial refueling subsystem interface that can result in damage to the interface such that mating is not possible and/or uncontrollable fuel leakage occurs. In addition, obstructions in and around the aerial refueling subsystem interface areas can become damaged and/or broken off resulting in a loss of capability to other air vehicle subsystems and/or becoming a source of FOD to the receiver air vehicle. Obstructions that have been identified in previous air vehicles include external air data sensors, external temperature sensors, raised structural fasteners, and antennae.

The U.S. Government has agreed to comply with NATO STANAG 3447 (ASSE), without reservation or exception. As such, all new aerial refueling subsystems must meet NATO STANAG 3447 (ASSE) with regard to clearance around the interface(s).

The tanker boom subsystem interface (boom nozzle) must comply with the dimensional requirements of MS27604 in order to be physically compatible with existing receiver receptacle subsystem interfaces. The tanker drogue subsystem interface (drogue/coupling) must comply with the dimensional requirements of NATO STANAG 3447 (ASSE) in order to be physically compatible with the existing receiver probe subsystem interfaces. The U.S. Government has agreed to comply with NATO STANAG 3447 (ASSE), without reservation or exception. As such, all new drogue subsystem interfaces must meet NATO STANAG 3447 (ASSE). Ensure an adequate target area is provided in the receiver receptacle and tanker drogue interfaces to facilitate engagement with the boom nozzle and probe nozzle, respectively.

Following any type of disconnect, it must be possible for the tanker and receiver to effect another contact, if required, to successfully meet mission requirements. The shorter the time duration; the faster the cycle time between successive contacts of the tanker subsystem with the receiver subsystem will be. From a fuel pressure standpoint, a time of three seconds has been required for the fuel pressure to relieve back down to head pressure after the tanker’s coupling disconnects from the receiver’s probe. For tanker drogue subsystems, the specified time must account for the hose extension time to its full trail position following an inadvertent disconnect of the receiver probe from the coupling from the inner most position within the fuel transfer envelope for the subsystem.

If it is a boom subsystem, to be compatible with existing receptacle subsystems, the boom subsystem must be designed to withstand an ultimate tension (pullout) load of 14,000 pounds divided by cosine A, where the angle A may vary throughout a 30 degree cone measured about the receptacle bore centerline with the load applied at the boom nozzle ball joint. The boom subsystem must also withstand an ultimate compression load of 20,000 pounds applied at the boom nozzle ball joint, with the ball joint angle anywhere within a 34 degree cone measured about the receptacle bore centerline. The boom subsystem should also be designed for limit tension and compression loads of 9000 pounds divided by cosine C, where the load is applied at the boom nozzle ball joint and the angle C may vary from 0 to 17 degrees. In addition, the boom subsystem should also be designed to withstand ultimate impact loads of 2000 pounds laterally and 5000 pounds vertically. If it is a drogue subsystem, the drogue subsystem must be able to withstand the design limit disconnect loads. In the past, drogue subsystems were designed to withstand 115 percent of the design limit disconnect load. The limit disconnect load was calculated by the following formula:

$$\text{Load} = [(D + 1500)^2 + (W - L)^2]^{1/2}$$

D = Aerodynamic drag of the hose/drogue when at the full-trail position and at the airspeed/altitude for maximum dynamic pressure.

W = Weight of the hose when full of fuel plus the weight of the drogue/coupling.

L = Aerodynamic lift of the hose at full trail.

The limit disconnect load was applied along the centerline and the extremities of a $\pm 20^o$ cone centered about the normal lay of the hose when at the full trail position during flight. Also, in the past, a hose load of 2770 pounds had been specified for a 40^o cone taken about the normal hose trail axis for the drogue subsystem within its specified operating airspeed/altitude envelope.

In addition, the drogue subsystem should be capable of withstanding impact loads produced by the receiver's probe nozzle contacting all positions of the drogue/coupling up to an angular position of 15^o off-center of the drogue/coupling centerline and at probe velocities 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.

The above loads are in addition to any aerodynamic/gust loads that may be imparted on the structure of the air vehicle, its aerial refueling subsystem and the aerial refueling interface 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 lines of the subsystem/interface must be considered. All loading conditions must be applied to the support structure to which the aerial refueling subsystem/interface attaches.

Drogue aerial refueling subsystems have used markings on the fuselage, wing, engine nacelles, and external stores to provide formation references for the receiver air vehicle(s) during the aerial refueling process. The hose of a drogue aerial refueling subsystem typically contains markings to also assist the receiver crew(s) in: (1) determining that the drogue aerial refueling system is properly functioning, (2) determining the receiver's position relative to the tanker air vehicle once engaged with the drogue, (3) determining where to position the receiver in order to receive fuel from the drogue aerial refueling subsystem.

Centerline boom aerial refueling subsystems have provided position markings on the boom's shaft. These markings have been provided to assist the boom operator in (1) determining the air vehicle's position relative to the tanker air vehicle once engaged with the boom and (2) determining where to position the air vehicle in order to receive fuel from the boom aerial refueling subsystem.

Some tanker boom and receiver receptacle aerial refueling subsystems permit a secure voice communication capability once the tanker's boom nozzle is properly engaged within the receiver's receptacle. This design approach only allows communication to one receiver air vehicle during the contact/fuel transfer phase of the aerial refueling process.

One form of required data communication between tanker and receivers is identification of the receiver by tail number for the tanker's fuel accounting/billing requirements. In boom/receptacle aerial refueling operations, one method used to communicate such data has been to identify the receiver's tail number near/around the receptacle so that it is clearly visible to the boom operator. However, for probe-equipped receivers using a tanker's centerline drogue aerial refueling subsystem, the tail number may have to be verbally communicated to the tanker by the receiver. Other possible required data communication may include the specific amount of fuel accepted by each receiver.

There may be mission requirements in which voice/data communication is required throughout the entire aerial refueling sequence; i.e., from rendezvous, formation, pre-contact, contact/fuel transfer, reformation). There also may mission requirements in which simultaneous voice/data communication is required between the tanker and multiple receivers throughout the aerial refueling process. Voice/data communication system(s) must be electromagnetically compatible with flight operation of the air vehicles involved in the aerial refueling operation.

When the air vehicle is a tanker, the type(s) of fuel that its aerial refueling subsystem(s) should be capable of delivering must be selected based upon the designated primary fuel(s) of the targeted receiver air vehicles. The type(s) of fuel to be delivered by each tanker aerial refueling subsystem may vary from subsystem to subsystem. When the air vehicle is a receiver, the primary fuel(s) for the air vehicle must be identical to the fuel(s) capable of being delivered by the tanker aerial refueling subsystem(s) of the targeted tanker(s). If the air vehicle's primary fuel is different than the primary fuel of the target tanker(s), special modifications will be required on the tanker(s) to support the air vehicle. See requirements under 3.4.11 Fuel designation.

The fuel specifications identify what the requirements are for the fuel at procurement. Once the fuel has been handled through the fuel delivery system (pipeline, storage tanks, hydrant tanks, refuel trucks, etc.), certain properties of the fuel can change prior to the introduction into the air vehicle. Once inside an air vehicle, the fuel properties can change again such that the fuel may no longer meet all of its original specification requirements. This feature must be recognized when transferring fuel from a tanker air vehicle to a receiver air vehicle. The receiver air vehicle may be accepting fuel that no longer meets its procurement specification requirements and may have different properties than that same fuel originally delivered on the ground.

If a tanker air vehicle uses its fuel for thermal management, and that fuel can be transferred to a receiver, the delivered fuel temperature from the tanker to the receiver may be incompatible for use in the receiver's aerial refueling/fuel subsystem, particularly if the receiver also uses its fuel for its own air vehicle thermal management.

Receiver aerial refueling subsystems are designed assuming a predetermined fuel delivery pressure at the aerial refueling interface from the tanker. If the fuel delivery pressure from the tanker is significantly lower than what the receiver's aerial refueling subsystem was designed for, the fill rate into the receiver will be different than what is expected for the receiver. In addition, a significantly lower delivery pressure could affect the fill sequence into the receiver, which could impact the center of gravity of the receiver as it aerial refuels. If the fuel delivery pressure from the tanker is significantly higher than what the receiver's aerial refueling subsystem was designed for, the result can be higher surge pressures being experienced within the receiver's aerial refueling subsystem than what is expected. These higher surge pressures could possibly exceed the proof pressure of the receiver's aerial refueling subsystem, which could lead to fuel leaks, and/or component damage within the receiver's aerial refueling subsystem.

The fuel delivery rates/pressures must consider the maximum delivery rate and delivery pressure possible for the given tanker/receiver combination, whether the limitation for delivery rate/pressure may be a tanker subsystem limitation or a receiver subsystem limitation.

Fuel surge pressures include, but are not limited to, those generated by pump start-up, tanker/receiver valve closures, and tanker/receiver disconnects (normal operational disengagement and inadvertent, fuel-flowing disengagement). These types of transient pressures are typical during the aerial refueling process; i.e., no subsystem failures within either the tanker or any receiver aerial refueling subsystem.

Proof pressure limitations must include positive and negative pressures.

In multipoint aerial refueling operations (i.e., a tanker having more than one aerial refueling subsystem and has at least two receivers simultaneously refueling), it is important to consider pressure transients generated by the refuel process to one receiver being able to propagate to the refueling process of another receiver. Where tanker subsystem designs permit such an occurrence, the resultant level of fuel surge pressures within the engaged receiver aerial refueling subsystem can be higher than those experienced during single receiver refueling due to a cumulative effect.

When applicable, consider those fuel surge pressures generated during reverse aerial refueling procedures.

Single failures of fuel pressure regulation mechanisms within the air vehicle's aerial refueling subsystem include any pressure regulator, whether it is installed in a component (e.g., coupling), part of a subassembly (e.g., pod), or is installed within the air vehicle's basic fuel/aerial refueling subsystem. Single failures of surge alleviation mechanisms include surge boots, surge accumulators, surge dampeners, etc.

The total fuel off-load capacity for a tanker must not compromise the air vehicle's ability to meet other performance requirements within its mission(s); e.g., range, loiter, etc.

4.4.6.2.2 Tanker interfaces verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Capability to refuel the specified receiver air vehicles in accordance with tables 3.4.6.2.2-I and 3.4.6.2.2-II	Pass/Fail (for each combination)	A,S	A,S	A,S		A,S, D,T
Visual cues	(1)	A,S	A,S	A,S		A,S, D,T

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.4.6.1.2)

Verification of the requirements for the aerial refueling tanker interfaces is based on initially quantifying the characteristics of the air vehicle receiver(s) that the tanker air vehicle must accommodate. Then, verification of the tanker interfaces requires the evaluation of each of the interface requirements between the air vehicle receiver(s) and the tanker air vehicle. The verifications should be accomplished by integrating a series of analyses followed by simulations, tests, and demonstrations to evaluate each of the interface requirements.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analyses and simulation of receiver to tanker interface physical, functional and procedural characteristics (e.g., mandatory STANAGs requirements and mandatory Joint Service characteristics) between the known receivers and the developmental tanker indicates the tanker aerial refueling interfaces are defined and agreed upon. Analyses of the tanker interfaces (e.g., clearance envelopes, communications, boom and probe loads, desired fuel transfer time, fuel delivery flow rate and fuel operating pressure, surge pressures and visual cues) between the different types of air vehicle receivers are defined and agreed upon. The totality of these analyses indicates that the requirements have considered all features related to each of the interface characteristics driven by the receivers and by the tanker ORD. Aerial refueling risks have been defined and needed trade studies have been defined or initiated.

PDR: Analysis of the provisions for tanker interfaces and the preliminary design for the tanker to receiver interfaces for compatibility with planned receivers has been completed. Analyses of planned simulations of aerodynamic characteristics of the tanker and the resulting impact on the receivers have been considered and evaluated relative to aerial equipment mounting locations. Structural analyses of the loads transferred from the tanker to the receiver have been evaluated and are within required limits. Tanker and receiver fuel system characteristics including fuel line sizing, operating pressure, surge pressure delivery flow rates analysis, simulation and analysis of lower-level component and iron bird testing are complete or in the final stages. Test plans to assist in mitigating the anticipated risks, prior to conducting any demonstrations, are being developed. All high to moderate risk items have been identified and mitigation approaches are in place.

CDR: Analysis of the completed design provisions, simulations and lower-level testing of the tanker design confirms compatibility with the specified requirements for achieving the tanker interfaces. Any area of incompatibility has been thoroughly researched and additional testing of areas of concern have been completed. Interface control documents, if any, have been fully negotiated, completed, and provided.

FFR: No unique verification action occurs at this milestone.

SVR: Simulations, demonstrations, analyses, and testing confirm that the tanker aerial refueling interfaces have been achieved.

Sample Final Verification Criteria

The air vehicle tanker interface requirements shall be satisfied when __(1)__ analyses, __(2)__ simulations, __(3)__ demonstrations, and __(4)__tests confirm the capability to refuel and provide specified visual cues.

> Blank 1. Identify the types and scope of analyses required to confirm the tanker air vehicle has met all of the requirements and is capable of interfacing with the specified receivers.
>
> Analyses should include, but are not limited to, aerodynamic and structural loading of the aerial refueling equipment and attachment structure throughout the specified operating envelope. Clearance of the tanker interfaces should be evaluated including clearance with multiple receivers. Tanker controllability should be performed throughout the c.g. and gross weight range. Analysis may be performed of the turbulence and wake generated by the tanker in the position of the receiver aircraft throughout the operating envelope and gross weight range of the tanker. Analyses with boom systems should include controllability of the boom while both connect and disconnected from the receiver, latch forces throughout the applicable range of temperatures and disconnect rates, latch and unlatch times, and flutter analysis throughout the operational envelope. Hose and drogue systems should consider hose response and take-up rate, hose extension capability, drogue stability, and catenary curve. Analyses of fuel line sizing to achieve desired flow rate, pump sizing with consideration for pressure drops and line losses, and system proof pressure

capabilities should be performed. Ventilation analysis for vapor dilution should be conducted for all phases of the mission including, but not limited to, static or low-speed ground operations, high altitude/low air density, and other unique conditions.

Blank 2. Identify the type and scope of the simulations required to confirm the tanker air vehicle has met all of the requirements and is capable of interfacing with the specified receivers.

Blank 3. Identify the type and scope of tanker aerial refueling ground and flight demonstrations required to confirm the tanker air vehicle has met all of the requirements and is capable of interfacing with the specified receivers.

Demonstrations should include, but are not limited to, tanker flying qualities throughout the altitude airspeed and gross weight ranges. Boom controllability and hose and drogue stability should be assessed throughout the operating envelope including evaluation of the gross weight range of the tanker and receiver. Bow wave effects of various receivers on a boom or drogue should be evaluated. For hose and drogue systems, catenary curve and hose response should be evaluated. For boom systems, latch and unlatch times must be determined. Demonstration and evaluation of the tankers visual cues to the receiver should be evaluated including status lights, markings and other visual indicators. Demonstration should include refueling capability in day versus night operations (with and without night vision goggles), turbulence and other adverse weather. Demonstration should include simultaneous refueling of receivers if system is a multipoint tanker. Evaluation should include communication systems between the tanker and receiver showing that no electromagnetic interference exists between the tanker and specified receivers.

Blank 4. Identify the scope and type of tanker aerial refueling ground and flight tests required to confirm the tanker air vehicle has met all of the requirements and is capable of interfacing with the specified receivers.

Tests should include structural load evaluation of the aerial refueling equipment probe and boom loads, latch forces of boom systems at all temperature extremes within the operating envelope to include rigid disconnects. Fuel pressure and flow rate testing should be first performed during ground tests for operating, surge and proof pressures. Tanker fuel surges during flowing disconnects should be evaluated on the ground throughout the range of tanker fuel flows. Flight tests should measure fuel flow rates, operating pressure and surge pressures throughout all phases of the aerial refueling process. During simultaneous refueling, testing should be performed to verify that surges are not reflected through the tanker as a result of level control valve closure or flowing disconnects of the opposite receiver aircraft.

VERIFICATION LESSONS LEARNED (4.4.6.2.2)

To Be Prepared

3.4.7 Facility interfaces

The air vehicle shall be capable of interfacing with the facilities identified in table 3.4.7-I.

TABLE 3.4.7-I. Air vehicle facility interfaces.

Facility	Facility Functional Capability	Status	Facility Description (Compatibility Requirements)

REQUIREMENT RATIONALE (3.4.7)

In order for an air vehicle to operate effectively at a desired location, facilities expected to shelter, maintain, and service the air vehicle should be identified. Appropriate interface design characteristics associated with existing facilities should be addressed in order to make the air vehicle compatible with these facilities, or to determine air system facility interface requirements. Facilities include the structure, building, utility system, pavement or underlying ground at a testing, training, or operating location where the air vehicle may be required to interface. A requirement to place an air vehicle in an existing structure can impose strict dimensional (and other) restrictions on the design of the air vehicle. Air vehicle interfaces with shipboard facilities present a unique set of requirements that are addressed in section 3.4.8 Ship compatibility.

REQUIREMENT GUIDANCE (3.4.7)

Guidance for completing table 3.4.7-I follows:

Facility: Identify the facility, preferably with the appropriate nomenclature. This nomenclature could include a class of facilities or reference facilities at a particular location i.e., hangars at Red Flag or Fallon. Reference to air capable ships should not be included with this requirement since they are addressed elsewhere within this document.

Functional Capability: Identify the function of the facility as it relates to the air vehicle. Examples of functions could include protection of the air vehicle from weather, protection of the air vehicle from a threat or group of threats, or housing/vehicle repair.

Status: Identify whether the subject facility is an existing facility or if it is a planned facility.

Facility Description: Reference to specifics of the facility interface should be addressed. Planned facility interface characteristics should also be addressed within this section. The following are examples of information that could be provided: size/dimensions, type, environmental control, access (door size and type if applicable) interface requirements with installed equipment (Include equipment unique to the facility, which is not addressed within the remainder of the interface section of this document), and classified material/equipment handling capability.

REQUIREMENT LESSONS LEARNED (3.4.7)

To Be Prepared

4.4.7 Facility interfaces verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Facility interfaces	Interface to each facility (table 3.4.7-I)	A	A	A	A	A,D

VERIFICATION DISCUSSION (4.4.7)

Verification of the facility interfaces requirement should be accomplished by integrating analyses with demonstrations of the air vehicle with the facility interfaces. During air vehicle developmental activities, substantial data is typically obtained that could be used to verify this requirement. Use of this type of data should be maximized to avoid the cost and schedule impacts of a formal demonstration.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the design concept indicates that requirements for the interfaces between the air vehicle and each required facility are defined and understood. Analysis indicates the preliminary design approach considers interfaces to each facility listed.

PDR: Analysis of the air vehicle preliminary design indicates compatibility with facility interfaces listed.

CDR: Analysis of the air vehicle final design confirms compatibility with the facility interfaces requirements. Any area of incompatibility has been thoroughly researched, and trade-offs identified.

FFR: Analysis confirms that all air vehicle-facility interfaces that impact first flight are compatible.

SVR: Analysis and demonstration confirms air vehicle compatibility with all facility interfaces.

Sample Final Verification Criteria

The air vehicle facility interfaces requirement shall be verified by __(1)__ analyses and demonstrations of the interface between the air vehicle and each required facility to confirm that the interface requirements defined by __(2)__ have been met.

> Blank 1. Identify the type and number of analyses and demonstrations required to confirm facility interfaces compatibility.
>
> Blank 2. Identify the interface requirement documents that must be met during the analyses and demonstrations.

VERIFICATION LESSONS LEARNED (4.4.7)

To Be Prepared

3.4.8 Ship compatibility

The air vehicle shall be capable of being operated and maintained from ships as specified in table 3.4.8-I. The air vehicle shall be compatible with ship elevators as specified in table 3.4.8-II.

TABLE 3.4.8-I. General ship compatibility.

Ship	Maximum Height	Spotting Factor	Catapult System/ Drawing Number	Arresting Systems/ Drawing Number	Barricade System/ Drawing Number	JBD Type/ Drawing Number	High Thrust Fitting Type/ Drawing Number	Conditions

TABLE 3.4.8-II. Ship elevator compatibility.

Ship	Elevator Dimensions	Number of Air Vehicles	Equipment	Conditions

REQUIREMENT RATIONALE (3.4.8)

This requirement is critical for air vehicles that are to be utilized for Navy shipboard missions. This requirement identifies all air vehicle design constraints associated with effective operation and maintenance from a ship.

REQUIREMENT GUIDANCE (3.4.8)

For fixed wing air vehicles, the following catapult compatibility requirement may be added to this requirement if applicable: “The air vehicle shall not contact other air vehicles of the same type when in tension on the bow catapults and one foot off-center toward the ship centerline.”

The table contained in this requirement identifies all applicable interfaces onboard ships on which the air vehicle will operate. The columns of the table can be completed or deleted in order to include appropriate levels of detail, but for the purposes of specification development, it is recommended that all columns be included in order to fully describe the ship interface.

Guidance for completing table 3.4.8-I follows:

<u>Ship</u>: Identify the ships from which the air vehicle will be required to operate. The column can be completed by identifying the class of ship, such as: aviation ships (fixed wing and rotary wing capable), amphibious aviation ships (fixed wing and rotary wing capable), amphibious air capable ships (rotary wing capable), and/or logistics force ships (rotary wing capable).

This column can also be completed with information such as “Nimitz class carriers” or with the designation of the ship(s) to be utilized, i.e., “CVN-70.” Care should be taken when completing this column to assure that the identified ship population represents consistency in relation to the other ship attributes identified in the remainder of the table.

Maximum Height: Identify the maximum allowable height of the air vehicle for all maintenance, stowage, and operating conditions. Maintenance conditions would include the maximum height of the air vehicle during various failure modes or air vehicle ground evolutions, e.g., flat tires; struts in their most compressed or extended condition; motion induced by the ship combined with a flat strut, flat tire or other condition; air vehicle jacked in a worst-case condition for maintenance such as to repair a flat tire or strut; passing over deck imperfections; or canopy or ejection seat removal. Stowage considerations should include the maximum heights attained during evolutions such as wing and/or tail folding; rotor blade stowing or unstowing; engine tilt; etc.

Maximum heights for various ship types include

Air Vehicle Type	Ship Type	Maximum Height	Conditions
Fixed Wing	Aviation and Amphibious Aviation Type	24 feet 6 inches	All air vehicle failure conditions, i.e., non-symmetric shock absorber deflections resulting from one wing being folded before the other with a flat tire on either side of the air vehicle passing over six inch deck imperfections
Fixed wing	Amphibious Air Capable Type	19 feet 6 inches	All loading configurations with worst case air vehicle height i.e., wings folded, tail folded, canopy open, passing over six inch deck imperfections, nose open or opening, and air vehicle on jacks with all of the aforementioned examples
Rotary Wing	Aviation Type Ships	24 feet 6 inches	Any loading configuration i.e., unfolding rotors, unfolding tail, passing over six inch deck imperfections
Rotary Wing	Aviation Type Ships	18 feet 6 inches	Folded rotors, folded tail, passing over six inch deck imperfections

Spotting Factor: The air vehicle-spotting factor should be derived from NAEC-ENG-7604 and from a higher-level sortie generation rate required for the ship. Normal spotting factor should exploit the variable geometry features of an air vehicle in order to assure maximum stowage capability within the ship(s) from which the air vehicle will be required to operate. However, consideration must be made for each significantly different configuration in which the air vehicle may be required to be stowed, with particular attention to the worst case spotting factor that may result from an air vehicle failure.

Catapult system: Identify the catapult system(s) for the ships from which the air vehicle will be required to operate. Refer to NAEC-MISC-06900 Rev D for current ship catapult systems. Refer to NAEC-MISC-OA136 for dead load catapult performance and the method to be used to calculate thrust effect on catapult end speed. The drawing number of the system should also be identified. It should be noted that the “Ski Jump” is a viable alternative to identify in this column as well.

Arresting Systems: Identify the arresting system for the ships from which the air vehicle will be required to operate. Appropriate entries may include MK 7 Mod 3 with service change 428, 1 7/16-inch cables otherwise known as MK 7 Mod 3+ arresting gear. The drawing number for the system should also be identified.

Barricade System: Although current barricade systems are similar in design, this column is inserted to identify any changes that might occur in barricade systems in the future. The drawing number of the system and maximum loading requirements should also be identified. Barricade performance is specified in NAEC-MISC-O8784.

Jet Blast Deflector (JBD) Type: Identify the JBD type. If a designation is not available to enable identification of JBD classes, the dimensions, material type and any limitations should be identified in this column. The drawing number for the system should also be identified.

High Thrust Fittings: The interface dimensions of the high thrust fittings for each ship or class of ships are defined in NAEC-ENG-6703 Rev 23. This column in the table should be completed with the applicable high thrust fitting type, deck location(s) and drawing number within the aforementioned document.

Conditions: If appropriate, identify more detailed criteria for the specific interface. Examples of catapult hook-up include

a. Hookup. Self-engaging with only the approved catapult holdback bar at an air vehicle maximum speed of 4 knots, with deck level visual indicators of hookup.

b. Hookup Retention. Establish a vertical down force of 30-50 pounds on the hookup provisions to assure hookup retention and contact with the catapult track.

c. Hookup Holdback. Capable of moving ± 15 degrees from a centered position in the vertical and horizontal axes with a lateral centering force to retain contact with the catapult holdback bar, damping large accelerations in the vertical axis, and restraining the full power engine run up. Holdback overloads are to be controlled.

d. Hookup Disconnect. Automatic retraction of the vertical down force at the end of the catapult power run; emergency automatic retraction if needed. Include a pilot operated capability for abort or retraction of the hookup.

Refer to report NAEC-ENG-7481 for information on the MK-2 Nose Gear Launch System, which is the current shipboard system. Refer to NAEC-DWG-607770 for details of the catapult nosegear launch system dimensions for launch bar and holdback design. Refer to MIL-DTL-85110 for a detailed specification of the Repeatable Release Holdback Bar system design.

Compatibility with existing deck markings and wheel stop clearances are items that might also be addressed.

Guidance for completing table 3.4.8-II follows:

Ship: Identify the ships from which the air vehicle will be required to operate. Guidance for completion of table 3.4.8-I applies.

Elevator Dimensions: Identify the elevator dimensions of the ships from which the air vehicle is required to operate. The drawing number for the elevator(s) should also be identified.

Number of Air Vehicles: The minimum number of air vehicles to be carried on the elevator at the same time may be prescribed by a higher-level sortie generation requirement. Typically, for fixed wing air vehicles, the minimum number of air vehicles to be carried on the elevator is two.

Equipment: Identify the maximum amount of support equipment and personnel that will be required to be spotted on the elevator along with the air vehicle(s). Items such as tow tractor, tow bar, and the maximum number of personnel required for launch may be included in this column.

Conditions: Identify the loading conditions of the air vehicle while on the elevator. Items such as internal fuel and store loadings may be included in this column. Identify other characteristics of the interface such as the ability to turn the air vehicle around on the elevator e.g.; For CV/CVN class ships, the air vehicle shall be capable of performing a 180-degree turn on the elevator at the hangar deck level. (For all other class ships the 180-degree turn on the elevator is not required.) Conditions for elevator compatibility should include the air vehicle spotted with its longitudinal axis perpendicular to the ship's centerline and nose pointing inboard.

REQUIREMENT LESONS LEARNED (3.4.8)

Past and present shipboard compatibility has been established through a closely regimented effort to ensure successful integration of new air vehicles into Navy ships. Deviations from proven interface methods and guidance in developing a ship-based air vehicle must be carefully considered to avoid costly and timely delays.

Past programs required an eighteen-inch clearance be maintained between the air vehicle and the ship structure for design purposes. The intent for the requirements was to develop a design point against which the system could be developed. This eighteen-inch clearance was specified in the past to account for ship motions and air vehicle loading. Since the requirement requires compatibility with the ship elevator the air vehicle should not strike the ship structure while utilizing the elevator and therefore the requirement should be achieved without mandating a required clearance. The eighteen-inch clearance requirement is therefore included in lessons learned to provide a design starting point for air vehicle/elevator compatibility. The same clearance issue is associated with the air vehicle tire positioning in relation to the outboard edge of the elevator platform. In the past, an eighteen-inch minimum clearance was required. The issue should be handled in verification along with the structural clearance.

4.4.8 Ship compatibility verification

(Note: The verification of 3.4.8.1 Shipboard tipback and turnover is included in this paragraph.)

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Requirement elements to be verified as part of other performance requirement verifications:						
Operational performance in specified shipboard environments	Performance characteristics specified in other air vehicle performance requirement paragraphs in section 3.1 Operations	A	A	A		A
Maintainability of the air vehicle in specified shipboard environments	Maintainability characteristics as specified in requirement 3.1.5 Maintainability	A	A	A		A
Requirement elements to be verified specifically as part of 3.4.8/3.4.8.1 performance requirement verifications:						
General ship compatibility	Table 3.4.8-I	A	A,S	A,S		A,S, D,T
Ship elevator compatibility	Table 3.4.8-II	A	A,S	A,S		A,S, D,T
Tipback and turnover	Dynamic tipback Turnover angle	A	A,S	A,S		A,D

VERIFICATION DISCUSSION (4.4.8)

This requirement provides condition information that must be considered in developing all air vehicle performance requirements and verifications for those air vehicles that will be operated from and aboard ships. In the event that shipboard design or operating conditions are defined or modified in other specific section 3 air vehicle performance requirements, the text of those specific requirements should take precedence over this requirement for that particular performance. Therefore, the verification approach defined below assumes that some of the air vehicle performance in specific shipboard environments should be verified via the specific performance requirements. However, there will be shipboard interface requirements that are best verified via this requirement paragraph. For example, verification of air vehicle interfaces while operating with specific catapult and arresting gear equipment should be verified as a unique 4.4.8 Ship compatibility verification effort.

Verification should be performed via a bottoms up approach, leveraging the analysis of design and subsystem compatibility with the shipboard environment until the requirement is ultimately verified during dedicated shipboard demonstrations and flight tests. Conversely, verification that the air vehicle achieves maintainability requirements under shipboard operating conditions should be addressed in 4.1.5 Maintainability verification, and verification of other operational requirements such as flight performance off of short runways, ground performance on ship decks, communication compatibility with the ship. Maintenance requirements will be performed as a portion of verification activities identified in other parts of section 4. Verification of the interface to items such as support equipment, fuels, and other items located on the ship should be handled in the appropriate paragraphs in the interface verification section of this document.

Requirement elements to be verified as part of other performance requirement verifications:

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements to be verified as part of other performance requirement verifications.)

SRR/SFR: Analysis indicates that shipboard interface conditions/requirements are defined for the specified operations, missions and service life usage profile. Analysis indicates that air vehicle planned usage (including the numbers of life cycle shipboard launches and recoveries that are expected to occur), maintenance concept for shipboard operations, and any unique requirements that would adversely impact compatibility with the identified ships are identified and are being considered for all associated requirements' verifications. Analysis indicates flight operation and maintenance scenarios that would drive air vehicle to ship interface characteristics are incorporated into verification of those specific requirements, and that the impacts to ship interfaces encountered during air vehicle launch, recovery, and basing are identified and defined.

PDR: Analysis of the verification plans for the operational performance and maintainability requirements indicates that the shipboard interfaces/conditions are considered. Analysis of the air vehicle preliminary design indicates ship interfaces are incorporated and that air vehicle planned usage, maintenance concept, and any unique requirements that would adversely impact compatibility with the identified ships are considered. Analysis indicates the preliminary design is addressing worst case arrangements of deck spotting and deck handling procedures for maximum density spots, spotting factors, operational spots and compliments, elevator fits, and related clearance considerations of the air vehicle for the ships from which it is intended to operate. Analysis indicates that any planned variable geometry features of the air vehicle consider ship design constraints. Analysis indicates that the air vehicle design is considering the barricade system and high thrust fittings for the ships from which it is intended to operate. Analysis indicates that interface control documentation for ship systems such as the catapult, arresting gear, elevators, etc. are incorporated into air vehicle preliminary design.

CDR: Analysis of the air vehicle final design confirms all ship interface requirements are incorporated and that the performance of the air vehicle in the shipboard environment is considered in all aspects of the design.

FFR: No unique verification action occurs at this milestone.

SVR: Analysis confirms that the performance of the air vehicle in the shipboard environment is considered in verification of all associated requirements.

Sample Final Verification Criteria

Analysis of verification results for each air vehicle performance requirement specified herein confirms that the shipboard interface requirements have been applied in defining the specific operational requirements/conditions for each air vehicle performance requirement.

Lessons Learned: To Be Prepared

Requirement elements to be specifically verified as part of paragraphs 3.4.8 and 3.4.8.1 performance requirements' verifications:

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements to be verified as part of other performance requirement verifications.)

SRR/SFR: Analysis of the air vehicle design concept indicates that the requirements for the interface between the air vehicle and ships are defined. Analysis of mission requirements identifies scenarios that would drive air vehicle to ship interface characteristics, including the impact to ship interfaces encountered during air vehicle launch, recovery, deck handling, maintenance, servicing, and other deck-based operations during normal and adverse deck movements. Analyses indicate the design approach includes provisions for height limitations, specified spotting factor, elevator clearances, and alignments with catapults, arresting gear and jet blast deflectors. Similarly, the design approach includes provisions for air vehicle characteristics such as landing weight and speed to assess continuing air vehicle compatibility with shipboard structural limitations, as well as catapulting, arresting, high thrust fitting, barricade and ship deck loading interfaces. Design considerations also include prevention of tip back at the most critical aft c.g. configuration and specified shipboard dynamic conditions, including air vehicle dynamic conditions such as arrestment pull backs, brake application during manual push backs and manual push backs into the flight deck coaming. Analysis of the design concept indicates consideration of dynamic tipback effects on air vehicle steering authority in high seas and on wet, worn and contaminated nonskid.

PDR: Analysis of air vehicle preliminary design indicates shipboard interface limitations and condition data are finalized and the design will be compatible with the ship interfaces listed. Analysis of the preliminary design indicates air vehicle planned usage, maintenance concept, and any unique requirements that would adversely impact compatibility with the identified ships given are considered. Analysis indicate various arrangements of deck spotting and deck handling procedures for maximum density spots, spotting factors, operational spots and complements, elevator fits, and related clearance considerations of the air vehicle for the ships from which it is intended to operate are considered. Analysis indicates that variable geometry features of the air vehicle, if implemented, such as sweeping or folding of various components are necessary to assure compatibility given the ship(s) design constraints. Analysis indicates that the air vehicle is compatible with the catapults, arresting gear, barricade system, and high thrust fittings for the ships from which it is intended to operate. Analyses and simulations using available air vehicle design data indicate compatibility with shipboard clearance requirements. Analyses of available test results (e.g., wind tunnel tests) and any shipboard arresting simulation, discloses changing landing loads are compatible with deck structural limitations, arresting, catapulting, and barricading interface requirements. Analysis indicates that the air vehicle will not tipback under specified worst case ship and air vehicle dynamic conditions.

CDR: Analysis and simulation using updated air vehicle design and subsystem data confirm compatibility with the ship interface requirements specified. As the design is finalized, analyses and simulations initiated during PDR have been continued without adverse impact on shipboard compatibility, or any areas of incompatibility, which dictate a unique design, have been thoroughly researched, and trade-offs identified. Updated simulations confirm that the air vehicle will not tipback during specified worst-case dynamic conditions.

FFR: No unique verification action occurs at this milestone, since air vehicle first flight does not typically utilize ship interfaces.

SVR: Analysis of lower-level demonstrations and tests confirm compatibility with ship systems, including arresting gear, catapult, jet blast deflector, etc. has been achieved. Dedicated land based and shipboard air vehicle demonstrations and tests confirm air vehicle compatibility with listed ships and ship subsystems, or instances of noncompliance have been corrected by a product definition change. Simulations using updated data, and shipboard demonstrations and tests confirm that tipback does not occur under shipboard operations such as arrestment pull backs, brake application during manual push backs and manual push backs into the flight deck coaming. Analysis and simulation using final air vehicle design confirm the air vehicle will not tipback during specified worst case dynamic shipboard conditions.

Sample Final Verification Criteria

The air vehicle to ship compatibility, tipback, and turnover requirements shall be verified by __(1)__analyses, __(2)__ demonstrations, __(3)__ simulations and __(4)__ tests of the interface between __(5)__ and the air vehicle confirm that the interface requirements specified in __(6)__have been met.

Note: Final verification criteria would be completed for each requirement element listed in the verification table above.

Blank 1. Identify the type and scope of analyses required to provide confidence that the shipboard compatibility requirement has been satisfied. Examples of analysis include nose gear analysis, arresting hook analysis, etc.

Blank 2. Identify the type and scope of demonstrations required to provide confidence that the requirement has been satisfied. Examples of demonstrations might include air vehicle servicing while in a stowed or confined location, spotting of the air vehicle in various locations on the ship (catapult, hangar deck, and operational spots), or the capability to handle the specified number of air vehicles on a shipboard elevator at the same time.

Blank 3. Identify the type and scope of simulations required to provide confidence that the requirement has been satisfied. Examples of simulations might include catapult launches and recoveries in a simulator.

Blank 4. Identify the type and scope of tests required to provide confidence that the requirement has been satisfied. Examples of tests might include land-based catapult launches and normal/barricade arrestments and shipboard catapult launches and recoveries.

Blank 5. Identify the ship or ship subsystem (requirements element from the verification table) with which the air vehicle is to be compatible. Separate criteria should be created for each requirement element listed.

Blank 6. Identify the interface requirements document that must be met during the demonstration. This should be the same document that is listed in table 3.4.8-I.

Lessons Learned: To Be Prepared

3.4.8.1 Shipboard tipback and turnover

The following applies consistent with figures 3.4.8.1-1 and 3.4.8.1-2.

At the most critical aft c.g. configuration, the air vehicle shall not tip back under the following dynamic conditions:

The air vehicle and a deck pitch and roll combination causing a __(1)__ slope in line with the angled deck, and with the air vehicle being pulled backwards during arrestment in the landing area at a maximum of __(2)__ mph, and then stopped by abrupt application of brakes with a co-efficient of friction of __(3)__. With no usable fuel in the internal tanks and a deck roll of __(4)__ degrees, and with the air vehicle being pushed backwards toward the deck edge at a maximum of __(5)__ mph and then stopped by the application of brakes with a co-efficient of friction of __(6)__ during deck spotting.

At the most critical c.g. configuration for turnover, the turnover angle shall not exceed __(7)__ degrees.

REQUIREMENT RATIONALE (3.4.8.1)

Operating air vehicles at sea imposes additional handling constraints on air vehicle designs. In addition to the static tipback requirement applicable to any air vehicle, consideration of dynamic tip back must be made for arrestment pull backs, brake application during manual push backs and manual push backs into the flight deck coaming. Steering authority must be maintained in high seas and on wet, worn and contaminated nonskid. Experience has shown good shipboard handling qualities for air vehicles with c.g. and gear locations as described in figures 3.4.8.1-1 and 3.4.8.1-2.

REQUIREMENT GUIDANCE (3.4.8.1)

The following are recommended values for blanks 1-7:

Blank 1. A value of __5__ is recommended.

Blank 2. A value of __5__ is recommended.

Blank 3. A value of _0.95_ is recommended.

Blank 4. A value of __5__ is recommended.

Blank 5. A value of __5__ is recommended.

Blank 6. A value of _0.95_ is recommended.

Blank 7. A value of __54__ is recommended.

REQUIREMENT LESSONS LEARNED (3.4.8.1)

The lessons learned of 3.4.8 Ship compatibility apply.

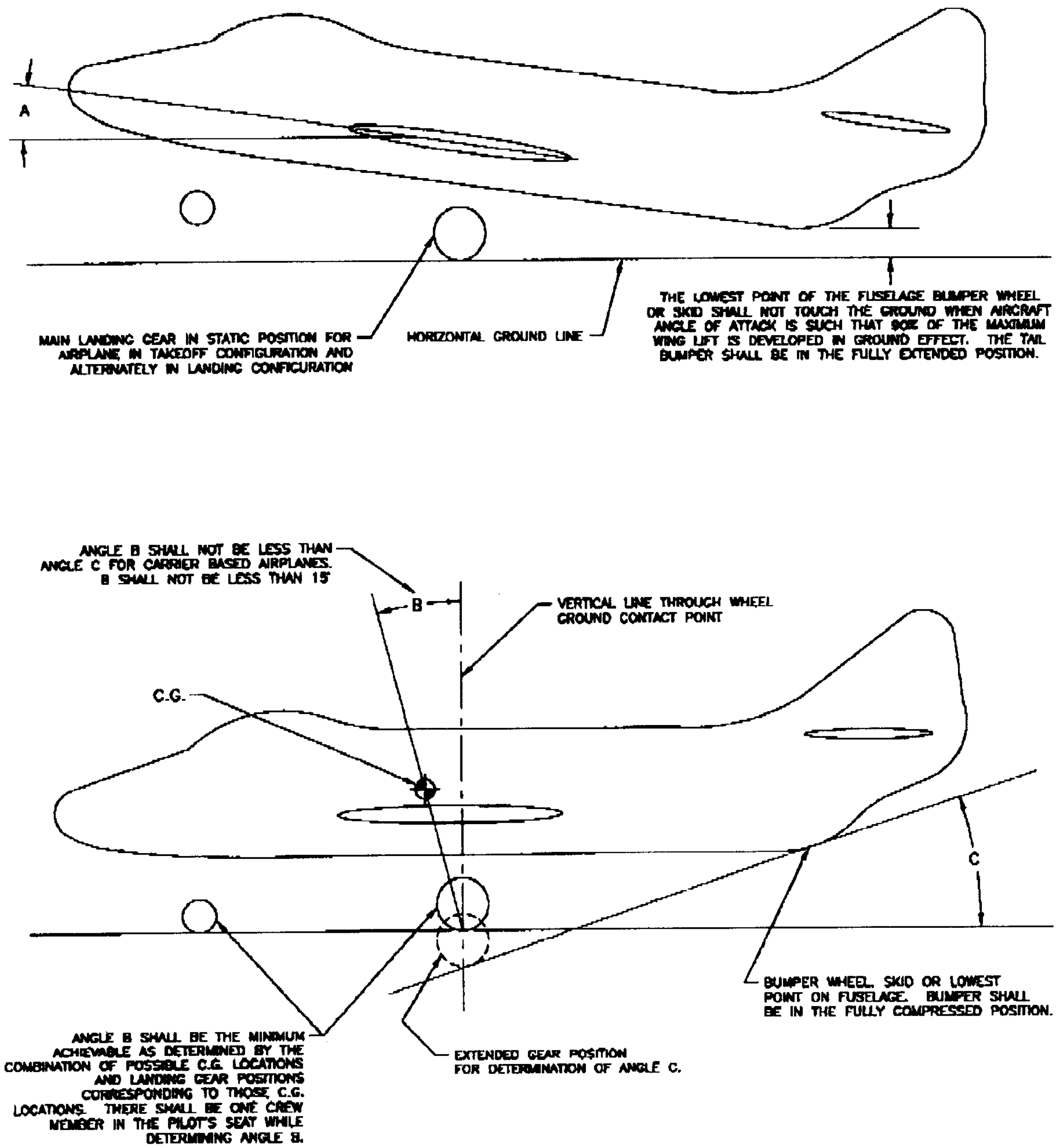


FIGURE 3.4.8.1-1. Tipback limits.

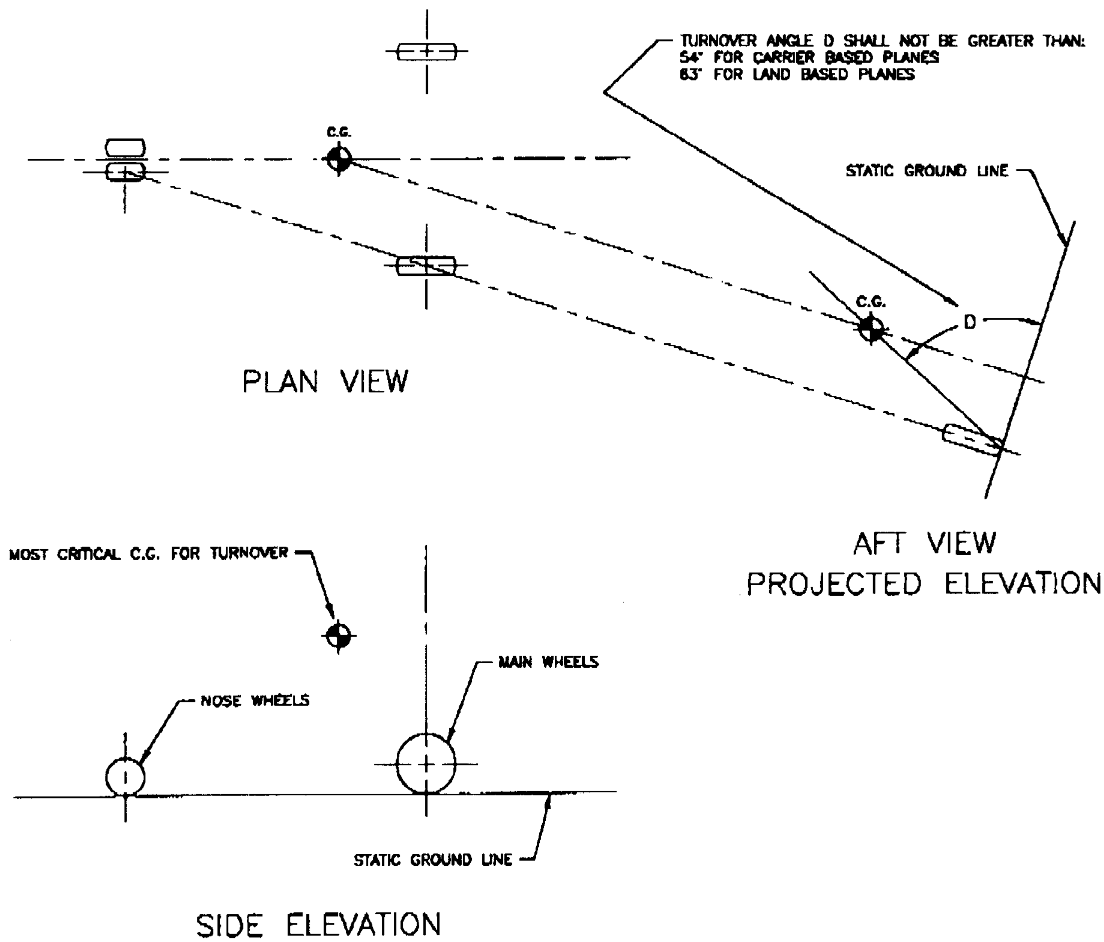


FIGURE 3.4.8.1-2. Turnover prevention.

4.4.8.1 Shipboard tipback and turnover verification

Verification for this requirement is included with 4.4.8 Ship compatibility verification.

3.4.9 Support equipment interface

The air vehicle shall be capable of interfacing with the support equipment (SE) identified in table 3.4.9-I.

TABLE 3.4.9-I. Support equipment interface.

Support Equipment Nomenclature	Functional Capability	Status	Standards	Support Equipment Description (Compatibility Requirements)

The following shall be applicable to all SE-to-air vehicle interfaces:

a. Peculiar and, where practicable, common SE interfaces shall preclude improper connection.

b. The air vehicle shall provide capability to store any SE necessary to safety the aircraft or its systems (e.g., ejection seat safety pins, pitot cover, landing gear downlocks, flight control locks) during transient operations.

REQUIREMENT RATIONALE (3.4.9)

SE is required to be physically and functionally compatible with the air vehicle and air vehicle equipment to ensure effective interoperability and logistic support. Program costs are often minimized when existing SE are utilized through savings in the area of unique SE development costs while also enabling multiple air vehicles to use the same equipment. An important benefit of using the same SE for multiple platforms is also realized in the area of space savings in confined areas such as carriers.

REQUIREMENT GUIDANCE (3.4.9)

Guidance for completing table 3.4.9-I follows:

Support Equipment Nomenclature: For existing support equipment, identify the nomenclature of the support equipment which the air vehicle will be required to interface with (e.g., tiedown fittings, air vehicle jacks, A/S32A-32 Spotting Dolly, etc.). For planned support equipment, identify the type of equipment with which the air vehicle must interface.

Functional Capability: Identify the functionality realized by the support equipment in relation to the air vehicle (e.g., hold air vehicle down, jack the air vehicle, spot the air vehicle, etc.).

Status: Identify whether this is an “Existing” support equipment with fixed interface requirements or a “Planned” support equipment for which interface capability must be defined.

Standards: Identify the standards applicable to the support equipment. The following provides examples of the applicable standards.

STANAG No.	Title
1095 HOS	Tiedown Fittings on Shipborne Aircraft
3098 ASSE	Aircraft Jacking
3105 ASSE	Aircraft Pressure Fuelling Connections
3208 ASSE	Air Conditioning Connections
3209 ASSE	Tire Valve Couplings
3212 ASSE	Diameters of Gravity Filling Orifices
3237 ASSE	Aperture of Terminal Ring or Link for Aircraft Lifting Slings
3278 ASSE	Towing Attachments on Aircraft
3294 ASSE	Aircraft Fuel Caps and Fuel Cap Access Covers
3296 GGS	Aircraft Gaseous Oxygen Replenishment Connections
3302 AE	Connectors for 28 Volt “DC” Servicing Power
3303 AE	Connectors for 115/200 Volt, 400 Hz, 3 Phase, AC Servicing Power
3315 ASSE	Aircraft Cabin Pressurizing Test Connections
3334 ASSE	Defueling of Aircraft
3372 ASSE	Low Pressure Air and Associated Electrical Connections for Aircraft Engine Starting
3447 ASSE	Aerial Refueling Equipment, Dimensional and Functional Characteristics
3499 GGS	Characteristics of Supply Equipment for Liquid Oxygen
3547 GGS	Characteristics of Replenishment Equipment for Liquid Nitrogen
3595 ASSE	Aircraft Fitting for Pressure Replenishment of Gas Turbine Engines with Oil
3632 AE	Aircraft and Ground Support Equipment Electrical Connections for Static Grounding
3766 ASSE	Grease Nipples
3802 ASSE	Screwdriver Recesses (High Performance)
3806 GGS	Aircraft Gaseous Air/Nitrogen Systems Replenishment Connectors

The following provides additional guidance on possible air vehicle interface provisions/requirements:

a. Select towing fittings and provisions using MIL-STD-805 as a guide. Ship based air vehicle should normally be compatible with the NT-4 or 15 ALBAR tow bar. Air vehicle towing, jacking, and tiedown requirements should be in accordance with document 2000-114-019.

b. Select jacking provisions using MIL-STD-809 as a guide. Jack points for wheels should accommodate a 6.25 inch high jack with tires fully deflated. Axle or landing gear strut jack points should be provided. Select removable jack-pads provisions using MIL-STD-809 as a guide. Attachment fittings should not fail when unsymmetrical loads are applied such as jacking up one side of the air vehicle when the other side is resting on the landing gear.

c. Tie-down fittings should be provided to allow securing the air vehicle using MIL-T-81259 as a guide. The surface finish of tie-down rings, lugs and eye fittings should provide electrical continuity for grounding cable attachment during air vehicle maintenance.

d. Fittings for attachment of slings should be provided to allow hoisting the complete air vehicle using MIL-A-8863 as a guide. The hoisting provision should be adjustable to compensate for balance of the air vehicle when in the loaded or empty condition. The hoisting provisions should be capable of hoisting the air vehicle at dockside and for retrieval by a rotary wing air vehicle. Hoisting slings should be attachable to the air vehicle hoist fittings without destroying the integrity of Level I, II or III preservation as specified in NAVAIR 15-01-500. For crash handling of ship-based air vehicles, the hoisting provisions should be capable of hoisting the air vehicle with either the nose gear, both main gears or one main gear and the nose gear in the catwalk. For sling clearance purposes, the air vehicle should be assumed to be tipped up to 45 degrees from its vertical axis. The air vehicle access openings and the method of sling attachment should allow sling attachment in not greater than 5 minutes and without the use of tools.

Support Equipment Description: In the event that the interface is not completely described within the standard referenced in the previous, reference an interface description or other document that characterizes the air vehicle/SE interface. In cases of planned SE, provide functions that the SE will be required to perform.

REQUIREMENT LESSONS LEARNED (3.4.9)

The inclusion of this requirement enforces planning for air vehicle logistic support and interoperability in concert with arriving at the design solution for the performance aspects of the air vehicle components. Lack of such planning has resulted in developing adapters, costly air vehicle changes and SE modifications to permit allied nations and organic SE to handle, replenish or service the air vehicle.

The following military documents contain the lessons learned: MIL-STD-805 for towing, MIL-STD-809 for jacking, MIL-T-81259 for tie-downs, and MIL-A-8863 for crash salvage hoisting.

4.4.9 Support equipment interface verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Support equipment interface	Interface to support equipment (table 3.4.9-I)	A	A	A	A,D	A,D

VERIFICATION DISCUSSION (4.4.9)

Verification of the support equipment interface requirement should be accomplished by integrating analysis with demonstrations of the interface to the support equipment listed in table 3.4.9-I. During air vehicle developmental activities, substantial data is typically obtained that could be used to verify this requirement. Use of this type of data should be maximized to avoid the cost and schedule impacts of a formal demonstration.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of air vehicle design concept identifies planned air vehicle usage, maintenance concept, and any unique requirements of the air vehicle that would tend to inhibit use of the required support equipment interfaces. Analysis indicates that requirements for the interface between the air vehicle and the support equipment are defined and understood. Analysis of preliminary air vehicle design concept indicated the design approach is considering interface to the support equipment listed.

PDR: Analysis of air vehicle preliminary design indicates compatibility with the support equipment interfaces listed, and that a preliminary Maintenance Plan is available for review and comment.

CDR: Analysis of the air vehicle design confirms compatibility with the support equipment interface requirements. Any areas of incompatibility that dictate a unique interface design have been thoroughly researched, and trade-offs identified.

FFR: Analysis and demonstrations of all support equipment interfaces with the air vehicle confirm that that the support equipment interface requirement will be met. Analysis confirms that preflight, postflight, and all maintenance checklists are available and have been reviewed for accuracy and completeness to ensure the air vehicle interfaces properly with the required support equipment.

SVR: Analysis and demonstrations confirm that all required support equipment interfaces are compatible between the air vehicle and the listed support equipment.

Sample Final Verification Criteria

The support equipment requirements shall be verified by __(1)__ analyses and demonstrations of the interface between __(2)__ and the air vehicle to confirm that the interface requirements defined by __(3)__ have been met.

Note: The sample final verification criteria would be completed for each support equipment item listed in table 3.4.9-I.

> Blank 1. Identify the type and scope of analyses and demonstrations required to provide confidence that the requirement has been satisfied.
>
> Blank 2. Identify the support equipment item.
>
> Blank 3. Identify the interface requirements document that must be met during the demonstration. This should be the same document that is listed in the column 4 of table 3.4.9-I.

VERIFICATION LESSONS LEARNED (4.4.9)

The use of standard support equipment to support an air vehicle can save significant acquisition and maintenance costs. The interfaces need to be thoroughly analyzed for their intended function. Sometimes an interface could drive undue cost to an air vehicle and it might be best to develop an external interface to adapt the support equipment to the air vehicle versus designing the interface into the air vehicle. New interfaces are constantly being developed by industry and may be more appropriate than the requirement listed. Future projections must be made for the long-term support of the air vehicle.

3.4.10 Furnishings

The air vehicle shall provide interfaces for __(1)__ furnishings.

REQUIREMENT RATIONALE (3.4.10)

This requirement only addresses furnishing interfaces. If a requirement exists for specific furnishings to be provided as part of the air vehicle, the requirement for such capability should be defined in the applicable lower-level specification.

REQUIREMENT GUIDANCE (3.4.10)

Blank 1. Complete by providing a table that lists the furnishings and a definition of the interface requirements for each furnishing. The following are examples of furnishings: food storage, food preparation facilities, toilet facilities, relief provisions, washbasins, baggage provisions, thermal insulation, acoustic insulation, trim, floor covering, sunshades, curtains, rearview mirrors, lockers, bunks, stretchers, drinking water, and other stowage. The mission duration should be considered in determining provisions for sustenance and waste management.

REQUIREMENT LESSONS LEARNED (3.4.10)

Major furnishings oversights that adversely impact weight, space, or cost can be avoided if they are incorporated in the initial design.

4.4.10 Furnishings verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Furnishings interface	Interface to furnishings (1)	A	A	A	A,D	A,D

*Number in parentheses in the Measurand column refers to numbered blank in the requirement.

VERIFICATION DISCUSSION (4.4.10)

Verification of the furnishings interface requirement should be accomplished by integrating analysis with demonstrations of the furnishings that must interface with the air vehicle. During air vehicle developmental activities, substantial data is typically obtained that could be used to verify this requirement. Use of this type of data should be maximized to avoid the cost and schedule impacts of a formal demonstration.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Preliminary analysis focuses on the design of the air vehicle, planned usage, maintenance concept, and any unique requirements of the air vehicle that would tend to inhibit use of the required furnishings interfaces. Requirements for the interface between the air vehicle and the furnishings are defined and understood. Preliminary analysis indicated the air vehicle design approach is considering interface to the furnishings listed.

PDR: Inspection of initial product definition data indicates air vehicle furnishing requirements have been adequately defined. Preliminary analysis of the air vehicle indicates the design is compatible with the furnishings interfaces listed.

CDR: Analysis of the air vehicle final design confirms compatibility with the furnishings interface requirements. Any areas of incompatibility that dictate a unique design have been thoroughly researched, and trade-offs are presented to the customer for review.

FFR: All identified furnishings and their interfaces have been analyzed and demonstrations as appropriate have been accomplished. Preflight, post-flight, and all maintenance checklists applicable to flight checks are available and have been reviewed for accuracy and completeness to ensure the air vehicle interfaces properly with the required furnishings.

SVR: Progressive inspection of usage inspection data and comparative analyses of product design with furnishing interface requirements should disclose air vehicle compatibility with the installed (permanent and removable) and carry-on furnishings has been achieved. Any nonconformance with the furnishings interface requirements has been corrected by a product definition change. The air vehicle will be considered compliant when all appropriate interfaces listed have been analyzed/demonstrated to be compatible between the air vehicle and the listed furnishings.

Sample Final Verification Criteria

The furnishings interface requirements shall be verified by __(1)__ analysis and/or demonstrations of the interface between __(2)__ and the air vehicle confirm that the interface requirements defined by __(3)__ have been met

Note: The sample final verification criteria would be completed for each furnishings item listed in table 3.4.9-I.

> Blank 1. Identify the type and scope of analyses and/or demonstrations required to provide confidence that the requirement has been satisfied. For instance, analysis should be performed to confirm that all known instances of incompatibility between furnishings and the air vehicle have been eliminated.
>
> Blank 2. Identify the furnishings item.
>
> Blank 3. Identify the interface requirements document that must be met during the demonstration.

VERIFICATION LESSONS LEARNED (4.4.10)

The use of standard furnishings to support an air vehicle can save significant acquisition and maintenance costs. The interfaces need to be thoroughly analyzed for their intended function. Sometimes an interface could drive undue cost to an air vehicle and it might be best to develop an external interface to adapt the furnishings to the air vehicle versus designing the interface into the air vehicle. New interfaces are constantly being developed by industry and may be more appropriate than the requirement listed. Future projections must be made for the long-term support of the air vehicle.

3.4.11 Fuel designation

3.4.11.1 Primary fuel

The air vehicle shall meet the performance requirements stated herein utilizing all primary fuels conforming to __(1)__. The air vehicle shall meet the requirements stated herein after transition between primary fuels.

REQUIREMENT RATIONALE (3.4.11.1)

Different fuels have different properties, which can affect the function of the air vehicle and various subsystems within the air vehicle. As such, the fuels that the air vehicle will encounter operationally must be identified so that all of these different fuel properties can be accounted for regarding the performance of the air vehicle and its subsystems, with and without restrictions imposed.

REQUIREMENT GUIDANCE (3.4.11.1)

Primary fuels are used to demonstrate contract compliance for complete steady state and transient operating conditions.

Blank 1. To complete the blank, for manned and unmanned air vehicles, consider listing fuels that conform to MIL-DTL-83133, grade JP-8 and its NATO equivalent F-34, and MIL-DTL-5624, grade JP-5 and its NATO equivalent F-44 per the primary fuels table below.

Primary fuels. - (Example table)

Military			Commercial[1]		Fuel Type
US	UK	NATO Code	US	UK	
MIL-DTL- 5624 Grade JP-5	Def Std 91-86 AVCAT/FSII	F-44	None	None	High Flashpoint Kerosene
MIL-DTL-83133 Grade JP-8	Def Std 91-87 AVTUR/FSII	F-34	ASTM D 1655 Jet A-1 with Additives[2]	DEF STAN 91-91 AVTUR w/ additives[2]	Kerosene
MIL-DTL-83133 Grade JP-8+100	None	F-37	ASTM D 1655 Jet A-1 with Additives[3]	None	Kerosene
None	None	None	ASTM D 1655 Jet A with Additives[2]	None	Kerosene

Notes:
1. Commercial fuels do not normally contain any additives. Once treated with the additives listed in note 2, the commercial fuel listed in this column is virtually identical to the corresponding military fuel.
2. The following additives must be injected into the fuel at the concentrations specified in MIL-DTL-5624 or MIL-DTL-83133:
   a. Corrosion inhibitor/lubricity improver (CI/LI) (MIL-PRF-25017)
   b. Fuel system icing inhibitor (FSII) (MIL-DTL-85470)
   c. An approved antioxidant (AO) material listed in MIL-DTL-5624 or MIL-DTL-83133
   d. An approved static dissipator additive (SDA) listed in MIL-DTL-5624 or MIL-DTL-83133

3. In addition to the additives listed in Note 2 above, the thermal stability improver additive listed in MIL-DTL-83133 shall be blended into the fuel.

REQUIREMENT LESSONS LEARNED (3.4.11.1)

Primary fuels are used to demonstrate contract compliance for complete steady state and transient operating conditions. The conversion of Air Force bases from JP-4 to JP-8 has been completed. Shipboard air vehicles continue to require JP-5 fuel due to 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 system.

The air vehicle functions depends on a clean, standard fuel to provide cooling for the power plant and airframe, lubricity for fuel pumps and gears without excessive maintenance or safety concerns. Different performance characteristics can be anticipated based on the fuel's viscosity, distillation curve, chemical composition, aromatics content, sulfur content, acidity, vapor pressure, freezing point, hydrogen content, filterability, water separation, conductivity and particulate contamination. These differences affect material compatibility, combustion properties, fuel atomization and fluidity at low temperature, and a myriad of other maintenance and safety problems that are crucial to the air vehicle's mission(s). Additives are generally used to enhance a fuel property such as oxidation stability or to improve fuel performance by providing lubricity, protection against icing, metal deactivation, etc. The followings are lessons learned based on fuel physical properties:

The aromatic content of jet fuels is controlled for two basic reasons. First, aromatics have the poorest combustion performance of the four major hydrocarbon types. Second, aromatics affect many of the elastomers used in air vehicle fuel systems. Field experience has shown that a switch from JP-4 to JP-5 or JP-8 will often result in fuel system leaks. The elastomers that have swollen with exposure to JP-4 (contain low molecular weight aromatics) will shrink slightly upon exposure to JP-5 or JP-8; this shrinkage is often sufficient to cause leaks.

Fuel Volatility - For engine starting, jet fuel must be sufficiently volatile for part of the fuel to vaporize prior to ignition. Because JP-8 (as well as JP-5) is a kerosene-based fuel with relatively low volatility, low temperature ground starting and altitude relight performance of older jet air vehicles originally designed for JP-4 have been affected. Although the technology is available to provide adequate starting and relight performance with JP-8, modification of some existing air vehicle engines have been required. The fuel tank pressurization system that was necessary for the fuel system for hot JP-4 was deleted providing a reduction in system complexity and air vehicle weight along with an improvement in system maintainability. JP-5's general volatility characteristics make it slightly worse than a typical Jet A or JP-8 in terms of engine durability, emissions, cold temperature start, and altitude relight characteristics.

Freeze Point - One of the most important safety concerns, on the performance of military fuels is the freeze point. When wing tank temperatures approach the freezing point of fuel, the fuel along the tank's wall turns into a slush layer between the fuel and the tank. The fuel is taken from the bottom of the fuel tank via suction. The slush layer blocks the fuel from going out of the tank. Sometimes the slush is sucked from the tank into the fuel system and therefor creates blockage in the fuel system. In either case fuel cannot reach the engine. Commercial air vehicles have temperature probes in their wing tanks to monitor the temperature in the tank. Some also have tank heaters. When the temperature gets close to the freezing point of the jet fuel, the crew is alerted and must change air speed or altitude until the temperature warms to an acceptable level. Most military air vehicles do not have these temperature probes in the wing tanks. Even if they did, mission requirements of the military air vehicles may not allow the crew to change air speed or altitudes during wartime. Therefore the fuel used by the military must have a freeze point performance that will keep the fuel from freezing during the air vehicle mission. This problem has been a particular problem with the larger military air vehicles, but is not limited to these larger air vehicles.

Antioxidants - Antioxidants are added to jet fuels and other petroleum products to prevent the formation of gums and peroxides. Peroxides are deleterious to the thermal stability of the fuel and are the precursors of deposition. Since antioxidants are effective in preventing peroxide formation, they help maintain the thermal stability of the fuel. Peroxides can also attack fuel tank polysulfide sealants, neoprene and nitrile rubber fuel hoses, sealing rings, diaphragms and other fuel system elastomers. The military specification requires that an antioxidant be added to the fuel immediately after refining, prior to the fuel seeing atmospheric conditions. If the additive is not added, the fuel will start to deteriorate once oxygen from the atmosphere is introduced to the fuel. This deterioration decreases the storage life of the fuel.

Static Dissipator Additive - Static charges build up during the movement of fuel and can lead to high-energy spark discharges capable of igniting flammable fuel and air mixtures. The static dissipator additive is designed to prevent this hazard by increasing the electrical conductivity of the fuel that promotes a rapid relaxation of any static charges. The electrical conductivity of F-34 (JP-8), F-37 (JP-8+100), and F-40 (JP-4) military jet fuels must be maintained between 150 to 600 pS per m for safety reasons. The military and commercial specification fuels have different conductivity performance, 150 - 600 versus 50 - 450 pS per meter. The additive is used to raise the electrical conductivity and keep it within the specification limits in order to prevent the buildup of strong electrostatic charges during mixing, transfer, and shipment of the fuel. Note: JP-5 does not contain static dissipator additive due to its impact on the performance of certain water and particulate removing equipment used onboard Navy ships. The Navy and Marine Corps refueling systems are designed and built to relax the static charges before the fuel reaches the air vehicle. F-44 (JP-5) generally has conductivity below 50 pS per meter.

Thermal Stability Additive - When a thermal stability additive as described in MIL-DTL-83133, paragraph 3.3.6 is injected into the JP-8 fuel. The fuel is then referred as JP-8 +100. This additive has been approved for use in most of the USAF fighter aircraft.

If the air vehicle has an aerial refueling tanker mission, the selection of the primary fuel(s) may not be limited to the fuel(s) that the air vehicle’s propulsion subsystem will use. If the air vehicle’s tanker mission requires it to be able to aerial refuel platforms that use a different primary fuel, the unique fuel(s) that the air vehicle must be able to carry and transfer to these other platforms becomes a primary fuel for the air vehicle.

4.4.11.1 Primary fuel verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Requirements to be verified as part of other performance requirement verifications						
Air vehicle performance with specified fuels	Performance characteristics specified in other requirement paragraphs	A	A	A	A	A
Air vehicle performance requirements after transition between __(1)__ conforming primary fuels	Performance characteristics specified in other requirement paragraphs	A	A	A	A	A

VERIFICATION DISCUSSION (4.4.11.1)

This requirement provides condition information that must be considered in developing all air vehicle performance requirements and verifications. Therefore, the verification approach defined below assumes the air vehicle performance with specified primary fuels should be verified as part of other performance requirement verifications. Primary fuel requirements should be verified by a limited set of duplicate testing with each fuel and analysis of the remaining performance requirements. For example, you may want to test range using each primary fuel while reliability would be evaluated by analysis. This set of duplicate tests should be agreed to when developing each performance verification specified elsewhere in the specification.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analysis of design concept and air vehicle performance requirements, including missions that require the transition between primary fuels indicates specified performance is achievable. Functional analysis indicates performance and fuel compatibility with air vehicle subsystems.

PDR: Analysis of requirements, design trade study results, and preliminary designs for the air vehicle's performance and compatibility using all primary fuels indicates specified performance is achievable. Analysis of preliminary design addresses risk associated with both performance and compatibility requirements, and transitioning between primary fuels and indicates specified performance is achievable.

CDR: Analysis of lower-level testing and demonstrations establish the air vehicle's performance characteristics and compatibility associated with each of the primary fuels.

FFR: Analysis of lower-level testing confirms that air vehicle operates with fuel to be used for first flight**.**

SVR: Analyses of lower-level component demonstrations and tests, as well as analyses of ground and flight tests conducted in other requirement verifications, confirm air vehicle performance requirements are achieved with all specified primary fuels.

Sample Final Verification Criteria

The primary fuel requirement shall be satisfied when __(1)__analyses confirm that the air vehicle can meet all specified performance requirements while using primary fuels and following the transition between primary fuels.

Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement elements have been met. Analyses should include review of those verifications conducted for other performance requirements.

VERIFICATIONS LESSONS LEARNED (4.4.11.1)

Tests are required to demonstrate the ability of the air vehicle to operate under all critical operating conditions.

A material compatibility and fuel aging deterioration test should be performed. Standards tests conducted in accordance with the procedures published by ASTM, Society of Automotive Engineers (SAE) may be used. Material fuel resistance should be verified by tests at the component level under all normal and extreme environmental conditions with all primary fuels. Long term material fuel resistance should also be addressed. The use of copper, brass, magnesium, and cadmium pleaded steel in contact with fuel should be prevented since they are susceptible to corrosion in the presence of fuel. The engine (s) and air vehicle fuel system, exhaust systems, and oil system components should be subjected to a pretest and post-test inspection to verify conformity and condition prior to and after test. There should be no deterioration or any other unsatisfactory condition in the air vehicle.

If more than one primary fuel is specified, the fuel used should be the fuel which makes the test the most difficult as determined by the Using Service. Fuel samples should be taken at the start and completion of verification and qualification tests, and other tests as applicable. The fuel samples should be analyzed for physical and chemical properties to determine conformance with applicable specifications. Fuel properties must be determined because significant batch to batch property variations can exist between fuels procured to the same specification. Their properties directly affect the results of the test. Fuel properties are required because certain fuel properties are used during testing (e.g., heating value, density, viscosity) to calculate air vehicle performance parameters (e.g., fuel flows, specific fuel consumption, etc.) also, fuel properties can directly affect propulsion system durability.

The capability of the air vehicle to perform at low temperatures with water saturated fuel must be verified.

3.4.11.2 Alternate fuel

The air vehicle shall perform its mission(s) without restrictions when using the following alternate fuels __(1)__; with __(2)__ degradations.

REQUIREMENT RATIONALE (3.4.11.2)

Different fuels have different properties, which can affect the function of the air vehicle and various subsystems within the air vehicle. As such, the fuels that the air vehicle will encounter operationally must be identified so that all of these different fuel properties can be accounted for regarding the performance of the air vehicle and its subsystems, with and without restrictions imposed.

REQUIREMENT GUIDANCE (3.4.11.2)

An alternate fuel is one on which the air vehicle can be flown without operational restrictions but which can have long term durability or maintainability impact if used for continuous operation (multiple flights). Alternate fuels are used only on an occasional or intermittent basis. There should be no adverse effect on the air vehicle mission(s).

Blank 1. Identify all of the fuels to be listed as alternate fuel consistent with the primary fuel option that was selected. Alternate fuels should be the commercial jet fuels listed in the following table.

3.4.11.2-I. Alternate fuels.

Military			Commercial [1]		Fuel Type
US	UK	NATO Code	US	UK	
None	None	F-35	ASTM D 1655 Jet A-1 w/o Additives[1]	DEF STAN 91-91 AVTUR	Kerosene
None	None	None	ASTM D 1655 Jet A w/o Additives[1]	None	Kerosene

[1] Commercial fuels do not normally contain any additives. If the air vehicle's mission profile and fuel system configuration are such that water ice plugging of fuel filters and screens is a concern, then fuel system icing inhibitor (FSII) must be in the fuel to assure safety of flight. In such a case, these commercial fuels could not be listed as alternated fuels.

Blank 2. Indicate the impact of long term or continuous use on component service life, maintenance frequency or resource usage.

REQUIREMENT LESSONS LEARNED (3.4.11.2)

These fuels can be routinely encountered in worldwide deployment and should be considered in the design of the air vehicle system. During the first few months of Desert Shield, Navy and Marine Corps aircraft were often required to use commercial Jet A-1 without additives since these materials and the required injection facilities were not available in country. Future conflicts could require even longer periods of commercial jet fuel use if additive and fuel supplies are affected. For this reason it is recommended that commercial jet fuels be included among alternate fuels.

Jet A and Jet A-1 are kerosene commercial jet fuels. Jet A is used almost exclusively by the commercial airlines operating within the continental United States. Jet A-1 is similar to Jet A except for having a lower freeze point, i.e., -47ºC versus -40ºC respectively. Jet A-1 is used primarily by the commercial airlines operating in countries outside the United States. Very little, if any, Jet A-1 is available at commercial airports in the United States.

The air vehicle functions depends on a clean, standard fuel to provide cooling for the power plant and airframe, lubricity for fuel pumps and gears without excessive maintenance or safety concerns. Different performance characteristics can be anticipated based on the fuel's viscosity, distillation curve, chemical composition, aromatics content, sulfur content, acidity, vapor pressure, freezing point, hydrogen content, filterability water separation, conductivity and particulate contaminants. These differences affect material compatibility, combustion properties, fuel atomization and fluidity at low temperature, and a myriad of other maintenance and safety problems that are crucial to the air vehicle's mission(s).

One of the most important safety concerns, on the performance of military fuels is the freeze point. When wing tank temperatures approach the freezing point of fuel, the fuel along the tank's wall turns into a slush layer between the fuel and the tank. The fuel is taken from the bottom of the fuel tank via suction. The slush layer blocks the fuel from going out of the tank. Sometimes the slush is sucked from the tank into the fuel system and therefore creates blockage in the fuel system. In either case fuel cannot reach the engine. Commercial air vehicles have temperature probes in their wing tanks to monitor the temperature in the tank. Some also have tank heaters. When the temperature gets close to the freezing point of the jet fuel, the crew is alerted and must change air speed or altitude until the temperature warms to an acceptable level. Most military air vehicles do not have these temperature probes in the wing tanks. Even if they did, mission requirements of the military air vehicles may not allow the crew to change air speed or altitudes during wartime. Therefore the fuel used by the military must have a freeze point performance that will keep the fuel from freezing during the air vehicle mission. This problem has been a particular problem with the larger military air vehicles, but is not limited to these larger air vehicles.

Antioxidants are added to jet fuels and other petroleum products to prevent the formation of gums and peroxides. Peroxides are deleterious to the thermal stability of the fuel and are the precursors of deposition. Since antioxidants are effective in preventing peroxide formation, they help maintain the thermal stability of the fuel. Peroxides can also attack fuel tank polysulfide sealants and other fuel system elastomers. Air Force testing has also shown peroxide attack of neoprene and nitrile rubber fuel hoses, sealing rings, and diaphragms. The military specification requires that an antioxidant be added to the fuel immediately after refining, prior to the fuel seeing atmospheric conditions. If the additive is not added, the fuel will start to deteriorate once oxygen from the atmosphere is introduced to the fuel. This deterioration decreases the storage life of the fuel. The commercial sector allows the use of the additive but does not require the use.

Static charges build up during the movement of fuel and can lead to high-energy spark discharges capable of igniting flammable fuel and air mixtures. The static dissipator additive is designed to prevent this hazard by increasing the electrical conductivity of the fuel that promotes a rapid relaxation of any static charges. The electrical conductivity of F-34 (JP-8), F-37 (JP-8+100), and F-40 (JP-4) military jet fuels must be maintained between 150 to 600 pS per meter for safety reasons. The additive is used to raise the electrical conductivity and keep it within the specification limits in order to prevent the buildup of electrostatic charges during mixing, transfer, and shipment of the fuel. The military and commercial specification fuels have different conductivity performance, 150 - 600 versus 50 - 450 pS per meter. There is no requirement for a minimum conductivity for F-44 (JP-5) and addition of static dissipator additive is not allowed by MIL-DTL-5624 due to its impact on the performance of certain water and particulate removing equipment used onboard Navy ships. F-44 generally has conductivity below 50 pS per meter. US commercial Jet A fuel is normally delivered without static dissipator additive and also typically has a conductivity below 50 pS per meter.

A difference should be noted between commercial Jet A and Jet A-1 in the thermal stability requirements of the fuel. JP-8 must meet thermal stability requirements at 260°C. The commercial specification ASTM D 1655 has a two-tier system where the fuel is tested for thermal stability at 260°C. If it fails it may be retested at 245°C. If the fuel passes at 245°C, the fuel still meets spec. This is a concern when commercial fuels are used in military aircraft with higher engine temperatures, since this could induce nozzle cocking. ASTM is currently in the process of eliminating this two-tier system but it may take several years before it is completed.

4.4.11.2 Alternate fuel verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Air vehicle performance requirements utilizing (1) alternate fuels	Meets specified air vehicle mission performance Not greater than (2) degradations	A	A,I	A,I, T	A,I, D,T	A,I, D,T

*Numbers in parentheses refer to numbered blanks in the requirement.

VERIFICATION DISCUSSION (4.4.11.2)

This requirement provides condition information that must be considered in developing all air vehicle performance requirements and verifications. Therefore, the verification approach defined below assumes the air vehicle performance with specified alternate fuels should be verified as part of other performance requirement verifications. Alternate fuel requirements should be verified by a limited set of duplicate testing with each fuel and analysis of the remaining performance requirements. For example, you may want to test range using each alternate fuel while reliability would be evaluated by analysis. This set of duplicate tests should be agreed to when developing each performance verification specified elsewhere in the specification. Fuel compatibility among all internal and external subsystems should also be analyzed and demonstrated.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analyses of the design concept, including mission analyses when using alternate fuels, indicates specified performance is achievable. Preliminary material compatibility analysis indicates air vehicle performance while using the alternative fuels and fuel compatibility with air vehicle subsystems is defined.

PDR: Analysis of requirements, design trade study results, and preliminary designs for the air vehicle's performance and subsystem compatibility using all alternate fuels indicates specified performance is achievable.

CDR: Analysis of lower-level testing and demonstrations establish the air vehicle's performance characteristics and compatibility associated with each of the alternate fuels. Analysis confirms that allowable performance degradations are not exceeded.

FFR: No unique verification action occurs at this milestone.

SVR: Analyses of lower-level component demonstrations and tests, as well as analyses of ground and flight tests conducted in other requirement verifications, confirm air vehicle performance requirements are achieved with all specified alternate fuels. Analysis confirms that allowable performance degradations are not exceeded.

Sample Final Verification Criteria

The alternate fuel requirement shall be satisfied when __(1)__ analyses confirm that the air vehicle can meet all specified performance requirements while using alternate fuels.

Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement elements have been met. Analyses should include review of those verifications conducted for other performance requirements.

VERIFICATION LESSONS LEARNED (4.4.11.2)

The following are some areas, which require special consideration as a consequence of using alternate fuels:

The energy per unit volume of the fuel affects the amount of fuel, which is metered to the engine. The lower the energy, an increased quantity of fuel is required to complete the same flight profile.

The fuel consumption varies with the energy density of the fuel. Fuel consumption effects, if any, on air vehicle range should be addressed.

Most commercial fuels have no lubricity additives. Poor lubricity fuels have BOCLE WSD diameters as high as 0.90 mm (0.035 inch). Fuel component problems on several engines have been caused by low lubricity of the fuel. Hydro mechanical controls have also experienced a variety of failures due to low lubricity. Engine fuel system components, which have moving parts (such as pumps, valves, and regulators), should be subjected to low lubricity test. The SAE ARP 1797 provides guidance on low lubricity testing. Durability test should be conducted with fuel without the lubricity improver additives or corrosion protection additives.

Since the alternate fuels do not contain fuel system icing inhibitor, the capability of the air vehicle to perform at low temperatures with water-saturated fuel must be verified.

3.4.11.3 Emergency fuel

When using __(1)__ emergency fuels, the air vehicle shall be capable of operating with __(2)__ degradations and/or restrictions.

REQUIREMENT RATIONALE (3.4.11.3)

Different fuels have different properties, which can affect the function of the air vehicle and various subsystems within the air vehicle. As such, the fuels that the air vehicle will encounter operationally must be identified so that all of these different fuel properties can be accounted for regarding the performance of the air vehicle and its subsystems, with and without restrictions imposed. This requirement identifies fuels which can be used in the air vehicle on a limited basis but which may cause degradation of the propulsion system or air vehicle subsystems under extended use.

REQUIREMENT GUIDANCE (3.4.11.3)

An emergency fuel is one which imposes operational restrictions on air vehicle. May cause significant damage, limited to one flight, only for emergency or countering emergency action. Examples of conditions that might warrant use of emergency fuels are accomplishing an important military mission, countering enemy actions, emergency evacuation flights, or emergency aerial refueling.

Blank 1. Identify all of the fuels to be listed as an emergency fuel. Consider listing fuels designated to ASTM D 4814 automotive gasoline, ASTM D 975 Diesel Fuel Oil, STANAG 7090 Diesel Fuel Oils NATO F-54 (CID A-A-52557), MIL-DTL-5624 Grade JP-4, ASTM D 6615 Jet B, MIL-F-16884 (NATO F-76) Naval Distillate, and ASTM D 910 Aviation Gasoline. Degradation of performance or any special maintenance activity caused by the use of an emergency fuel shall be identified.

Blank 2. Identify the operating limitations, special inspection or maintenance actions required associated with each emergency fuel listed in blank 1 of Emergency fuels.

REQUIREMENT LESSONS LEARNED (3.4.11.3)

The air vehicle functions depends on a clean, standard fuel to provide cooling for the power plant and airframe, lubricity for fuel pumps and gears without excessive maintenance or safety concerns. Different performance characteristics can be anticipated based on the fuel's viscosity, distillation curve, chemical composition, aromatic content, sulfur content, acidity, vapor pressure, freezing point, hydrogen content, filterability, water separation, conductivity and particulate contaminants. These differences affect material compatibility, combustion properties, fuel atomization and fluidity at low temperature, and a myriad of other maintenance and safety problems that are crucial to the air vehicle's mission(s).

While most military organizations around the world have converted to the use of F-34 (JP-8) fuel, a few have elected to continue operating on wide-cut F-40 (JP-4) type fuel. In 1994, some fighter air vehicles experienced engine operation abnormalities that could easily result in a stall or flameout. After extensive engine testing, it was concluded that the cause was attributable to the JP-4 fuel that had an unusually large amount of low boiling hydrocarbons. The boiling range of JP-4, in the military specification, was revised to disallow the purchase of fuel that would contain a large amount of low boiling hydrocarbons. The current boiling range of commercial fuel, Jet B, has not been revised and can contain this large amount of low boiling hydrocarbons

4.4.11.3 Emergency fuel verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Air vehicle performance requirements utilizing __(1)__ emergency fuels	Not greater than (2) degradations and/or restrictions	A	A,I	A,I, T	A,I,D ,T	A,I, D,T

*Numbers in parentheses refer to numbered blanks in the requirement.

VERIFICATION DISCUSSION (4.4.11.3)

Initial verification should consist of analysis activities and final verification should include both analyses and lower-level tests or demonstrations.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analyses of design concept, including mission analyses when using emergency fuels indicates specified performance is achievable. Preliminary material compatibility analysis indicates air vehicle performance while using the emergency fuels and fuel compatibility with air vehicle subsystems is defined. Analysis indicates the maximum operating time period, altitude and power ranges and maximum specific fuel consumption is established based on missions requirements or mission operational trade studies and have been considered in the development of the design concept.

PDR: Analysis of requirements, design trade study results, and preliminary designs for the air vehicle's performance and subsystem compatibility using all emergency fuels indicates specified performance is achievable. Analysis of preliminary design addresses risk associated with both performance and compatibility requirements when using emergency fuels.

CDR: Analysis of lower-level testing and demonstrations establish the air vehicle's performance characteristics and compatibility associated with each of the emergency fuels. Analysis confirms that allowable performance degradations and/or restrictions are not exceeded.

FFR: No unique verification action occurs at this milestone.

SVR: Analyses of lower-level component demonstrations and tests confirm air vehicle performance requirements are achieved with all specified emergency fuels. Analysis confirms that allowable performance degradations and/or restrictions are not exceeded.

Sample Final Verification Criteria

The emergency fuel requirement shall be satisfied when __(1)__ analyses confirm that the air vehicle can meet the specified performance requirements while using emergency fuels.

> Blank 1. Identify the type and scope of analyses required to provide confidence that the requirement elements have been met. Analyses should include review of those verifications conducted for other performance requirements.

VERIFICATION LESSONS LEARNED (4.4.11.3)

Fuel consumption varies with the energy density of the emergency fuel. Typically, the lower the energy density, the greater the fuel consumption. Fuel consumption effects on air vehicle range should be addressed.

The octane rating of the fuel affects the tendency of the fuel to detonate in the air vehicle spark ignition propulsion system. The higher the rating, the lower the probability of encountering detonation. There are a number of octane ratings established by the ASTM.

A material compatibility and fuel aging deterioration test should be performed. Standards tests conducted in accordance with the procedures published by ASTM, Society of Automotive Engineers (SAE) may be used. Establish compatibility of air vehicle fuel wetted and oil wetted materials (elastomers, sealants, seals, liners, hoses, etc.) and components.

Establish compatibility with the fuel quantity gauging system and evaluate the unusable fuels quantity. Evaluate the fuel flow. Evaluate the effects of the alternate fuel weight per volume difference.

Engine starting characteristics may be affected by the use of emergency fuels. Tests should be conducted to verify the air vehicle engine restart capability at altitude. Also, engine starting capability at cold and hot ambient temperature should be verified. Useable fuel quantities can be significantly affected by the fuel's low temperature properties. High freeze point or viscose fuels may "hold up" inside the air vehicle's tanks and not be available if low ambient temperatures are experienced during the aircraft's mission. Any air vehicle limitations in term of temperature and altitude should be documented.

3.4.12 Government furnished equipment and directed contractor furnished equipment

The air vehicle shall deliver specified performance with the Government furnished equipment (GFE) and directed contractor furnished equipment (CFE) in table 3.4.12-I.

TABLE 3.4.12-I. Government furnished equipment and directed contractor furnished equipment.

GFE/CFE	Nomenclature	Part No.	Documentation	Qty/Air Vehicle

REQUIREMENT RATIONALE (3.4.12)

Due to various reasons, the Government specifies utilization of specific equipment. This equipment varies from WRAs or LRUs to flight instrumentation and engines.

REQUIREMENT GUIDANCE (3.4.12)

Complete table 3.4.11-I with a listing of GFE that is identified for installation by the contractor and with CFE designated by the Government for inclusion in the air vehicle.

<u>GFE/CFE</u>: List either "GFE" or "CFE"

<u>Nomenclature</u>: List the name of the equipment

<u>Part No</u>.: List the part number for each item

<u>Documentation</u>: Include the requirements/interface documentation (ICD, specification, etc.).

<u>Qty/Air Vehicle</u>: Cite the number of units of this item to be provided for each air vehicle. Following are examples of GFE items that could be used to complete the table.

Anti-g Suit: CSU-13B/P with male connector (NSN 4730-00-821-2481)

Oxygen Mask: MBU-12/P with U-93A/U communications plug (NSN 5935-00-642-0626), MBU-20/P

Flier's Gloves: GS/FRP-2

Flier's Winter Jacket: CWU-45P

Torso Harnesses: PCU-15A/P and PCU-16A/P with oxygen connector mounting bracket (NSN 1660-00-656-2522)

Oxygen Connector: CRU-60/P

Flier's Helmet: HGU-53/P and HGU-55/P
Flier's Coveralls: CWU-27/P
Flier's Summer Jacket: CWU-36/P
Flier's Boots: FWU-8/P
Automatic Life Preserver: LPU-9/P

REQUIREMENT LESSONS LEARNED (3.4.12)

On any air vehicle procured by the Government there is usually at least one or more items of GFE that the contractor will be required to install.

4.4.12 Government furnished equipment and directed contractor furnished equipment verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Specified air vehicle performance with table 3.4.12-I GFE/CFE	Performance characteristics specified in other air vehicle performance requirement paragraphs	A,I	A,I	A,I		I

VERIFICATION DISCUSSION (4.4.12)

This requirement mandates the use of specific equipment, furnished by the government or contractor, to be used in meeting the performance requirement specified elsewhere in this document. Therefore, the verification approach defined below assumes that the air vehicle performance using the specified government furnished equipment (GFE) and directed contractor furnished equipment (CFE) should be verified via the specific performance requirements.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Government furnished equipment and directed contractor furnished equipment have been analyzed to determine what performance parameters they affect. Inspection of design concepts indicates compatibility with GFE/Directed CFE.

PDR: Government furnished equipment and directed contractor furnished equipment have been analyzed to update what performance parameters they affect. Inspection of preliminary design indicates presence of specified GFE/Directed CFE. Analysis of preliminary design indicates that the design requirements incorporate GFE/Directed CFE considerations.

CDR: GFE and CFE have been analyzed to update what performance parameters they affect. Inspection of design confirms presence of specified GFE/Directed CFE. Analysis of design confirms that the design requirements incorporate GFE/Directed CFE considerations.

FFR: No unique verification action occurs at this milestone.

SVR: Verification results for each air vehicle performance requirement should be inspected to confirm the utilization of the specified GFE/Directed CFE.

Sample Final Verification Criteria

The GFE/Directed CFE requirement shall be satisfied when inspection of verification results for each air vehicle performance requirement specified herein confirms that the required performance has been met utilizing the specified government furnished equipment and directed contractor furnished equipment.

VERIFICATION LESSONS LEARNED (4.4.12)

To Be Prepared

3.5 Manufacturing

The air vehicle shall be able to be repeatably, reliably, and economically manufactured at the expected production rate.

REQUIREMENT RATIONALE (3.5)

Producibility is a significant design constraint. In the past, the goal of developing and deploying economically producible and supportable weapon systems capable of meeting all performance requirements has proven difficult to achieve. Historically, weapon system acquisition programs have experienced cost overruns, performance shortfalls, and schedule delays, especially as they transition from development to production. Many of these problems are driven by (1) not understanding the linkage between performance requirements, key design attributes, and the manufacturing processes needed to support them; and (2) the failure to recognize manufacturing process capability limitations in the design phase.

This requirement encourages the consideration of manufacturing capabilities during the initial design. Specifically, the design should be producible in accordance with the overall program's schedule requirements, anticipated production rate, and affordability goals.

REQUIREMENT GUIDANCE (3.5)

This requirement may be tailored to include a specific measure of producibility.

REQUIREMENT LESSONS LEARNED (3.5)

The Manufacturing Development Guide contains tools for achieving these requirements. These include design trade studies, manufacturing process capability assessments, production cost modeling, key characteristics, variability reduction, and virtual manufacturing.

Early involvement of the manufacturing community in the design process is critical. The best opportunities for influencing the design and for reducing overall life-cycle costs are in the beginning of the program. Production issues should be analyzed in conjunction with design issues and manufacturing risks must be identified as soon as possible while there is time to develop design alternatives and investigate trade-offs. Key suppliers must also be involved early in the design team.

4.5 Manufacturing verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Repeatably & reliably manufacturable	Pass/Fail	A	A	A		A,I,T
Economically manufacturable	Pass/Fail	A	A	A		A

VERIFICATION DISCUSSION (4.5)

To the maximum extent possible, final verification should rely on the analysis of quantifiable results as opposed to merely demonstrating that best practices have been employed. The tools and processes described in the Manufacturing Development Guide are excellent ways to achieve the requirements, but their use does not guarantee that the requirements have been achieved. Useful manufacturing data may be difficult to obtain early in the program so the verification activities at early milestones revolve around planning for and "doing the right things'" but move more towards relying on data later in the program. For final verifications, objective results from process capability studies, and quality metrics are desired, as well as evidence that design and process changes were made if producibility risks were identified. Manufacturing simulation's role in developing and verifying producible designs and repeatable production processes has grown significantly along with new, more powerful simulation software tools. The use of appropriate simulation and analysis may reduce the need for other objective product and process verification data.

<u>**Repeatably & reliably manufacturable**</u>

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the design concept indicates that: manufacturing risks have been identified for processes that may not be capable or for immature manufacturing technologies; producibility studies are considering key characteristics; simulation tools are being developed to demonstrate production concepts; key manufacturing processes are being identified; and measures of manufacturing quality are being developed.

PDR: Analysis of the preliminary design indicates that: risk mitigation plans have been developed for manufacturing risks; producibility studies identify key characteristics; manufacturing simulations demonstrate production concepts are repeatable and reliable; key process capabilities are characterized and integrated with design requirements; initial process control plans are developed; and measures of manufacturing quality are identified.

CDR: Analysis of the detailed design confirms that: risk mitigation plans are being implemented; producibility studies have been completed and recommendations are incorporated in the product design; manufacturing simulations verify production planning; design requirements match process capabilities; process control plans have been implemented; and measures of manufacturing quality are being implemented and corrective action plans are developed to correct areas of concern.

FFR: No unique verification action occurs at this milestone.

SVR: Inspection and/or test of first article air system and its applicable subsystems confirm the manufacturing processes produce a conforming product. Analysis confirms that: manufacturing risk mitigation actions are complete or risk is determined to be acceptable; manufacturing simulations incorporate actual experience and verify manufacturing planning; process control plans yield products that consistently conform to design requirements; and quality metrics demonstrate that conforming product is being delivered.

Sample Final Verification Criteria

The reliable and repeatable manufacturing element shall be satisfied when __(1)__ analyses and __(2)__ inspections and/or tests confirm that the air system meets all specified performance requirements.

> Blank 1. Identify the type and scope of analyses required to provide confidence that the reliable and repeatable manufacturing element has been met. Consider the following analyses: manufacturing risk mitigation, producibility studies, manufacturing simulations, process controls,
>
> Blank 2. Identify the type and scope of inspections and/or tests required to provide confidence that the reliable and repeatable manufacturing element has been met. Consider first production article inspections and quality metrics.

Lessons Learned: The systematic development of robust design and manufacturing processes is more important than ever, due to recent fluctuations in program production quantities. For example, recent programs have entered EMD planning for production runs of several hundred aircraft only to be cut by a factor of ten. Their production strategy would have been significantly different if the final quantity were known when the production facility was laid out and suppliers were brought on board. While it will never be possible to develop a strategy that is optimal at any possible quantity, consideration of the risks up front will influence the design trade-offs by changing how producibility will impact unit cost. Lean Manufacturing techniques provide some independence from production quantity constraints, and manufacturing simulation is a useful tool in the exploration of many options in a short period of time.

Economically manufacturable

While the requirement to be economically manufactured does not quantify a specific cost goal, the intent is to be able to demonstrate that the air vehicle can be produced within the given cost constraints of the program. Production cost estimates should reflect impacts of alternate design approaches as well as data from the most current actual manufacturing experience in building the air vehicle.

Key Development Activities

Key development activities include, but are not limited to, the following:

SRR/SFR: Analysis of the design concept indicates that the air system is manufacturable within initial program cost goals.

PDR: Analysis of the preliminary design indicates that: production cost models reflect the current design approach; production cost estimates demonstrate cost objectives are achievable; and cost risk mitigation actions are identified, as needed.

CDR: Analysis of the detailed design confirms that: production cost models reflect the impact of the design solution on manufacturing costs; production cost estimates demonstrate cost objective is achievable; and cost mitigation actions are being completed.

FFR: No unique verification action occurs at this milestone.

SVR: Analysis confirms that manufacturing cost mitigation actions are complete and production cost estimates reflect actual manufacturing data and demonstrate cost goals have been met.

Sample Final Verification Criteria

The economically manufacturable element shall be satisfied when __(1)__ analyses confirm that the air system meets all specified performance requirements within the cost goals of the program.

> Blank 1. Identify the type and scope of analysis required to provide confidence that the economically manufacturable element has been met.

Lessons Learned: As with the lessons learned above, variations in quantities dramatically affect the ability to economically produce a weapon system. However, the Lean Aerospace Initiative, led by MIT and a consortium of industry, government, labor, and academia, may provide some solutions. One of the over-arching principles of Lean is the ability to be responsive to change. The Lean principles and practices are designed to enable a company to be less sensitive to changes in production rate. Aggressive implementation of this initiative may therefore result in a more stable and reliable production cost estimate.

VERIFICATIONS LESSONS LEARNED (4.5)

See Lessons Learned above under "Repeatably & reliably manufacturable" and "Economically manufacturable" requirement elements.

3.6 Logistics support

3.7 Training

3.7.1 Embedded training

The air vehicle shall provide embedded training to include __(1)__. Embedded training modes shall be selectable. Embedded training shall not be detrimental to the safe operation of the air vehicle.

REQUIREMENT RATIONALE (3.7.1)

Embedded training reduces the need for support equipment and other associated aids.

However, extensive embedded training capability/functions can be expensive and care should be exercised when specifying. Trade studies at the system level should be conducted to determine the most cost-effective and operationally effective methods for providing training. The allocations to the air vehicle are a portion of the total training allocation of the air system and should be developed in concert with other specified training requirements. Training conducted using the air vehicle, whether in-flight or on the ground with systems powered or operating, consumes service life and may be a significant factor in specifying air vehicle life usage.

REQUIREMENT GUIDANCE (3.7.1)

Blank 1. Complete with all or a combination of the following based on the results of system-level training trade studies, such as

a. Pilot tutoring such as mission walk-through, flight simulation, impacts resulting from the potential dynamics of airborne/ground threat, terrain effects, simulation of weapons, tactics, and subsystem failure modes; and

b. Ground maintenance tutoring which provides an understanding of the air vehicle and air vehicle subsystem(s). The capability shall include a walk through of troubleshooting within the air vehicle and shall also include simulated failure troubleshooting. A “Red Flag” or other EW-type training scenario shall be supported without the need for a separate instrumentation package or a specific range or test site. Weapon system functionality to include range, field of regard, and other characteristics of weapon operation to train an operator in use of various weapons without carrying weapon simulation hardware. Information that intuitively reminds the operator of presence in a training mode.

(Note: Implementation of embedded training on the air vehicle could be complex and costly. Specific subsets of the following embedded training capabilities may be appropriate for air vehicle implementation; however, these must be carefully and completely specified.)

REQUIREMENT LESSONS LEARNED (3.7.1)

To Be Prepared

4.7.1 Embedded training verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Embedded training (a)	Course features are present	A	A	A	D,T	A,D, T
Embedded training (b)	Course features are present	A	A	A	D,T	A,D, T
Embedded training (…)	Course features are present	A	A	A	D,T	A,D, T
Safety features/interlock	No interference, no degredation to air vehicle operation	A	A	A	D,T	A,D, T

VERIFICATION DISCUSSION (4.7.1)

Verification of the embedded training requirement should be accomplished by integrating analysis with demonstrations/testing of the air vehicle’s on-board embedded training capability. Verification of embedded training capability should first consider verifying the functional performance of the embedded training features that have been designed into the air vehicle. This may be accomplished by analysis of results from demonstrations or testing of these features at the subsystem (i.e., avionics) level and verification of the feature's ability to meet allocated performance requirements in the lower-tier specifications. Training verification of air vehicle embedded training features should be a part of the overall verification of the training curriculum (i.e., courseware) and may be accomplished in conjunction with verification of the training capability of the Training System and/or Support System. Verification of embedded training features should consider the training capability of the feature (or combination of features) to train the student(s) to the required proficiency and to meet the training requirements (i.e., training tasks, training objectives, etc.) that have been allocated to the air vehicle for this purpose. Training functions should be verified for training functionality; compatibility with onboard operational (e.g., interchangeable OFPs) and maintenance requirements; and increased trainee capability.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analysis of the design concept indicates that the embedded training performance and training requirements, as defined by the data products from the Training System Requirements Analysis (TSRA), have been properly allocated to the air vehicle, are complete and will support the types of embedded training defined in blank 1. Analysis indicates that the conceptual design features (e.g., for pilot tutorial) will support the embedded training performance and training requirements, and will not be detrimental to the safe operation of the air vehicle.

PDR: Analysis of the preliminary design and lower-level verification results indicates the embedded training features will satisfy the requirements specified in blank 1, and provides the on-equipment training capability specified in the Air System Specification paragraph 3.7.2. Analysis indicates that the training conducted utilizing the embedded training features, will not be detrimental to the safe operation of the air vehicle (ex. Safety interlock).

CDR: Analysis of the final design and lower-level verification results confirms the embedded training features will satisfy the requirements specified in blank 1, and provides the on-equipment training capability specified in the Air System Specification paragraph 3.7.2. Analysis indicates that the training conducted utilizing the embedded training features, will not be detrimental to the safe operation of the air vehicle (ex. Safety interlock).

FFR: Demonstrations/testing confirms embedded training should not be detrimental to the safe operation of the air vehicle.

SVR: Analysis, demonstration, test and analyses of lower-level test and demonstration data confirm all training capabilities specified in blank 1 have been provided.

Sample Final Verification Criteria

Requirements for embedded training shall be satisfied when results from __(1)__ analyses, __(2)__ demonstrations, and __(3)__ tests of the air vehicle meet or exceed specified requirements.

> Blank 1. Identify the type and scope of analyses required to produce confidence that requirements for air vehicle's embedded training features have been provided.

Blank 2. Identify the type and scope of demonstrations required to produce confidence that requirements for air vehicle's embedded training features have been provided.

Blank 3. Identify the type and scope of tests required to produce confidence that requirements for air vehicle's embedded training features have been provided.

VERIFICATION LESSONS LEARNED (4.7.1)

To Be Prepared

3.8 Disposal

The air vehicle and any portions of the air vehicle (components, parts, materials, etc.) shall provide for being permanently stored, salvaged, cannibalized, recovered, reused, recycled, demilitarized, and disposed. The air vehicle shall provide for the identification, isolation, and control of hazardous and radiological material to ensure personnel safety and environmental protection.

REQUIREMENT RATIONALE (3.8)

This requirement is to ensure the air vehicle or portions and/or components of the air vehicle can be withdrawn from service, reutilized, or disposed, in an economical, safe, and environmentally responsible manner. Although disposal is often thought of as occurring at the end of a air vehicle's useful life, disposition of excess, residual, obsolete, and condemned items begins during development, occurs during acquisition, and continues throughout the life of the air vehicle.

Certain portions of air vehicles (normally either weapons (guns, energetics, etc.) or classified material) require demilitarization prior to resale or disposal. Other portions of the air vehicle require special handling to protect the environment or personnel safety. From some portions, strategic or precious materials can be recovered. Some portions can be recovered or salvaged for reuse. The objective of this requirement is to provide the basis for economical withdrawing from service and reutilization, or disposal, of air vehicle assets.

REQUIREMENT GUIDANCE (3.8)

The degree to which the disposal aspects of the air vehicle need to be "designed in" is dependent on costs, benefits, and risks. The cost-benefit of ensuring that precious metals can be recovered from integrated circuit leads may be questionable, but the manpower and equipment costs to remove and dispose of hazardous and radiological materials can be mitigated by smart design choices. Similarly, the risks involved in simply "throwing away" explosive and related materials outweigh the alternatives.

This requirement may be amplified in a number of ways. For example, a table identifying specific materials to be precluded from use in the air vehicle's design or criteria to be used in defining quantities and thresholds for recovery of precious and strategic materials.

REQUIREMENT LESSONS LEARNED (3.8)

A program was known to spend more than a year working with EPA officials to get approval to use a government specified process before checking with the government for a waiver.

4.8 Disposal verification

Requirement Element(s)	Measurand	SRR/ SFR	PDR	CDR	FFR	SVR
Provide for being permanently stored, salvaged, cannibalized, recovered, reused, recycled, demilitarized, and disposed	Disposal provisions are present	A	A	A,I		A,I
Provide for the identification, isolation, and control of hazardous and radiological material	Personnel safety and environment protection are present	A	A	A,I		A,I

VERIFICATION DISCUSSION (4.8)

Verification of the requirement to withdraw from service, reutilize, or dispose, in an economical, safe, and environmentally responsible manner should be accomplished by integrating analysis and inspections of the air vehicle and its components. During air vehicle developmental activities, substantial data is typically obtained that could be used to verify this requirement. Use of this type of data should be maximized to avoid the cost and schedule impacts of a formal demonstration.

Key Development Activities

Key development activities include, but are not limited to, the following:

(Note: The key development activities identified below apply to all of the requirement elements.)

SRR/SFR: Analysis of the air vehicle design concept indicates that requirements for withdrawing from service, reutilizing, or disposing the air vehicle and its components in an economical, safe, and environmentally responsible manner are defined and understood.

PDR: Analysis of the air vehicle preliminary design indicates the air vehicle and its components can be withdrawn from service, reutilized, or disposed in an economical, safe, and environmentally responsible manner. Tradeoff analyses have been initiated, which may include, but are not limited to, occupational health considerations/risks, such as employee personal protective costs, health monitoring costs, cleanup and/or decontamination costs, etc., during reutilization or disposal, and total costs of mishaps during reutilization or disposal; number of mishaps involving damage to equipment or personnel (injured/killed) during reutilization or disposal; and number of environmental violations during reutilization or disposal.

CDR: Analysis of the air vehicle final design and inspection of components confirms that the air vehicle and its components can be withdrawn from service, reutilized, or disposed in an economical, safe, and environmentally responsible manner. Analyses confirm that any problem areas have been thoroughly researched, and trade-offs are implemented.

FFR: No unique verification action occurs at this milestone.

SVR: Analysis and inspection of the final design of the air vehicle and its components confirms they can be withdrawn from service, reutilized, or disposed in an economical, safe, and environmentally responsible manner. Analyses of program documentation confirms that the disposal processes are in place and correct, and all known instances of noncompliance have been identified and design solutions presented.

Sample Final Verification Criteria

The disposal requirement shall be satisfied when __(1)__analyses and __(2)__inspections, confirm that the air vehicle and its components can be withdrawn from service, reutilized, or disposed in the manner specified.

> Blank 1. Identify the type and scope of analyses required to provide confidence that the requirements have been met. Analyses include identification of item and category; determination of proper procedures and required actions for the category; and evaluation of the safety, and environmental impact of following the proper procedures and taking the required actions.
>
> Blank 2. Identify the type and scope of inspections required to provide confidence that the requirements have been met. Inspections include examination of the air system and its portions and components as they are built up, and determining the safety and environmental impact of following the proper procedures and taking the required actions.

VERIFICATION LESSONS LEARNED (4.8)

To Be Prepared

5. PACKAGING

Packaging requirements shall be as specified in the contract or order. When actual packaging of material is to be performed by DoD personnel, these personnel need to contact the responsible packaging activity to ascertain requisite packaging requirements. Packaging requirements are maintained by the Inventory Control Point's packaging activity within the Military Department or Defense Agency, or within the Military Department's System Command. 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

6.1 Intended use

This specification is intended to be applied and tailored for the performance and verification of manned airborne vehicles.

6.2 Specification tree

This section identifies the JSSG specification tree. Completion of the tree of requirements documentation is normally the developing contractor's responsibility. See the Integrated Performance Based Business Environment Guide and the Performance Based Product Definition Guide for additional information.

A specification tree is a program-unique construct to organize the requirements flow-down into documentation that describes requirements for segments of the system and items that comprise the system. An air system specification is nominally the top-level document in the specification tree for system development. This is not intended to preclude the use of another document as the top-level specification on a modification program such as using a tailored avionics specification for a radar upgrade. As always, significant insight and planning is necessary when constructing a set of requirements for the program. For example, how much of that radar upgrade needs to be verified in its installed environment (air vehicle) or how much of that requirements set is dependent on system environments, interfaces, and other factors, such as impacts on support and training.

This Air Vehicle Joint Service Specification Guide (JSSG) has been developed in concert with seven other JSSGs. Future plans for JSSG publications include developing a Weapon JSSG and converting existing Air Force Guide Specifications (AFGS) for Training Systems and Support Systems into JSSGs. The nominal JSSG hierarchy depicted in figure 6.2-1 should not be construed as a program specification tree. While the JSSGs shown at tier 2 may represent program-unique specifications to be developed, those specification guides shown under the Air Vehicle JSSG at tier 3 may or may not have a resemblance to a program-specific specification architecture. These tier 3 JSSGs nominally communicate performance expectations for areas of air vehicle functionality. While they could exist in a program-specific form, some (or some portions) of these documents express functionality that would frequently be expressed as part of the functionality of the air vehicle. That is, in developing a program-specific air vehicle specification, portions of the tier 3 documents may be appropriately tailored and incorporated in an air vehicle specification. Additionally, the choices on how best to organize requirements are frequently driven by the organization of the program, risk, and complexity, among other factors. For example, the use of integrated product teams may make it desirable to consolidate all requirements for avionics into a single specification even though some of the performance expectations are tier 2 (i.e., air vehicle requirements) and some tier 3 (e.g., radar requirements). This would enable making a single team accountable for the development and implementation of a given area of requirements. The organization of the JSSG specification tree is intended to assist the program office in constructing appropriate sets of requirements, not in hindering factors such as teamwork, team accountability, or other mechanism used to organize requirements.

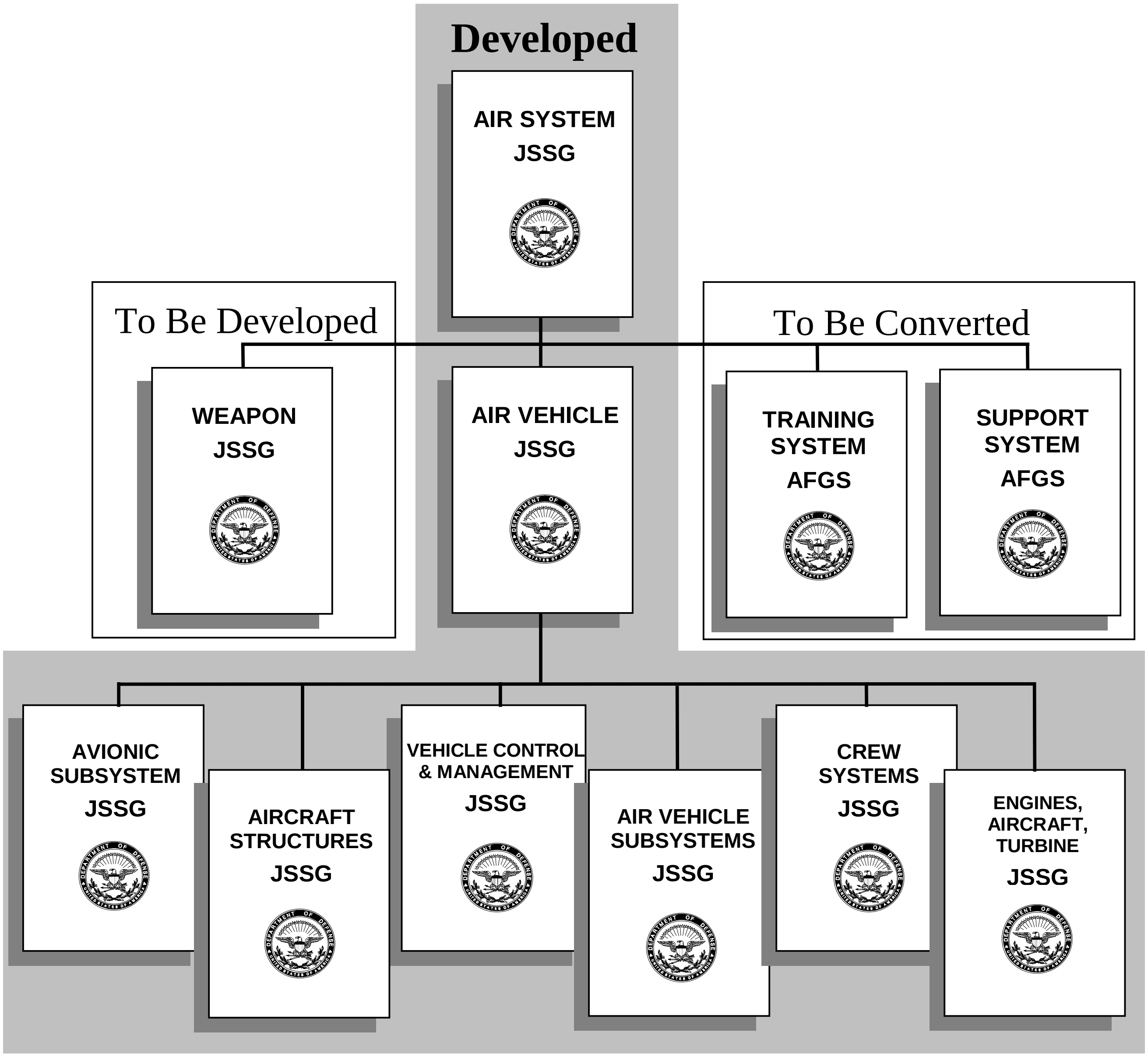


FIGURE 6.2-1. Joint Service Specification Guide specification tree.

6.3 Acronyms and abbreviations

The following acronyms and abbreviations are used in the Air Vehicle JSSG. Flying quality acronyms, abbreviations and symbols are located under 6.4.6 Flying qualities definitions, abbreviations, and symbols. Otherwise, one-time use of acronyms and abbreviations in the same paragraph do not appear in the listing.

Abbreviation	Definition
A	analysis
AA	air-to-air
AAA	anti aircraft artillery
AC	alternating current
ADF	automatic direction finding
AI	air intercept
AM	amplitude modulation
AOA	angle of attack
API	armor piercing incendiary
APU	auxiliary power unit
BIT	built-in-test
C	centigrade
c.g.	center of gravity
CAGE	commercial and government entity
CB	chemical and biological
CBR	California bearing ratio
CCM	counter-countermeasures
CCV	control-configured vehicle
CDL	common data link
CDR	critical design review
CEP	circular error probable
CFE	contractor furnished equipment
C-H	Cooper-Harper
CI	configuration item
cm	centimeter
COTS	commercial off-the-shelf
CW	continuous wave

Abbreviation	Definition
D	demonstration
DAA	designated approval authority
DADT	durability and damage tolerence
dB	decibel
dbsm	frequency band
DC	direct current
Deg., °	degree
DEMEA	damage modes and effects
DME	distance measuring equipment
DoD	Department of Defense
DODISS	Department of Defense Index of Specifications and Standards
e.g.	for example
E3, E^3	electromagnetic environmental effects
ECD	environmental control document
ECM	electronic countermeasures
ECP	engineering change proposal
ESRT	essential system repair time
EID	electrically initiated devices
EMC	electromagnetic compatibility
EMCON	emission control
EMD	engineering and manufacturing development
EME	electromagnetic environment
EMI	electromagnetic interference
EMP	electromagnetic pulse
EP	electronic protection
EW	electronic warfare
F	Fahrenheit
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FARP	forward arming and refueling point
FCA	functional configuration audit
FFR	first flight review
FLOT	forward line of own troops

Abbreviation	Definition
FM	frequency modulation
FMECA	failure modes and effects criticality analysis
FMET	failure modes and effects test
FOD	foreign object damage
FOR	field of regard
FOV	field of view
FPS	feet per second
FT, ft	feet
G, g	gravity
GATM	global air traffic management
GFE	government furnished equipment
GOTS	government off-the-shelf
GPM	gallons per minute
GPS	global positioning system
GW	gross weight
HEI	high explosive incendiary
HF	high frequency
Hz	hertz, giga (ghz), kilo (khz), mega (mhz)
I	inspection
IBS	Integrated Broadcast Service
ICD	interface control document
ICWG	interface control working group
IFF	identification, friend or foe
ILS	instrument landing system
INS	inertial navigation system
IOC	initial operational capability
IR	infrared
JBD	jet blast deflector
JSSG	Joint Service Specification Guide
JTA	joint technical architecture
KCAS	knots calibrated air speed
Lbs	pounds
LF	low frequency

Abbreviation	Definition
LFT&E	live fire test and evaluation
LO	low observable
LRU	line replaceable unit
Max	maximum
Min	minimum
MLS	microwave landing system
MM, mm	millimeter
MMH/FH	maintenance manhours per flight hour
MOA	memorandum of agreement
MOPP	mission oriented protective posture
MOU	memorandum of understanding
MTBF	mean time between failure
MTBMA	mean time between maintenance action
MTBME	mean time between maintenance event
MTBMF	mean time between mission failure
MTBR	mean time between removal
MTTR	mean time to repair
NATO	North Atlantic Treaty Organization
NBC	nuclear, biological, chemical
NM	nautical mile
NSN	national stock number
OFP	operational flight program
ORD	operational requirements document
OSHA	Occupational Safety and Health Administration
P_d	probability of detection
PDR	preliminary design review
P_s	probability of survival
R&M	reliability and maintainability
RAA	risk acceptance authority
RCS	radar cross section
RF	radio frequency
RMA	rate monotonic analysis
rms	root-mean-square

Abbreviation	Definition
RMS	rate monotonic scheduling
RORH	region of recoverable handling
ROSH	region of satisfactory handling
ROTH	region of tolerable handling
S	simulation/modeling
SA	surface-to-air
SAM	surface-to-air missile
SATCOM	satellite communication
SAWE	Society Of Allied Weight Engineers
SCAS	stability control augmentation system
SE	support equipment
Sec	Second
SFR	system functional review
SPA	spaces per aircraft
SRR	system requirement review
STANAG	standardization agreements (NATO)
STAR	system threat assessment report
STOL	short take-off and landing
SVR	system verification review
T	test
TACAN	tactical air navigation
TCAS	traffic alert/collision avoidance system
TF/TA	terrain following/terrain avoidance
TREE	transient radiation effects on electronics
UHF	ultra high frequency
USAF	United States Air Force
USMC	United States Marine Corps
V/STOL	vertical/short take-off and landing
VCMS	vehicle control and management system
VHF	very high frequency
WCA	warnings, cautions, and advisories
WOD	wind over deck
WRA	weapon replaceable assembly

6.4 Definitions

6.4.1 Aircrew

The aircrew consists of the normal operating complement of the air vehicle.

6.4.2 Commercial-off-the-shelf

Commercial off-the-shelf hardware and software products, technology, and designs purchased through commercial retail or wholesale distributors as is; modified to meet specified functional requirements; or ruggedized to meet service requirements.

6.4.3 Computer definitions

Integrated architecture	Guidelines that include the physical and electronic packaging of system elements into standard modules co-located in common racks
Main memory	That component of the computer from which stored programs are executed and within which data manipulated by programs, or involved in I and O operations is stored
Modularity	A system composed of discrete elements, each of which is defined in sufficient completeness and detail such that selected element(s) can be replaced and/or modified in a competitive environment with minimal or no modifications to other system elements while maintaining equal or improved system performance and capability
Processing node	A processing unit with associated program memory and communications interfaces
Processor throughput	The rate at that the processing unit can execute native instructions for a given sequence of such instructions. The sequence is determined by the software used for the measurement, the compiler and the linker
Real-time access	A communication procedure that is faster than the worst case response time needed for execution of the software task
Secondary storage	Storage auxiliary to main memory, such as optical disks, bulk storage or magnetic tapes

6.4.4 Critical parts

A critical part is one in which its single failure, during any operating condition, could cause the following: loss of the air vehicle or one of its major components, loss of control, unintentional release of or inability to release any store, failure of air vehicle installation components, or significant injury to occupants of the air vehicle.

6.4.5 Environmental definitions

Climate	The long-term environmental definitions manifestation of weather, how ever it may be expressed. More rigorously, the climate of a specified area is represented by the statistical collection of its weather conditions during a specified interval of time (usually several decades).
Environmental control	A control method by which the severity of damaging environmental stress is reduced to a level tolerable by equipment or personnel.
Environmental design control	Environmental parameters which represent a given degree of severity of conditions existing in nature, in equipment operation, or in storage, which are to be incorporated in the design of equipment.
Environmental operating conditions	The factors of the environment which, singly or in combination, have a significant effect upon military operations, and must, therefore, be considered in the design and testing equipment.
Environmental protection	Research and its application designed to maintain or improve the degree of effective performance of man and equipment under all types of environmental stress.
Environmental resistance features	The characteristics or the properties of an item which protect the item against the effects of an environmental exposure and which prevent internal conditions that might lead to deterioration.
Induced environment	Any man-made or equipment-made environment which directly or indirectly affects the performance of man or equipment.
Induced radiation	Radiation produced as a result of exposure to radioactive materials, particularly the capture of neutrons.
Natural environment	That part of the total environment that comprises the complex of conditions found in nature. The term is loosely used for an environment dominated by natural environmental factors.
Wind over deck (WOD)	The velocity, measured in knots, of the headwind component of the relative wind measured at the bow of the ship.

6.4.6 Flying qualities definitions

Airspeed	Magnitude of the velocity with respect to the air mass
Air vehicle class	An air vehicle falls under one of the following six classes:
Class I	Small light air vehicles such as light utility, primary trainer, or light observation
Class II	Medium weight, low-to-medium maneuverability air vehicles such as heavy utility/search and rescue; light or medium transport/cargo/tanker; early warning/electronic countermeasures/airborne command, control, or communications relay; antisubmarine; assault transport; reconnaissance; tactical bomber; heavy attack; or trainer for Class II
Class III	Large, heavy, low-to-medium maneuverability air vehicles such as heavy transport/cargo/tanker; heavy bomber; patrol/early warning/electronic countermeasures/airborne command, control, or communications relay; or trainer for Class III
Class IV	High-maneuverability air vehicles such as fighter/interceptor; attack; tactical reconnaissance; observation; or trainer for Class IV
Class V	Rotorcraft
Class VI	V/STOL air vehicles Note: The letter -L following a class designation identifies an air vehicle as land-based; carrier-based air vehicles are similarly identified by -C. When no such differentiation is made in requirement guidance, the requirement applies to both land-based and carrier-based air vehicles.
Air vehicle configuration	A configuration is defined by the positions and adjustments of the various selectors and controls available to the crew, except for pitch, roll, yaw, throttle, and trim controls. Examples are the flap control setting and the yaw damper ON or OFF.
Air vehicle loadings	The loading of an air vehicle is determined by what is in (internal loading) and attached to (external loading) the air vehicle. The loading parameters that influence flying qualities are weight, c.g. position, and moments and products of inertia. In addition to these, external stores also affect aerodynamic coefficients.

Air vehicle state	The state of the air vehicle is defined by the selected configuration together with the functional status of each of the air vehicle components or systems, throttle setting, weight, moments of inertia, c.g. position, and external stores complement. The trim setting and the position of the pitch, roll, and yaw controls are not included in the definition of air vehicle state since they are often specified in the requirements.
Air vehicle normal states	Air vehicle normal states are air vehicle states with no component or system failure.
Air vehicle extreme states	Air vehicle extreme states are air vehicle normal states with extremely heavy loads or extremely asymmetric loads for which Level 1 flying qualities may not be practicable.
Air vehicle failure states	Air vehicle failure states consist of air vehicle normal states modified by one or more malfunctions in air vehicle components or systems.
Air vehicle special failure states	Special failure states are air vehicle failure states, which have extremely remote probabilities of failure during a given flight.
Atmospheric disturbances	For the purpose of showing compliance with this specification, atmospheric disturbances are defined in two atmospheric disturbance models: a low-altitude model and a medium/high-altitude model (see below).
Low-altitude atmospheric disturbance model	The low-altitude atmospheric disturbance model defines the atmospheric disturbances to be used to show compliance with the requirements of this specification at altitudes below 2000 ft AGL. It consists of four parts: a steady wind, random turbulence, discrete gusts, and a wind shear (see below).
Medium/ high-altitude disturbance model	The medium/high-altitude atmospheric disturbance model defines the atmospheric disturbances to be used to show compliance with the requirements of this specification at altitudes above 2000 ft AGL. It consists of two parts: random turbulence and discrete gusts (see below).

Discrete gusts

Discrete gusts have the "1-cosine" shape given by:

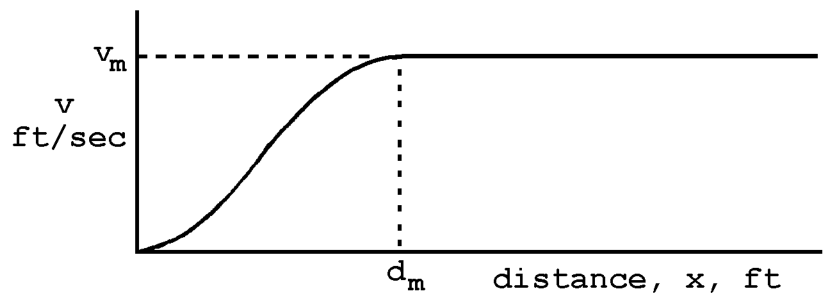
$V = 0$ for $x < 0$

$V = v_m [1 - \cos(\pi x/d_m)]/2$ for $0 \le x \le d_m$

$V = v_m$ for $x > d_m$

Where v is the gust velocity, x is distance traveled measured from the beginning of the gust, v_m is the gust magnitude, and d_m is the gust length measured from the beginning of the gust.

The discrete gust model may be used for any of the three gust velocity components. Discrete gusts may be used singly or in combinations. For example, the discrete gust above might be coupled with an equal but opposite gust beginning at d_m. The two halves of a double gust do not have to be the same length or magnitude. Step function or linear ramp gusts may also be used. Several values of d_m should be used, each chosen so that the gust is tuned to each of the natural frequencies of the air vehicle and its flight control system (higher frequency structural modes may be excepted). Alternatively, specific discrete gust data are available that have been extracted from gusts actually encountered during air vehicle flight tests. These may also be included in the definition of the atmospheric disturbance model for evaluating air vehicle response. Figure 6.4.6-1 presents one such actual discrete gust profile.



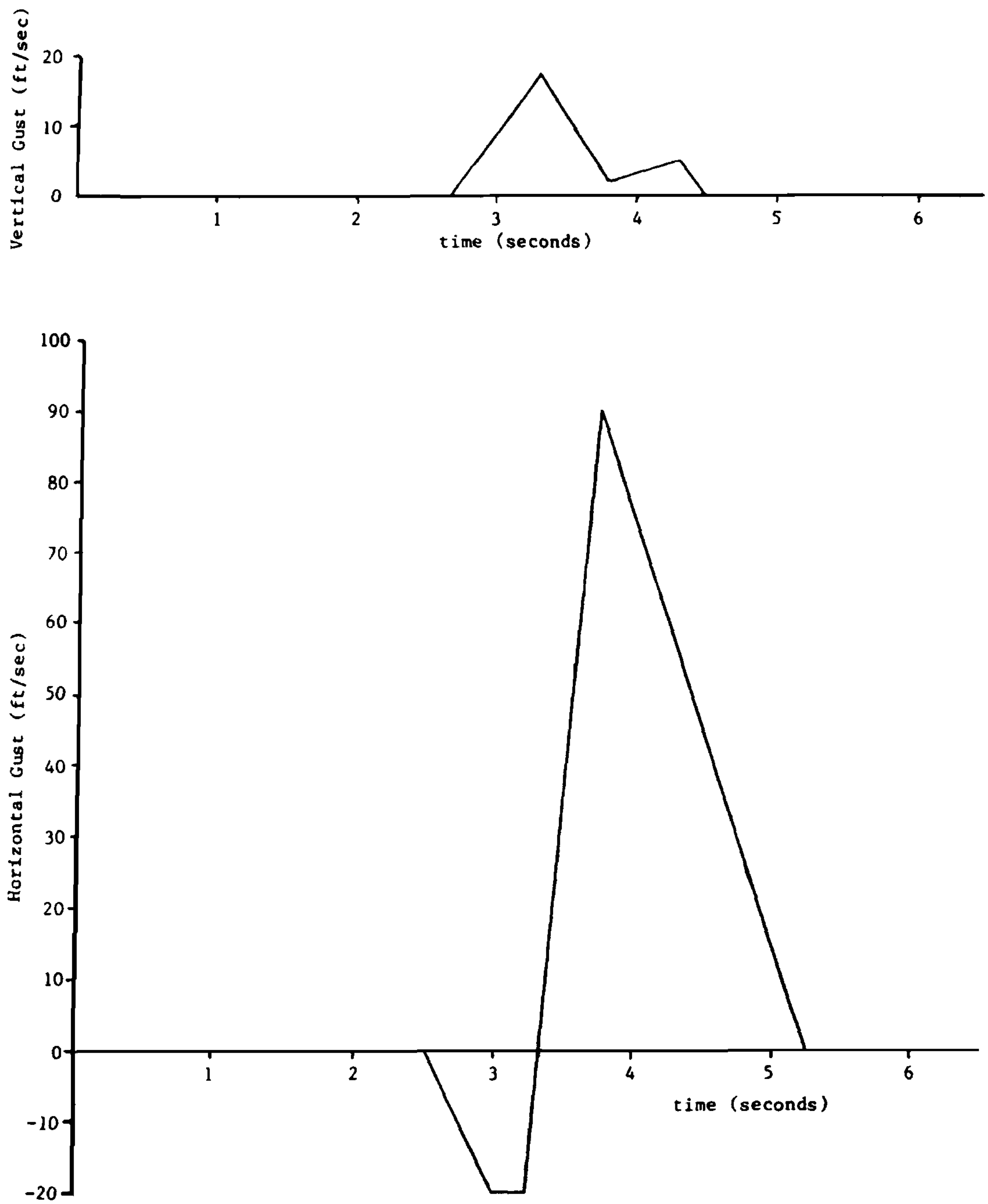


FIGURE 6.4.6-1. Example discrete gust profile (earth-axis winds).

Random turbulence

Random u_g, v_g, and w_g have Gaussian (normal) distributions. The spectra for the turbulence velocities can be either the von Karman form or the Dryden form (see below).

The appropriate scale lengths for the low-altitude model are shown on figure 6.4.6-2 as functions of altitude. The turbulence intensities to be used for the low-altitude model are $\sigma_w = 0.1\ u_{20}$, and σ_u and σ_v as given on figure 6.4.6-3 as functions of σ_w and altitude.

The scales and intensities for the medium/high-altitude model are based on the assumption that turbulence above 2,000 ft is isotropic. Then

$$\sigma_u^2 = \sigma_v^2 = \sigma_w^2$$

and $L_u = 2L_v = 2L_w$

The scales to be used for the medium/high-altitude model are

$L_u = 2L_v = 2L_w = 2{,}500$ feet using the von Karman form or

$L_u = 2L_v = 2L_w = 1{,}750$ feet using the Dryden form

Root-mean-square turbulence intensities for the medium/high-altitude model are shown on figure 6.4.6-4 as functions of altitude and probability of exceedance. These magnitudes apply to all axes. The dashed lines, labeled according to probability of encounter, are based on MIL-A-8861A and MIL-F-9490D. The solid lines indicate a simplified approximation to this model for application to the specification requirements herein. A minimum rms magnitude of 3 ft/sec is specified at all altitudes in order to assure that air vehicle handling will be evaluated in the presence of some disturbance.

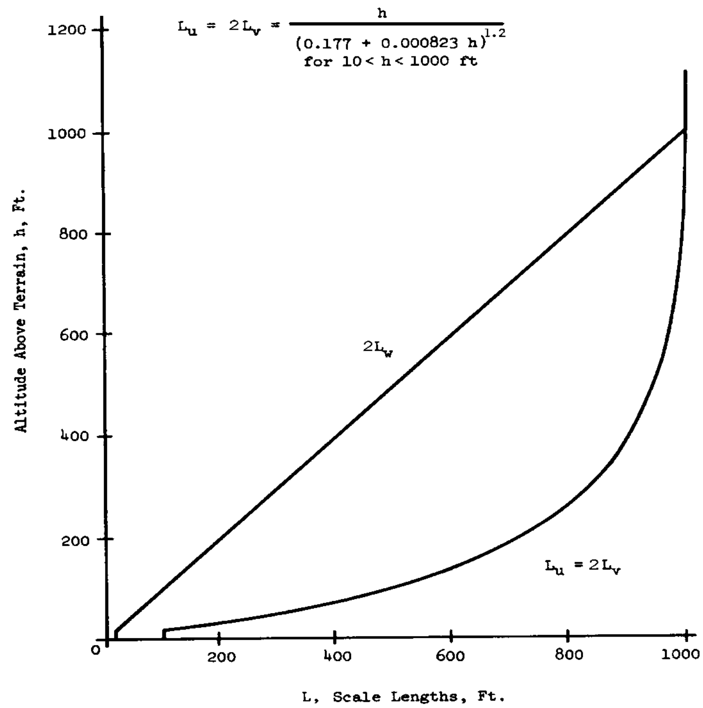


FIGURE 6.4.6-2. Low-altitude turbulence integral scales.

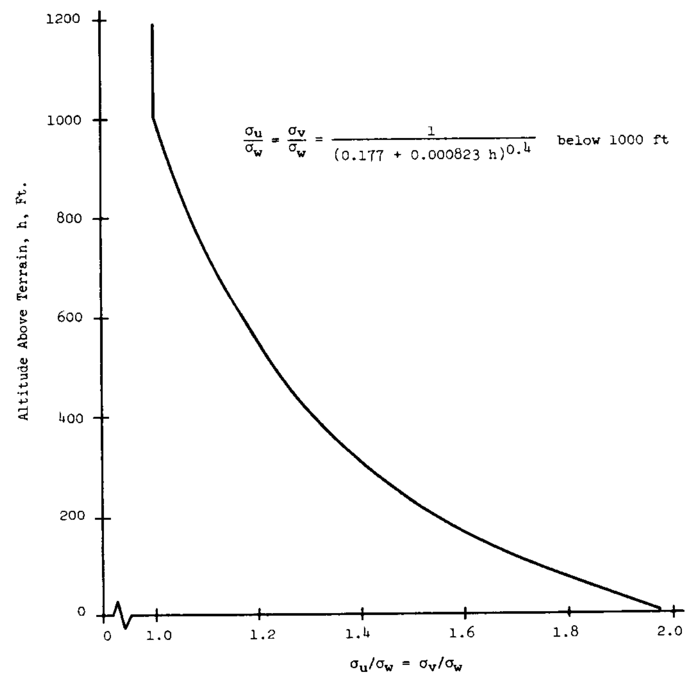


FIGURE 6.4.6-3. Horizontal turbulence intensities.

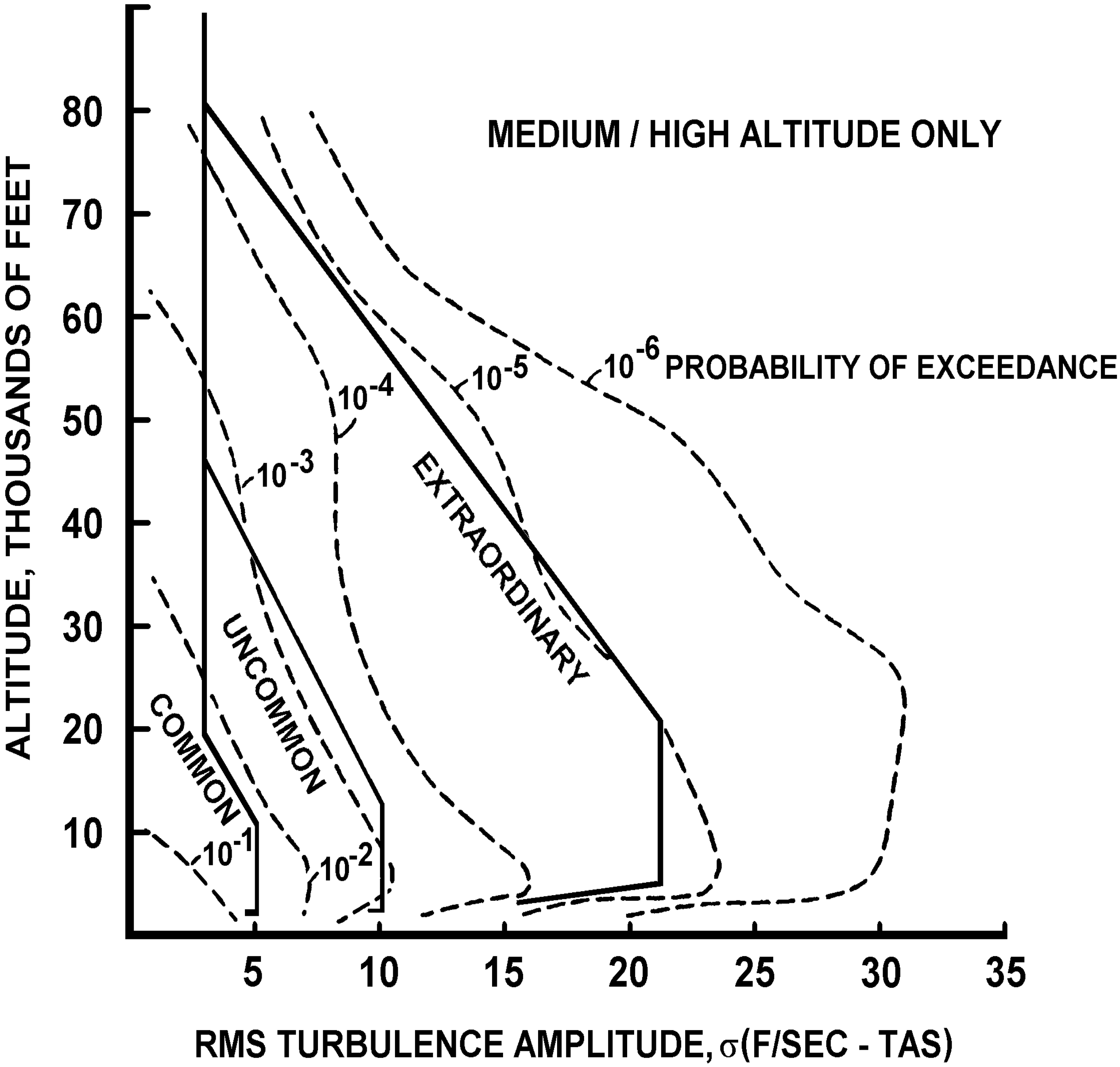


FIGURE 6.4.6-4. Turbulence intensities and probability of exceedance.

Dryden turbulence spectra

The Dryden form of the spectra for random turbulence velocities is

$$\Phi_{u_g}(\Omega) = \sigma_u^2 \frac{2L_u}{\pi} \frac{1 + 12(L_u\Omega)^2}{\left[1 + 4(L_u\Omega)^2\right]^2}$$

$$\Phi_{v_g}(\Omega) = \sigma_v^2 \frac{2L_v}{\pi} \frac{1 + 12(L_v\Omega)^2}{\left[1 + 4(L_v\Omega)^2\right]^2}$$

$$\Phi_{w_g}(\Omega) = \sigma_w^2 \frac{2L_w}{\pi} \frac{1 + 12(L_w\Omega)^2}{\left[1 + 4(L_w\Omega)^2\right]^2}$$

Von Karman turbulence spectra

The von Karman form of the spectra for random turbulence velocities is

$$\Phi_{u_g}(\Omega) = \sigma_u^2 \frac{2L_u}{\pi} \frac{1}{\left[1 + (1339L_u\Omega)^2\right]^{5/6}}$$

$$\Phi_{v_g}(\Omega) = \sigma_v^2 \frac{2L_v}{\pi} \frac{1 + \frac{8}{3}(2.678L_v\Omega)^2}{\left[1 + (2.678L_v\Omega)^2\right]^{11/6}}$$

$$\Phi_{w_g}(\Omega) = \sigma_v^2 \frac{2L_w}{\pi} \frac{1 + \frac{8}{3}(2.678L_w\Omega)^2}{\left[1 + (2.678L_w\Omega)^2\right]^{11/6}}$$

Steady wind

The steady wind is the mean wind speed. In the absence of a wind shear, the mean wind speed and direction are constant. Different orientations of the mean wind relative to the runway for Category C, or relative to the air vehicle flight path for other flight phases should be considered.

Wind shear

The magnitude of the wind scalar shear is defined by the use of the following expression for the mean wind profile as a function of altitude:

$$u_w = u_{20} \frac{\ln(h/z_0)}{\ln(20/z_0)}$$

where z_0 = 0.15 feet for Category C flight phases

= 2.0 feet for other flight phases

The wind vector shear is defined by a change in direction of the mean wind speed over a given height change. A range of values for the initial wind orientation and the initial altitude for onset of the shear should be considered.

Calm air — In the context of this specification, calm air is considered to be no wind, no turbulence, no gusts, and no shears.

Common atmospheric disturbances — For the purposes of compliance with this specification, common atmospheric disturbances are defined in table 6.4.6-I.

TABLE 6.4.6-I. Common atmospheric disturbances.

	Steady Wind Speed	Turbulence Scale Lengths and Intensities	Discrete Gust Length and Magnitude	Wind Shear
Low-altitude model	u_{20} up to 15 kts; tailwind component no more than 10 kts at 20 ft	L_u, L_v, L_w as shown on figure 6.4.6-2; $\sigma_w = 0.1\ u_{20}$; σ_u, σ_v as given on figure 6.4.6-3	d_m as defined; v_m as determined from figure 6.4.6-5 using the appropriate values from figure 6.4.6-2 and figure 6.4.6-3	scalar shear as defined for u_{20}; no vector shear
High/ medium-altitude model		L_u, L_v, L_w as defined; rms turbulence intensities as shown on figure 6.4.6-4	d_m as defined; v_m as determined from figure 6.4.6-5 using appropriate rms turbulence intensities from figure 6.4.6-4	

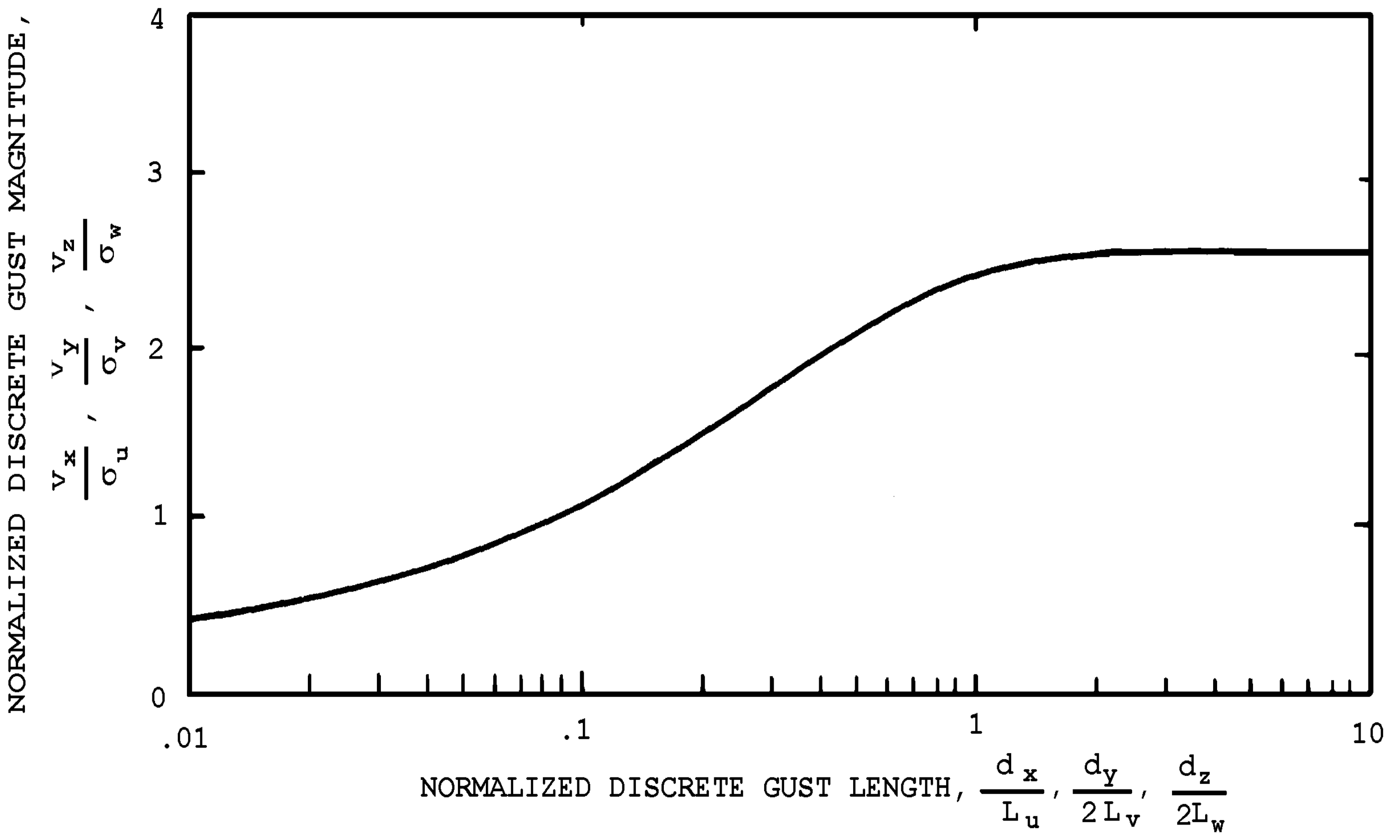


FIGURE 6.4.6-5. Magnitude of discrete gusts.

Uncommon atmospheric disturbances — For the purposes of compliance with this specification, uncommon atmospheric disturbances are defined in table 6.4.6-II.

TABLE 6.4.6-II. Uncommon atmospheric disturbances.

	Steady wind speed	Turbulence scale lengths and intensities	Discrete gust length and magnitude	Wind shear
Low-altitude model	15 kts < $u_{20} \leq$ 30 kts; tailwind component no more than 10 kts at 20 ft; crosswind component no more than 20 kts at 20 ft for Class I air vehicles	L_u, L_v, L_w as shown in figure 6.4.6-2; $\sigma_w = 0.1\ u_{20}$; σ_u, σ_v as given in figure 6.4.6-3	d_m as defined; v_m as determined from figure 6.4.6-5 using the appropriate values from figure 6.4.6-2 and figure 6.4.6-3	scalar shear as defined for u_{20}; 90° change in mean wind heading in a height change of 600 ft
High/ medium-altitude model		L_u, L_v, L_w as defined; rms turbulence intensities as shown on figure 6.4.6-4	d_m as defined; v_m as determined from figure 6.4.6-5 using appropriate rms turbulence intensities from figure 6.4.6-4	

Extraordinary atmospheric disturbances — For the purposes of compliance with this specification, Extraordinary atmospheric disturbances are defined in table 6.4.6-III.

TABLE 6.4.6-III. Extraordinary atmospheric disturbances.

	Steady Wind Speed	Turbulence Scale Lengths and Intensities	Discrete Gust Length and Magnitude	Wind Shear
Low-altitude model	30 kts < u_{20} ≤ 45 kts; tailwind component no more than 10 kts at 20 ft; crosswind component no more than 20 kts at 20 ft for Class I, no more than 30 kts at 20 ft for Class II, III, or IV	L_u, L_v, L_w as shown on figure 6.4.6-2; $\sigma_w = 0.1\ u_{20}$; σ_u, σ_v as given on figure 6.4.6-3	d_m as defined; v_m as determined from figure 6.4.6-5 using the appropriate values from figure 6.4.6-2 and figure 6.4.6-3	scalar shear as defined for u_{20}; 90° change in mean wind heading in a height change of 300 ft
High/ medium-altitude model		L_u, L_v, L_w as defined; rms turbulence intensities as shown on figure 6.4.6-4	d_m as defined (values of d_m less than the corresponding random turbulence scale length may be excepted); v_m as follows: At or below 20,000 ft: 66 ft/sec EAS at V_G 50 ft/sec EAS at $V_{o_{max}}$ 25 ft/sec EAS at V_{max} 50 ft/sec EAS at speeds up to V_{max}(PA) with landing gear and other devices which are open or extended in their max open or max extended positions For altitudes between 20,000 ft and 50,000 ft, v_m may be reduced linearly with altitude from: 66 to 38 ft/sec EAS at V_G 50 to 25 ft/sec EAS at $V_{o_{max}}$	

	Steady Wind Speed	Turbulence Scale Lengths and Intensities	Discrete Gust Length and Magnitude	Wind Shear
			25 to 12.5 ft/sec EAS at V_{max} For altitudes above 50,000 ft, v_m is the appropriate value of v_m at 50,000 ft multiplied by the factor $\sqrt{\rho/\rho_{50}}$, the square root of the ratio of air density at altitude to the standard atmospheric density at 50,000 ft	

Breakout force	Breakout forces refer to the cockpit control force required to effect movement of the surface.
Calibrated airspeed, CAS	Airspeed-indicator reading corrected for position and instrument error but not for compressibility.
Conversion	Conversion is defined as the physical changes in the air vehicle configuration that are required to achieve transition from powered-lift flight to fully wing-borne flight.
Combat ceiling	The highest altitude at which the maximum rate of climb is 500 ft/min for a given weight and engine thrust.
Control power	Effectiveness of control surfaces in applying forces or moments to an air vehicle.
Cooper-Harper rating scale	A pilot rating scale used to evaluate air vehicle flying qualities (see figure 6.4.6-6).
Cruise ceiling	The highest altitude at which the maximum rate of climb is 300 ft/min at NRT at a given weight.
Dangerous	A condition in which loss of control, loss of the air vehicle, or death or injury to the crew is probable.
Direct force controllers	Direct force controllers include direct lift control systems and lateral translations systems.
Equivalent airspeed, EAS	True airspeed multiplied by $\sqrt{\sigma}$ where σ is the ratio of free-stream density at the given altitude to standard sea-level air density.
Fail-operate	The capability of the FCS for continued operation without degradation following a single failure and to fail passive in the event of a related subsequent failure.
Fail-soft	The capability of the FCS to continue with degraded operation that does not result in dangerous or unsafe flight conditions following a single failure (also known as fail-degrade).
Flight control system	The flight control system includes any stability and control augmentation systems, manual and automatic control and trim functions, the pitch, roll, and yaw system controls, direct force controls, including leading-edge and trailing-edge flaps, trim selectors, and all mechanisms and devices that they operate, including the feel system.

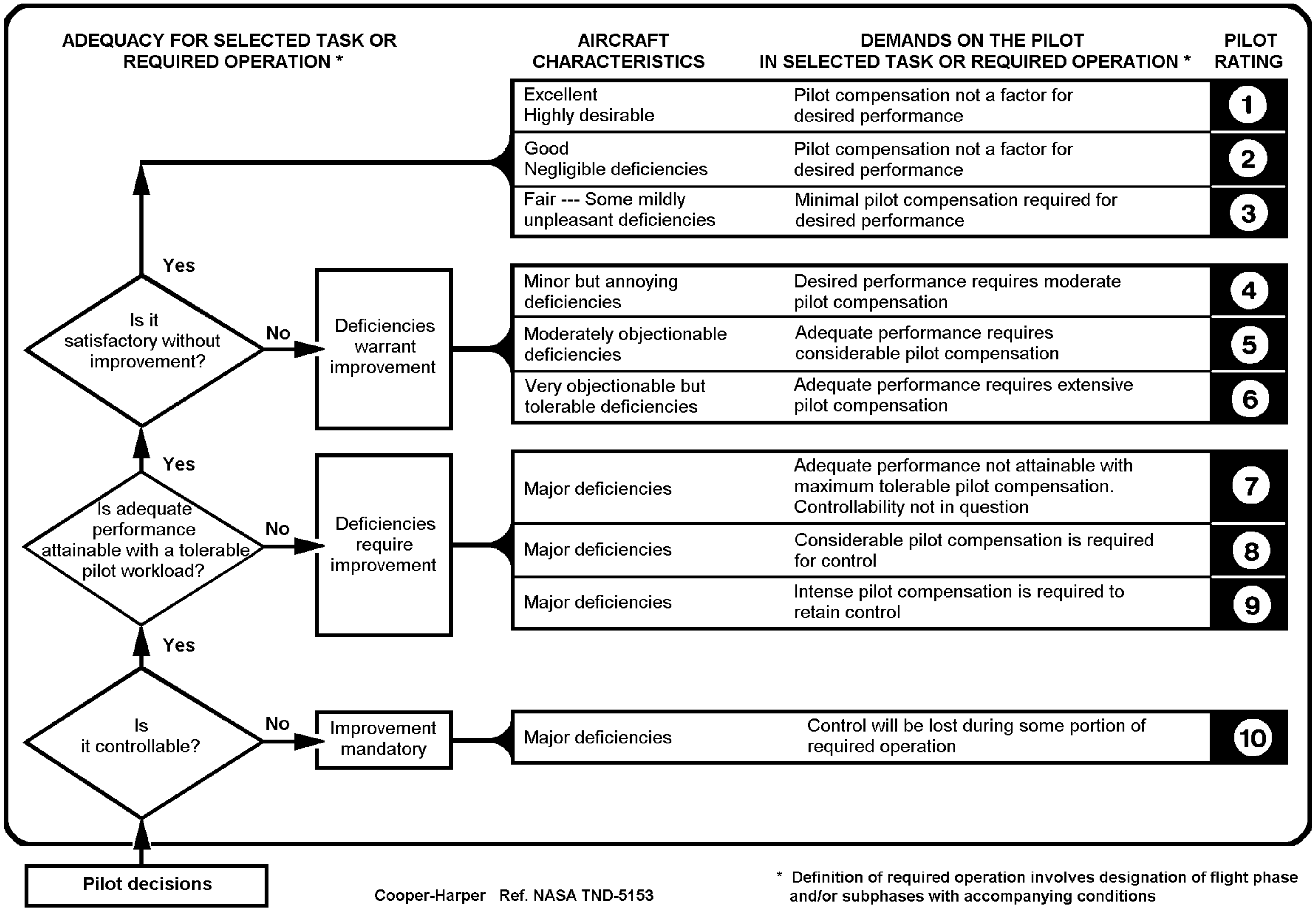


FIGURE 6.4.6-6. Cooper-Harper pilot rating scale.

Flight envelope	The flight envelope defines boundaries in terms of speed, altitude, load factor, and any other parameters which form flight limits (such as sideslip) which encompass all regions in which operation of the air vehicle is both allowable and possible, and which the air vehicle is capable of safely encountering.
Flight phase	Air vehicle missions are subdivided into segments known as flight phases. Together the flight phases constitute the entire mission, with no gap between successive flight phases and with smooth transitions between them. For example, the flight phases for a ground attack mission might consist of ground operation, takeoff, climb, cruise, in-flight refueling, ground attack, descent, approach, and landing.
Flight phase categories	The similarity of tasks in many flight phases, plus the limited amount of evaluation data on specific flight phases, has led to grouping the phases into three categories:

Category A — Those nonterminal flight phases that require rapid maneuvering, precision tracking, or precise flight path control. Included in this category are

a. Air-to-air combat (CO)

b. Ground attack (GA)

c. Weapons delivery/launch (WD)

d. Aerial recovery (AR)

e. Reconnaissance (RC)

f. In-flight refueling (receiver) (RR)

g. Terrain following (TF)

h. Antisubmarine search (AS)

i. Close formation flying (FF)

j. Low-altitude parachute extraction (LAPES)

Category B	Those nonterminal flight phases normally accomplished using gradual maneuvers and without precision tracking, although accurate flight path control may be required. Included in this category are a. Climb (CL) b. Cruise (CR) c. Loiter (LO) d. In-flight refueling (tanker) (RT) e. Descent (D) f. Emergency descent (ED) g. Emergency deceleration (DE) h. Aerial delivery (AD)
Category C	Terminal flight phases are normally accomplished using gradual maneuvers and usually require accurate flight path control. Included in this category are a. Takeoff (TO) b. Catapult takeoff (CT) c. Approach (PA) d. Wave-off/go-around (WO) e. Landing (L)
Intolerable	"Intolerable" is to be interpreted in the context of controllability: an annoyance, distraction, or discomfort so great as to interfere with the ability to maintain control.
Lateral translation	Lateral translations occur at essentially zero bank angle and zero change in heading.
Levels of flying qualities	In calm air, Level 1 is satisfactory, Level 2 is tolerable, and Level 3 is controllable. In the presence of atmospheric disturbances, 3.3.11.1.2 Flying qualities degradations in atmospheric disturbances states the relationship between levels and qualitative degrees of suitability.
Objectionable	"Objectionable" is to be interpreted in the context of operational missions: an annoyance, distraction, or discomfort so great as to interfere with task performance.
Pilot-In-the-loop Oscillation	An unintentional sustained or uncontrollable oscillation that results from the efforts of the pilot to control the air vehicle.

PIO rating scale	A pilot rating scale used to evaluate PIO tendencies (see figure C-3 in Appendix C).
Post-stall	The flight regime involving AOAs greater than nominal stall AOAs. The air vehicle characteristics in the post-stall regime may consist of three more or less distinct consecutive types of air vehicle motion following departure from controlled flight: post-stall gyration, incipient spin, and developed spin.
Post-stall gyration	Uncontrolled motions about one or more air vehicle axes following departure from controlled flight. While this type of air vehicle motion involves AOAs higher than stall angle, lower angles may be encountered intermittently in the course of the motion.
Powered-lift	The flight regime of any air vehicle in which controlled level flight is possible below the power-off stall speed and in which part or all of the lift and/or control moments are derived directly from powerplant(s).
Qualitative degrees of suitability	The degrees of suitability are defined as
Satisfactory	Flying qualities clearly adequate for the mission flight phase. Desired performance is achievable with no more than minimal pilot compensation.
Tolerable	Flying qualities adequate to accomplish the mission flight phase, but some increase in pilot workload or degradation in mission effectiveness, or both, exists.
Controllable	Flying qualities such that the air vehicle can be controlled in the context of the mission flight phase, even though pilot workload is excessive or mission effectiveness is inadequate, or both. The pilot can transition from Category A flight phase tasks to Category B or C flight phases, and Category B and C flight phase tasks can be completed.
Recoverable	Flying qualities such that control can be regained following loss of control due to departure, failures, or atmospheric disturbances.

Regions of handling	For each air vehicle normal state, the flight envelope is divided into three regions defined in terms of speed, altitude, and load factor, plus any other parameters which may form flight limits (such as sideslip), within which the flying qualities requirements apply.
Regions of satisfactory handling (ROSH)	Regions of the flight envelope derived from operational mission requirements and in which Level 1 flying qualities are required.
Regions of tolerable handling (ROTH)	Regions of the flight envelope derived from air vehicle performance margins rather than from mission requirements.
Regions of recoverable handling (RORH)	Regions of the flight envelope in which operation of the air vehicle is both allowable and possible, and which the air vehicle is capable of safely encountering.

Ride discomfort index

$$D_i = \left[\int_{0.1}^{f_t} |w(f)|^2 |T_{cs}(f)|^2 \Phi_u(f) df \right]^{1/2}$$

where:

D_i	Ride discomfort index, (vertical or lateral)
$w(f)$	Acceleration weighting function (vertical or lateral) 1/g
$T_{cs}(f)$	Transmissibility, at crew station, g/ft/sec
$\Phi_u(f)$	Von Karman gust power spectral density of intensity
f	Frequency, Hz
f_t	Truncation frequency beyond which aeroelastic responses are no longer significant in turbulence

Acceleration weighting functions are defined for vertical and lateral acceleration on figure 6.4.6-7. Probability of exceedance versus turbulence intensity is specified on table 6.4.6-IV.

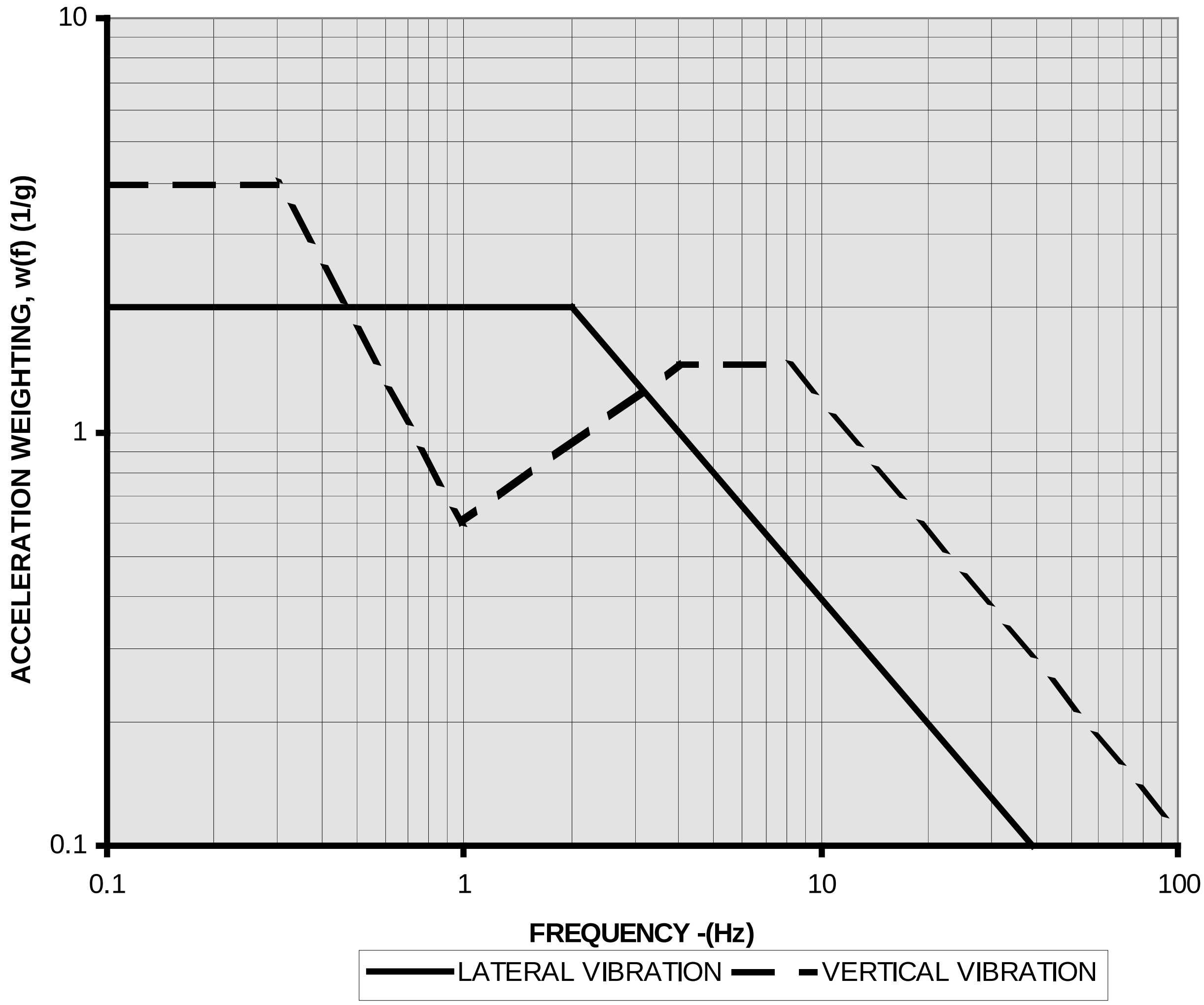


FIGURE 6.4.6-7. Acceleration weighting functions.

TABLE 6.4.6-IV. Root-mean-square (rms) gust intensities for selected cumulative exceedance probabilities, ft/sec TAS.

Flight Segment	Altitude (FT-AGL)	Probability of Exceedance	
		2×10^{-1}	10^{-2}
Terrain Following	UP TO 1000 (Lateral)	4	8
	UP TO 1000 (Vertical)	3.5	7
Normal Flight Climb Cruise and Descent	500	3.2	6.6
	1,750	2.2	6.9
	3,750	1.5	7.4
	7,500	0	6.7
	15,000	0	4.6
	25,000	0	2.7
	35,000	0	0.4
	45,000	0	0
	55,000	0	0
	65,000	0	0
	75,000	0	0
	OVER 80,000	0	0

Service ceiling — The highest altitude at which the maximum rate of climb is 100 ft/min at a given weight and engine thrust.

Spin — That part of the post-stall air vehicle motion which is characterized by a sustained yaw rotation. The spin may be upright or inverted, flat (high AOA) or steep (low but still stalled AOA), and the rotary motions may have oscillations in pitch, roll, and yaw superimposed on them. The incipient spin is the initial, transient phase of the motion during which it is not possible to identify the spin mode, usually followed by the developed spin, the phase during which it is possible to identify the spin mode.

Takeoff — The term takeoff includes the ground run, rotation, and liftoff; the ensuing acceleration to V_{max}(TO); and the transient caused by assist cessation. Takeoff encompasses operation both in and out of ground effect.

Transition — The transition region is defined as the range of speeds between hover and the maximum at which conversion is initiated (inbound) or complete (outbound), including all of the conversion process.

6.4.6.1 Abbreviations and symbols

a_y	lateral acceleration
AD	aerial delivery flight phase
AFFTC	Air Force Flight Test Center
AGL	above ground level
AOA	angle of attack
AR	aerial recovery flight phase
AS	anti-submarine search flight phase
ASRM	automatic spin recovery mode
BIT	built-in test
c.g.	center of gravity
C-H	Cooper-Harper
CAP	control anticipation parameter
CL	climb flight phase
C_L	lift coefficient
$C_{L_{stall}}$	lift coefficient at α_S defined below
C_m	pitching moment coefficient
C_{m_α}	nondimensional variation of C_m with α, $\lvert C_m / \alpha \rvert$
CO	air-to-air combat flight phase
CFD	computational fluid dynamics
CR	cruise flight phase
CT	catapult takeoff flight phase
CV	aircraft carrier
D	descent flight phase
DATCOM	data compendium
DE	emergency deceleration flight phase
Deg., °	degree
D_I	ride discomfort index
d_m	generalized discrete gust length (always positive), m = x, y, or z (feet)
ED	emergency flight phase
FAR	Federal Aviation Regulation
FF	close formation flying flight phase
FMECA	failure modes and effects criticality analysis
FMET	failure modes and effects test

ft	feet
G	acceleration of gravity
GA	ground attack flight phase
GW	gross weight
h_L	maximum attainable altitude
h_{max}	maximum service altitude: for a given speed, the maximum altitude at which a rate of climb of 100 ft/min can be maintained in unaccelerated flight with MAT
$h_{o_{max}}$	maximum altitude boundary for the ROSH
$h_{o_{min}}$	minimum altitude boundary for the ROSH
HQDT	handling qualities during tracking
i	$\sqrt{-1}$
KCAS	knots calibrated airspeed
L	landing flight phase
Lbs	pounds
LHA	amphibious assault ship (landing helicopter assault)
LHD	amphibious assault ship (landing helicopter dock)
LO	loiter flight phase
L_u	scale for u_g (feet)
L_v	scale for v_g (feet)
L_w	scale for w_g (feet)
MAT	maximum augmented thrust: maximum thrust augmented by all means available for the flight phase
Max	maximum
Min	minimum
MRT	military rated thrust: maximum thrust at which the engine can be operated for a specified period
MSL	mean sea level
N	normal acceleration measured at the instantaneous center of rotation for pitch control inputs
n_L	symmetrical flight limit load factor for a given air vehicle normal state, based on structural considerations
$n_{L_{max}}$	maximum limit load factor (positive-g limit load factor)
$n_{L_{min}}$	minimum limit load factor (negative-g limit load factor)

n_{max}	maximum service load factor: maximum load factor boundary for the ROTH
n_{min}	minimum service load factor: minimum load factor boundary for the ROTH
$n_{o_{max}}$	maximum load factor boundary for the ROSH
$n_{o_{min}}$	minimum load factor boundary for the ROSH
NRT	normal rated thrust: maximum thrust at which the engine can be operated continuously
P	roll rate
PA	approach flight phase
PIO	pilot-in-the-loop oscillation
R	yaw rate
RC	reconnaissance flight phase
rms	root-mean-square
RORH	region of recoverable handling
ROSH	region of satisfactory handling
ROTH	region of tolerable handling
RR	in-flight refueling (receiver) flight phase
RT	in-flight refueling (tanker) flight phase
SAS	stability augmentation system
SCAS	stability and control augmentation system
sec	second(s)
STEMS	standard evaluation maneuver set
STO	short take-off
STOL	short take-off and landing
T	time (seconds)
TBE	to be established
TF	terrain-following flight phase
TLF	thrust for level flight
TO	takeoff flight phase
u_{20}	mean wind speed at 20 feet above the ground
u_g	disturbance velocity along the x-axis, positive forward (feet per second)

USAF	United States Air Force
USAFTPS	United States Air Force Test Pilot School
USN	United States Navy
USNTPS	United States Naval Test Pilot School
V_C	catapult end airspeed
$V_{C_{min}}$	minimum catapult end airspeed
VCMS	vehicle control and management system
V_{end}	speed for maximum endurance
v_g	disturbance velocity along the y-axis, positive to the pilot's right (feet per second)
V_G	gust limit speed
V_H	level flight maximum airspeed
VL	vertical landing
V_L	limit airspeed, maximum attainable airspeed
V_{LF}	takeoff, approach, and landing limit airspeed
v_m	generalized discrete gust intensity, positive along the positive axes, m = x, y, or z (feet per second)
V_{MAT}	maximum level speed with maximum augmented thrust
V_{max}	maximum service speed

The maximum speed boundary for each altitude should be the lowest of

a. The maximum speed at which a safe margin exists from any potentially dangerous flight condition.

b. A speed which is a safe margin below the speed at which intolerable buffet or structural vibration is encountered.

In setting the maximum speed, the designer need not consider speed-altitude combinations that can only be reached in an attitude that would not permit recovery to level flight with a nominal 2000 foot clearance above sea level while remaining within the RORH.

V_{min}	Minimum service speed The minimum speed boundary for each altitude should be the highest of a. 1.1 VS. b. VS + 10 knots equivalent airspeed. c. The speed below which full air vehicle-nose-up pitch control power and trim are insufficient to maintain straight, steady flight. d. The lowest speed at which level flight can be maintained with MRT. e. A speed limited by reduced visibility or an extreme pitch attitude that would result in the tail or aft fuselage contacting the ground.
$V_{o_{max}}$	maximum speed boundary for the ROSH
$V_{o_{min}}$	minimum speed boundary for the ROSH
V_{MRT}	maximum level speed with military rated thrust
V_{NRT}	maximum level speed with normal rate thrust
V_{range}	speed for maximum range
$V_{R/C}$	speed for maximum rate of climb
V_S	stall speed (equivalent airspeed), at 1g normal to the flight path, defined as the highest of a. Speed for steady, straight flight at CLmax -- the first local maximum of the curve of lift coefficient (L/qS) vs. AOA, which occurs as CL, is increased from zero. b. Speed at which uncommanded pitching, rolling, or yawing occurs. c. Speed at which intolerable buffet or structural vibration is encountered.
V_S(X), V_{min}(X), V_{max}(X)	Shorthand notation for the speeds V_S, V_{min}, V_{max} for a given configuration, weight, c.g. position, and external store combination associated with flight phase X. For example, the designation V_{max}(TO) is used to emphasize that the speed intended (for the weight, c.g. and external store combination under consideration) is V_{max} for the configuration associated with the takeoff flight phase. This is necessary to avoid confusion, since the configuration and flight phase change from takeoff to climb during the maneuver.
V/STOL	vertical/short take-off and landing
$V_{w/d}$	magnitude of the wind over the aircraft carrier deck (feet per second)
WD	weapon delivery/launch flight phase
w_g	disturbance velocity along the z-axis, positive down (feet per second)
W.O.	wash out

WO	wave-off/go-around flight phase
X	distance from air vehicle to ship center of pitch, negative aft of ship (feet)
α	angle of attack
α_S	The stall AOA at constant speed for the configuration, weight, c.g. position, and external store combination associated with a given air vehicle normal state; defined as the lowest of
	AOA for the highest steady load factor, normal to the flight path, that can be attained at a given speed or Mach number
	AOA, for a given speed or Mach number, at which uncommanded pitching, rolling, or yawing occurs
	AOA, for a given speed or Mach number, at which intolerable buffeting is encountered
β	sideslip angle
γ	flight path angle, positive for climbing flight
	$\gamma = \sin^{-1}$ (vertical speed/true airspeed)
δ_a	aileron deflection
δ_e	elevator deflection
δ_F	flaperon deflection
δ_{HT}	horizontal tail deflection
δ_r	rudder deflection
σ, rms	root-mean-square disturbance intensity, where
	$\sigma^2 = \int_0^\infty \Phi(\Omega)\, d\Omega = \int_0^\infty \phi(\omega)\, d\omega$
σ_u	root-mean-square intensity of u_g
σ_v	root-mean-square intensity of v_g
σ_w	root-mean-square intensity of w_g
$\Phi_{u_g}(\Omega)$	spectrum for u_g, where $\Phi_{u_g}(\Omega) = V\phi_{u_g}(\omega)$
$\Phi_{v_g}(\Omega)$	spectrum for v_g, where $\Phi_{v_g}(\Omega) = V\phi_{v_g}(\omega)$
$\Phi_{w_g}(\Omega)$	spectrum for w_g, where $\Phi_{w_g}(\Omega) = V\phi_{w_g}(\omega)$
ψ_w	mean wind direction relative to runway
ω	temporal frequency (radians per second), where $\omega = \Omega V$
Ω	spatial (reduced) frequency (radians per foot)

6.4.7 Diagnostics definitions

Mechanical and electrical	Any line replaceable unit or module that is not identified as avionic and electronic (e.g., backplanes, bearings, gears, cables, wiring, and connectors). Cables and connectors will be included in the mechanical and electrical requirement.
Avionic and electronic	Any line replaceable unit or module that has active electronic circuitry or contain an embedded controller and uses a logic state machine. Also, a mechanical assembly which incorporates active electrical and electronic devices, whose failures are BIT-detectable.
Fault detection and fault isolation (FD FI) time	FD FI time is an element of maintainability $MTTR_e$ and MaxTTR.
Automated isolation	A failure identified in an LRU or LRM by on-board systems (e.g., ACMS, BIT), PMA, PIP, or other off-board support equipment.
Relevant failure	For diagnostic purposes, a failure in a line replaceable item that affects the item or any other higher assembly functional performance in any operating mode under service conditions. Non-relevant failures that do not affect functional performance (e.g., corrosion, wear, chafe, and fatigue) in avionic and electronic equipment or wiring may become relevant if they propagate such that they affect functional performance.

6.4.8 Maintainability definitions

Essential systems repair time (ESRT)	The elapsed time, in clock hours, required to repair and or replace any mission essential equipment in order to return an air vehicle to mission-capable status (includes all repair activities; i.e., detection, isolation, access, repair and or replacement, verification, cure and application times, close and or seal and inspection of same) divided by the total number of flight hours (or sorties) accumulated over a specified measurement period. ESRT should be specified in terms of hours per flight hour (or per sortie) that support the required levels of availability (often provided as a Sortie Generation Rate (SGR)).
Maintenance man hours per flight hour (MMH/FH)	The sum of maintenance man hours spent performing maintenance (preventive, scheduled or corrective) divided by the total number of air vehicle flight hours.

Mean time to repair (MTTR)	The sum of corrective maintenance times for restoration of the air vehicle, divided by the total number of failures. Repair time includes all repair activities; i.e., detection, isolation, access, repair and or replacement, verification, cure and application times, close and/or seal and inspection of the same.

6.4.9 Manufacturing variation

Manufacturing variation is the difference between the weight empty value obtained from the contractor weight records and the actual (scale) weight empty for an individual air vehicle. It is due to (1) inaccuracies in the weight records, (2) the differences from air vehicle to air vehicle due to variations inherent in the manufacturing process, such as variations in sheet stock thickness, depth of machining cuts, and (3) variability associated with the weighing process.

6.4.10 Nondevelopmental item

Nondevelopmental items are configuration items not requiring development. They include

a. Any item available in the commercial marketplace;

b. Any previously developed item in use by a Federal, state, or local agency of the United States or a foreign government with which the United States has a mutual defense cooperation agreement;

c. Any item described in (a) or (b) above that requires only minor modification in order to meet the requirements of the procuring agency; or

d. Any item currently being produced that does not meet the requirements of (a), (b), or (c) above solely because the item is not yet in use or is not yet available in the commercial marketplace. (DoDI 5000.2).

6.4.11 Nonstructural parts

Nonstructural parts or components are those that are not relied upon, and not considered by stress analyses, to carry structural loads.

6.4.12 Open system

A system composed of discrete elements, each of which is defined in sufficient completeness and detail such that selected element(s) can be replaced and/or modified in a competitive environment with minimal or no modifications to other system elements while maintaining equal or improved system performance and capability.

6.4.13 Provisions, contractor (expressions)

Complete provision for (expression)	"Complete provision for" or "provision should be made for" means that all supports, brackets, tubes, fittings, electrical wiring, hydraulic lines, etc., have been installed and adequate weight and space allowed in order that the equipment can be installed without alteration to the specified equipment or the air vehicle. No additional parts are required for installation, other than the item itself. Standard stock items such as nuts, bolts, cotter pins, etc., need not be furnished. The weight of the item is to be included in weight empty and in all design gross weights for the air vehicle including structural design gross weights. Power for the item should be provided as specified in "Power provision for" below. Cooling for the item shall be provided based on equipment specification.
Group A provisions	Group A provisions accommodate future installations of equipment, specifically space, weight, power and cooling. Space and weight provisions are based on the volume of generic classes of equipment which would allow for future installation of equipment without changes to existing structure, mounting location, or other compartment features. Included in the provisions are space and weight for shock mounts, connectors, cooling ducts, etc., as might be required. Weight for these items should be included in the specification weights, and location should be such that vehicle balance and inertia are unaffected whether the item(s) are installed or not. Power provisions require the allocation of generator and/or battery capacity such that the future capability can be added without changing the electrical system configuration or capacity. Cooling provisions require allocation of cooling capacity such that the future capability can be added without changing the environmental control system configuration or capacity. Access doors, if needed, shall be incorporated into the basic design. For computers, this would include card slots.
Group B provisions	Group B provisions accommodate future installation of known equipment. In addition to group A provisions, installation features such as supports, brackets, tubing, wiring, fittings, ducting, etc. should be provided such that no additional parts are required for installation other than the item itself.
Power provision for (expression)	"Power provision for" means that the primary electrical, hydraulic and pneumatic power and distribution systems should be of sufficient capacity to allow later incorporation of the specific equipment without modification to the primary power and distribution systems. This capacity is in addition to the excess capacity provided for growth in the load demand. "Power provision for" does not include electrical wiring, hydraulic or pneumatic lines, brackets, bolt holes, etc.

Space provision for (expression)	"Space provision for" means that space only should be allocated for the installation, and that brackets, bolt holes, electrical wiring, hydraulic lines, etc., are not required. "Space provision for" does not imply that adequate attaching structure is provided, unless otherwise specified.
Weight provision for (expression)	"Weight provision for" means that suitable weight allowance to simulate later incorporation of the item or complete installation should be included in weight empty and all design gross weights and structural design conditions.
Shall be installed (expression)	The expression "shall be installed" means that the item or equipment is to be furnished by the Government and installed by the contractor.
Shall be provided (expression)	The expression "shall be provided" means that the item or equipment is to be furnished and installed by the contractor.

6.4.14 Reliability and maintainability definitions

Reliability, maintainability and failure definitions used in this document are defined below. For the purpose of reliability, the word “failure” refers to chargeable failures.

Corrective maintenance	All maintenance actions performed as a result of failure, to restore an item to a specified condition. Corrective maintenance can include any or all of the following steps: Localization, Isolation, Disassembly, Interchange, Re-assembly, Alignment, and Checkout.
Essential Systems Repair Time (ESRT)	ESRT should be specified in terms of hours per flight hour (or per sortie) that support the required levels of availability (often provided as a Sortie Generation Rate (SGR)). ESRT per flight hour is defined as the elapsed time, in clock hours, required to repair and or replace any mission essential equipment in order to return an aircraft to mission-capable status (includes all repair activities; i.e., detection, isolation, access, repair and or replacement, verification, cure and application times, close and or seal and inspection of same) divided by the total number of flight hours (or sorties) accumulated over a specified measurement period.

Failure(s)	All failures (hardware or software) that occur during a specified period without consequence to mission success. Failures must be defined in such a way that the contractor has design influence/control over. Failure relevancy criteria for requirement verification should be developed and included with the specification. Service/Agency and program-unique elements can also be accommodated in the criteria. Failures outside the control the designer's ability to control should not be included (i.e., failures due to improper use, maintenance errors, test equipment failures, etc.).
Logistics reliability	Logistics reliability describes an attribute that controls the overall logistics demand or all actions necessary for retaining or restoring the air vehicle to a specified operating condition. (This includes both demand for manpower and demand for spares.)
Maintenance action(s)	One or more preventive, scheduled or corrective maintenance tasks necessary to retain an item in or restore it to a specified condition. See definitions below for preventive and corrective maintenance.
Maintenance event(s)	One or more preventive, scheduled or corrective maintenance actions necessary to retain an item in or restore it to a specified condition. See definitions below for preventive and corrective maintenance.
Maintenance man hours per flight hour (MMH/FH)	The sum of maintenance man hours spent performing maintenance (preventive, scheduled or corrective) divided by the total number of air vehicle flight hours.
Mean time between failure (MTBF)	The total amount of operating time divided by the total number of failures.
Mean time between maintenance action (MTBMA)	The total amount of operating time divided by the total number of maintenance actions.
Mean time between maintenance event (MTBME)	The total amount of operating time divided by the total number of maintenance events.
Mean time between mission failure (MTBMF)	The total amount of mission time, divided by the total number of mission failures during a stated series of missions.
Mean time between removal (MTBR)	The total amount of operating time divided by the total number of maintenance removals.
Mean Time to Repair (MTTR)	The sum of corrective maintenance times for restoration of the air vehicle, divided by the total number of failures.
Mission(s)	A time-phased description of the events and environments the air vehicle experiences from initiation to completion of a specified mission, to include the criteria of mission. Mission duration and functions will vary by air vehicle and by mission type.

Mission failures	A failure, or combination of failures (hardware or software), that prevents the air vehicle from performing a specified mission. The user must define the type mission and essential operating characteristics required to successfully complete the mission.
Mission reliability	The probability that the air vehicle can perform all the mission functions, when required, for as long as required, to successfully complete the desired mission, when operated in the environment and usage defined herein. (Expressed in percent, i.e., 95% or 0.95).
Mission time	The universal measure of duration or life units. In general, air vehicle life units are typically specified in terms of flight hours.
Preventive maintenance	All maintenance actions performed in an attempt to retain an item in specified condition by providing systematic inspection, detection, and prevention of incipient failures.
Scheduled maintenance	All maintenance actions performed as a result of on-condition indications of scheduled activities based on design requirements and life limits.
Time	The universal measure of duration or life units. In general, air vehicle life units are typically specified in terms of flight hours.

6.4.15 Safety definitions

Suggested definitions for hazard consequences indices are outlined below:

Catastrophic	Dollar: loss of a capital asset or damage thereto and resources in excess of one million dollars (production acquisition value). Human: injury to the public or the operator resulting in death or permanent disability. Environmental: irreversible, severe environmental damage that violates law or regulation. Combined consequences shall be considered as any event which leads to loss of a capital asset or damage thereto and resources in excess of one million dollars (production acquisition value) or injury to the public or the operator resulting in death or permanent disability or irreversible severe environmental damage that violates law or regulation.

Critical	Dollar: capital equipment or resource loss or damage of less than one million dollars but more than $250,000. Human: one or more injuries that result in partial disability. Environmental: reversible environmental damage causing a violation of law or regulation. Combined consequences include those that result in capital equipment or resource loss or damage of less than one million dollars but more than $250,000 and/or resulting in one or more injuries that result in partial disability or reversible environmental damage causing a violation of law or regulation.
Significant	Dollar: capital equipment and resource loss or damage of less than $250,000 and more than $100,000. Human: personal injury, or injuries, resulting in temporary partial or complete disability of greater than fifteen (15) days. Environmental: mitigable environmental damage causing a violation of law or regulation. Combined consequences include those that result in capital equipment and resource loss or damage of less than $250,000 and more than $100,000 or personal injury, or injuries, resulting in temporary partial or complete disability of greater than fifteen (15) days or mitigable environmental damage causing a violation of law or regulation.
Marginal	Dollar: capital equipment and resource loss or damage of less than $100,000 and more than $10,000. Human: personal injury, or injuries, resulting in temporary disability of less than fifteen (15) days and more than one (1) lost day. Environmental: mitigable environmental damage without violation of law or regulation in which restoration activities can be accomplished. Combined consequences include those that result in capital equipment and resource loss or damage of less than $100,000 and more than $10,000 or personal injury, or injuries, resulting in temporary disability of less than fifteen (15) days and more than one (1) lost day or mitigable environmental damage without violation of law or regulation in which restoration activities can be accomplished.
Negligible	Dollar: capital equipment and resource loss or damage of less than $10,000. Human: personal injury, or injuries, resulting in first aid requirements and one (1) or less days lost to disability. Environmental: minimal environmental damage not violating law or regulation.

6.4.16 Hazard frequency indices

Suggested definitions for hazard frequency indices are outlined below:

Frequent	All hazards which are likely to occur often in the life of an item with a probability of occurrence greater than 0.1 in that life for an air vehicle operated in accordance with the operational scenarios and missions as defined herein.
Probable	All hazards which will occur several times in the life of an item with a probability of occurrence less that 0.1 but greater than 0.01 in that life for an air vehicle operated in accordance with the operational scenarios and missions as defined herein.
Occasional	All hazards which are likely to occur some time in the life of an item with a probability of occurrence less than 0.01 but greater than 0.001 in that life for an air vehicle operated in accordance with the operational scenarios and missions defined herein.
Unlikely	All hazards which are unlikely but possible to occur in the life of an item with a probability of occurrence less than 0.001 but greater than 0.0001 for an air vehicle operated in accordance with the operational scenarios and missions defined herein.
Remote	All hazards which are unlikely but possible to occur in the life of an item with a probability of occurrence less than 0.0001 but greater than 0.000001 for an air vehicle operated in accordance with the operational scenarios and missions defined herein.
Improbable	All hazards which are so unlikely it can be assumed occurrence may not be experienced with a probability of occurrence less than 0.000001 in that life for an air vehicle operated in accordance with the operational scenarios and missions defined herein.

6.4.17 Survivability definitions

Survivability is the capability of a weapon system to avoid and or withstand a man-made hostile threat environment. Survivability may be achieved by threat avoidance as well as by incorporating the ability to withstand the threat. Survivability consists of two subsets, susceptibility and vulnerability.

Susceptibility	Susceptibility is the likelihood that a weapon system is impacted by a threat weapon. The signatures of a weapon system have a significant impact on susceptibility.

Vulnerability	Air vehicle vulnerability is a measure of the probability that an air vehicle will be degraded to one of the defined kill levels after responding to threat mechanisms. Vulnerability of a system to NBC contamination is defined as “the lack of capability of equipment and personnel to withstand an NBC-contaminated environment and decontamination while maintaining the ability to accomplish the mission of the system.” In more recent guidance, DoDR 5000.2-R, 15 March 1996, Appendix IV (IV-2) provides a similar definition of vulnerability, and emphasizes a “definite” degradation which results from a defined threat level.

6.4.18 Verification definitions

The verification methods used in this document are defined as follows:

Inspection/ evaluation (I)	Inspection applies to reviewing/examining equipment, drawings, or documentation. This method does not require extensive analysis, and is primarily a review of items in order to make an assessment.
Analysis (A)	A method of verification that utilizes established technical or mathematical algorithms (math representation models), charts, graphs, circuit diagrams, or other scientific principles and procedures. Note: When the verification effort consists of reviewing/analyzing test data from lower-level tests, the verification method at the higher level should be Analysis (analysis of lower-level test data). For instance, if an air vehicle requirement is to be verified by a tier three avionics test, the air vehicle verification would call out an "A" and the tier three avionics verification would call out a "T."
Simulation/ modeling (S)	The process of conducting experiments using analog or digital devices, laboratory models, or “test bed” sites. Simulation involves the use of emulators, prototypes, simulators, or stimulators in a laboratory environment to evaluate an engineering design under varying performance and failure conditions either statically or over time to establish design margins and risks. Simulations can be aggregates of models run under particular constraints for a specified period of time.
Demonstration (D)	A method that generally utilizes, under specific scenarios, the actual operation, adjustment, or re-configuration of items. Demonstration usually applies when an event is to be observed to support the verification process. Instrumentation is generally not used within the demonstration process.

Test (T)	A method of verification that generally determines, quantitatively, the properties or elements of items, including functional operation, and involves the application of established scientific principles and procedures. Test verification usually applies when data are taken during testing that requires some degree of manipulation to determine the outcome of the event. Instrumentation is generally used within the test process. Note: When the verification effort consists of reviewing/analyzing test data from lower-level tests, the verification method at the higher level should be Analysis (analysis of lower-level test data). For instance, if an air vehicle requirement is to be verified by a tier three avionics test, the air vehicle verification would call out an "A" and the tier three avionics verification would call out a "T."

6.4.18.1 Verification by milestones.

The incremental verification approach is intended to accomplish several important objectives, ensuring that

a. Air vehicle level performance requirement is consistent with the requirement allocations made and implemented in lower-tier specifications/product definition documentation;

b. Product design decisions support the allocated performance requirements; and

c. The air vehicle-level performance requirements are met.

To ensure that product design decisions support and properly allocate performance requirements, verification should be accomplished in iterations at appropriate program milestones. Ideally, iterative verifications, while accomplishing the same basic objective each time, are done with greater and greater fidelity and accuracy as designs mature and more detailed information becomes available. Some verifications may progress in method from inspection to analysis to simulation to test through successive milestones. Other verifications may call for using the same method (i.e., analysis) through each program milestone but requiring successively more insight into and fidelity in data and assumptions.

Requirements should be verified prior to each major air vehicle milestone to provide the greatest assurance that verification criteria are achieved. The milestones for a specific program may differ or be called by a different name. There may be more milestones or fewer. Milestone objectives may be different. These are all program choices. In all cases, program milestones must be defined. However, the verification criteria must be matched to the milestones selected and the milestone objectives.

The following are typical milestones intended for use in the Joint Service Specification Guides:

a. System Requirements Review (SRR)/System Function Review (SFR) or equivalent.

b. Preliminary Design Review (PDR) or equivalent.

c. Critical Design Review (CDR) or equivalent.

d. First Flight Review (FFR) or equivalent.

e. System Verification Review (SVR) or equivalent.

The key objectives of each milestone, applicable to specifications, are summarized:

System Requirements Review (SRR)/System Functional Review (SFR) or equivalent. Confirm convergence on and achievability of air vehicle requirements and readiness to initiate preliminary design by confirming that

a. Air vehicle functional and performance requirements have converged and characterize an air vehicle for which one or more design approaches exist that satisfy established customer needs and requirements;

b. The air vehicle's draft physical architecture and draft lower-level product performance requirements definition establish an initial assessment of, the adequacy, completeness, and achievability of functional and performance requirements, and quantification of cost, schedule, and risk;

c. Critical technologies have been verified at an acceptable level of risk for availability, achievability, needed performance, and readiness for transition;

d. Consensus is reached on the verification/validation of reliability and maintainability levels (whether numerical or levels of detail) at program milestones. Verification test methods and acceptance criteria based on employment of an agreed-to verification method are incorporated into schedules, facilities requirements, manpower needs, and other programmatic imperatives. Measurement and growth management of mission reliability and maintainability have been integrated into program management;

e. Life cycle requirements have been defined, within acceptable limits of certainty, that provide the encompassing essential functionality, capability, interfaces, and other requirements/constraints; and

f. Pre-planned product and process improvement and evolutionary acquisition requirements planning has been defined as required.

Preliminary Design Review (PDR) or equivalent. Confirm that the detailed design approach satisfies air vehicle requirements and the total system is ready for detailed design. PDR confirms that the process completely defines air vehicle requirements for design, including

a. The air vehicle physical architecture is an integrated detailed design approach to satisfy requirements, including interoperability and interfaces;

b. An audit trail from SRR is established with changes substantiated;

c. Available developmental test results support the air vehicle design approach;

d. The product performance requirements are defined;

e. Sufficient detailed design has been accomplished to verify the completeness and achievability of defined requirements, and quantification of cost, schedule, and risk; and

f. Pre-planned product and process improvement and evolutionary acquisition requirements planning have been refined.

Critical Design Review (CDR) or equivalent. Confirm that the total air vehicle detailed design is complete, meets requirements, and that the total air vehicle is ready for manufacturing. CDR confirms that the process completely defined air vehicle design requirements, including:

a. The air vehicle physical architecture is an integrated detailed design to satisfy requirements, including interoperability and interfaces

b. An audit trail from PDR is established with changes substantiated, and product performance requirements are refined;

c. Product design definition and product manufacturing/fabrication and support definition for the system is defined;

d. The air vehicle design compatibility with external interfaces has been established;

e. Developmental test results are consistent with air vehicle design and interface requirements and design constraints;

f. Critical air vehicle design and interface requirements and design constraints are supported by developmental test results; and

g. Pre-planned product and process improvement and evolutionary acquisition requirements planning has been defined.

First Flight Review (FFR) or equivalent. Confirm prior to testing that air vehicle items, individually or in combination, demonstrate that:

a. The safety inherent in the test article(s) and the procedures and plans for its use have been evaluated as being safe;

b. Personnel involved in the testing are trained in both the objectives of the test(s) and the jobs they are responsible for accomplishing;

c. The configuration control process necessary to support flight testing is established;

d. Planning for testing is complete, has been evaluated for adequacy, and is available to all applicable personnel;

e. Hazardous materials and procedures are defined and documented, and handling equipment, instructions, and special actions have been defined and provided to affected personnel with warnings, instructions, and special training as appropriate;

f. Resources (people, equipment, and materials) needed to accomplish the testing are available and ready for the testing;

g. The test article(s), equipment, facilities, and ranges (if applicable) are evaluated as ready for test; and

h. Documentation of evaluations, assessments, plans, procedures, training, and other factors applicable to the tests are available, correlated, and complete.

System Verification Review (SVR) or equivalent. Confirm that the total air vehicle has been verified. SVR confirms the completion of all incremental accomplishments for air vehicle verification (e.g., Test Readiness Reviews, system Functional Configuration Audits) and confirms within acceptable limits of certainty that

a. Air vehicle verification procedures are complete and accurate (including verification by test and demonstration of critical parameters as well as key assumptions and methods used in verifications by analytic models and simulations);

b. The air vehicle has been confirmed to be ready for verification;

c. Verifications have been conducted in accordance with established procedures; and are completed;

d. All lower-level requirement verification activities have been analyzed;

e. An audit trail from CDR is established with changes substantiated and the air vehicle verified;

f. The interface compatibility has been achieved;

g. All incidences of noncompliance have been identified and corrected by product definition change;

h. Plans and procedures for downstream processes (production, training, support/ sustainment, deployment/fielding, operations, and disposal) have been evaluated for adequacy; discrepancies resolved; and documentation and results incorporated in the air vehicle data base;

i. Program documentation has been inspected to confirm the information provided has been incorporated into the training, support and prime mission specifications; and,

j. Pre-planned product and process improvement and evolutionary acquisition requirements and plans have been refined.

6.4.19 Weight and balance definitions

Not included in normal weight	The expression "not included in normal weight" means that the items of equipment are not intended for installation on missions for which the air vehicle is designed. The weight of such items or equipment is not included in weight empty or useful load and hence does not influence the basic structural or aerodynamic design of the air vehicle. However, supports for such items or equipment will possess strength consistent with the special conditions under which the item or equipment will be carried.
Unusable fuel	"Unusable fuel" is defined as the total fuel that is unavailable to the engine under the conditions specified in MIL-F-17874 for normal flight and landing conditions.
Unusable oil	"Unusable oil" is defined as the total oil that is unavailable to the engine and other auxiliaries serviced by the engine oil tanks.
Weight empty	Weight empty is the weight of the complete air vehicle dry, clean, and empty except for fluids in closed systems such as the hydraulic system. Weight empty includes total structure group, propulsion group, flight controls group, avionics group, auxiliary power plant group, electrical group, etc. The weight empty also includes allowances for future growth items. The initial weight empty estimate (the estimate at contract initiation) includes an appropriate contingency for subsequent increases in weight due to unforeseen or underestimated design and development considerations.
Operating items	Operating items typically include the crew, oil, unusable fuel and air vehicle type- and mission-dependent items such as internal and external auxiliary fuel tanks, gun, ammunition, weapon suspension and release equipment, cargo handling equipment, crew baggage, food and emergency items which are not included in weight empty. The sum of the weight empty and the weights of the operating items for a mission is the operating weight for that mission.

Payload	Payload includes any item being transported that is directly related to the purpose of the mission as opposed to items necessary for the mission. Payload can include, but is not limited to passengers, cargo, passenger baggage, ammunition, internal and external stores, and fuel which is to be delivered to another air vehicle or site. Payload may or may not be expended.
Gross weight	Gross weight includes air vehicle weight empty, operating items, usable fuel and payload, and items to be expended during flight.
Basic flight design gross weight	The basic flight design gross weight is the highest flight weight required for the maximum positive and minimum negative load factors required for maneuvering. Note 1. For bombers, cargo, observation, trainers, and utility air vehicle, the flight design gross weight is the weight at engine start with the primary mission payload and fuel load. Note 2. For attack and fighter air vehicle the flight design gross weight is the greater of the following: a. The maximum flight weight minus 50 percent of the maximum internal and external payload for which provisions are made with either full internal fuel or 80 percent of total fuel (internal plus external) whichever is greater. The basis for fuel weight is the fuel at engine start. b. The take-off weight with primary useful load, including either full internal or 80 percent of the total fuel (internal and external) whichever is greater for land based air vehicle and primary useful load plus 60 percent of the internal fuel for ship based air vehicle. The basis for external fuel weight is the fuel at engine start.
Maximum flight weight	Maximum flight weight is the highest weight required for flight. The normal definition of maximum flight weight is the weight empty of the air vehicle plus operating items, maximum internal and external payload and maximum internal and external fuel. Care should be taken when addressing air vehicles with in-flight refueling capability. In these air vehicles, the maximum flight weight may exceed the maximum takeoff weight.
Maximum zero fuel weight	Maximum zero fuel weight is the highest weight required of the loaded air vehicle without any usable fuel. The normal definition for maximum zero fuel weight is the weight empty plus operating items and maximum payload.

Minimum flight weight	Minimum flight weight is the lowest weight required for flight. The normal definition of minimum flight weight is the weight empty plus the minimal crew, unusable fuel, oil, minimal equipment, and five percent of the total usable internal fuel capacity or reserve fuel as specified in the detailed specification. (Care must be taken in defining minimum flying weight. A recent attack air vehicle minimum flying weight included 250 ammo cases. Because of this, the air vehicle balance was determined to include these 250 cases. Therefore, whenever the air vehicle flew, it had to carry the cases or ballast to keep it within the c.g. limits.)
Maximum ground weight	Maximum ground weight is the highest weight required for ramp, taxiway, and runway usage. This weight is frequently referred to as maximum ramp weight. It is used for ground handling, jacking, taxiing, and runway usage. It is usually higher than the maximum take-off weight by the amount of fuel used in taxiing the air vehicle for take-off.
Maximum take-off weight	Maximum takeoff weight is normally defined as the weight of the air vehicle with the maximum internal and external loads and full fuel except for fuel used during taxi and warm-up. However, an air vehicle may have more than one maximum takeoff gross weight such as one for runway operations and one for rough-field operations.
Maximum catapult design gross weight	Maximum catapult design gross weight is the maximum catapult launch weight to be used to determine maximum tow force and in determining maximum launch constant selector valve (CSV) settings. The maximum catapult design gross weight is the weight of the air vehicle with maximum internal fuel and maximum external load for which provision is required, without any reduction permitted for fuel used during pre-launch operations. (This weight, which is used to determine the limit tow force loads, is normally the maximum mission weight plus an anticipated weight growth factor (initial operating capability plus 10 percent weight empty). Almost every current Navy carrier air vehicle has experienced significant weight growth and without a pre-design growth capability, the ship speed and available wind over deck would be insufficient, within the structural design to provide the required launch end speed. The maximum launch tow force resulting from this weight will be used to determine the maximum CSV setting in the launch bulletins to preserve static demonstrated strength.)

Maximum catapult weight	Maximum catapult weight is the maximum launch weight for which shipboard launch is required within the structural limits of the airframe, wind over deck (WOD) capability and launch end speed of the ship system. Consider ship speed, wind over deck, and maximum catapult end speed. This weight should be used to determine airframe strength limits.
Primary catapult mission weight	Primary catapult mission weight is the minimum weight used to determine the maximum horizontal acceleration used in setting launch bulletin limits. This weight corresponds to the primary mission for each catapult separately, and defines the weight at which the maximum Nx (horizontal load factor) will be determined, based on maximum tow force and maximum thrust. The Nx value is used to determine both mass item design requirements resulting from minimum weight launches and to establish catapult/weight CSV setting limitations.
Landplane landing weight	The landplane landing weight is the highest landing weight required for the maximum land based sink rate. This defines the highest weight that is to be used in combination with the maximum sink speed consistent with the intended use of the air vehicle. The normal definitions of landplane landing weight are as follows: a. For observation, trainers, and utility air vehicle, the maximum flight weight minus all payload items expected to be expended, all external fuel, and 25 percent internal fuel. b. For cargo air vehicle, the maximum flight weight minus all external fuel and 25 percent internal fuel. c. For bombers, attack, and fighter air vehicle, the maximum flight weight minus all external fuel and 60 percent internal fuel.
Maximum landing weight	Maximum landing weight is the highest weight required for any landing. This defines the highest landing weight required for design purposes. The normal definition of maximum landing weight is the maximum flight weight minus assist-takeoff fuel, droppable fuel tanks, items expended during routine take-off, and fuel consumed or dumped during one go-around or 3.0 minutes, whichever results in the minimum amount of fuel. An air vehicle may have more than one maximum landing weight, such as one for runway operations and one for rough-field operations.

Carrier landing design gross weight	Carrier landing design gross weight is the maximum air vehicle weight for initiating shipboard recovery, and consists of the weight empty plus the maximum weight of a fully loaded air vehicle (stores, gun, ammunition, pylons, racks, launchers, ejectors, empty fuel tanks, pods, etc.) minus the weight of all allowable expendables, minus the weight of all usable fuel plus the specific bring-back payload (fuels and stores). This defines the highest weight at which shipboard landings and arrestments and shore-based FCLP (Field Carrier Landing Practices), and Navy Field Landings will be determined for design purposes.
Barricade design gross weight	Barricade design gross weight is the maximum weight at which shipboard barricade recovery can be initiated. This defines the highest weight at which emergency shipboard barricade engagements are required for design purposes. This weight is the normal equivalent to the carrier landing design gross weight, and along with engaging speed, is used to set barricade recovery limits, based on results of shore-based barricade tests. (This weight and the allowable MK-7 MOD 2 Barricade characteristics will determine the strap loads to be used for on-center and off-center ultimate loads, and the resultant airframe design requirements resulting from this condition. Airframe design configuration should be such that propeller placement or sharp leading edges will not damage the barricade straps. Also based on location of external stores, strap loads will impinge on them causing load conditions for configuration/design consideration.)
Maximum landing gear jacking weight	Maximum landing gear jacking weight is the highest weight required for landing gear jacking. This defines, for design purposes, the highest weight that can be jacked at the landing gear for purposes of wheel and brake changes. The maximum landing gear jacking weight is normally the maximum ground weight since it is desired not to off-load fuel and payload when a tire change is required.
Maximum airframe jacking weight	Maximum airframe jacking weight is the highest weight required for jacking on the airframe at locations other than the landing gear. This defines, for design purposes, the highest weight at which the airframe may be jacked at locations other than the landing gear. This weight is usually defined as the maximum ramp weight minus the crew and passengers and is used to define the jacking point loads and related structure.
Hoisting weight	Hoisting weight is the highest weight required. This defines the highest weight at which the air vehicle may be hoisted. This weight is usually defined as the maximum ramp weight minus the crew and passengers, and is used to design the hoisting point loads and related structures. This is to allow for a more timely removal of an air vehicle disabled on a runway.

6.4.20 Fuel definitions

Primary fuel	Used to demonstrate contract compliance for complete steady state and transient operating range.
Alternate fuel	An alternate fuel is one on which the air vehicle can be flown without operational restrictions but which can have long term durability or maintainability impact if used for continuous operation (multiple flights). Alternate fuels are used only on an occasional or intermittent basis.
Emergency fuel	An emergency fuel is one which imposes operational restrictions on air vehicle. May cause significant damage, limited to one flight, only for emergency or countering emergency action.

6.5 Acquisition requirements

Acquisition documents must specify the following:

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

b. Issue of DoDISS to be cited in the solicitations, and if required, the specific issue of individual documents referenced (see 2.1 Government documents through 2.2 Non-Government publications).

c. Packaging requirements (see 5. PACKAGING).

6.6 International interest

Certain provisions of this document may be the subject of international standardization agreements. When change notice, revision, or cancellation of this document is proposed that will modify the international agreement concerned, the preparing activity will take appropriate action through international standardization channels, including departmental standardization offices, to change the agreement or make other appropriate accommodations.

6.7 Key words

acquisition reform
acquisition requirements
aerial refueling
cargo
diagnostics
embedded training
flight performance
flying qualities
interface
interoperability
performance specifications
refueling

reliability
safety
service life
specification templates
stores
structures
subsystems
survivability
systems engineering
tailorable specifications
transportability
verification
weapons

6.8 Responsible engineering office

The office responsible for development and technical maintenance of this Joint Service Specification Guide is Department of the Navy; Commander; AIR 4.1C, Suite 2140, Bldg.2185; Naval Air Systems Command Headquarters; 22347 Cedar Point Rd, Unit 6; Patuxent River, Maryland; 20670-1161. Requests for additional information or assistance on this specification can be obtained from AIR 4.1C, DSN 342-7073, commercial (301) 342-7073, FAX (301) 757-1853. Address e-mail comments to (AugerEP@navair.navy.mil). Any information relating to Government contracts should be obtained through the contracting officer for the program or project under consideration.

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AIR VEHICLE

JOINT SERVICE SPECIFICATION GUIDE

APPENDIX A

AIR VEHICLE/AIR SYSTEM REQUIREMENTS LINKAGES

A.1. SCOPE

Scope.

This appendix provides air vehicle-to-air system requirements linkages. It is intended as a guide for coordinating the development of air system and air vehicle requirements and to ensure a complete set of air vehicle performance requirements.

A.2 APPLICABLE DOCUMENTS

This section is not applicable to this appendix.

A.3 REQUIREMENTS LINKAGES

The following shows the linkage between the section 3 requirements of the Air Vehicle and Air System Joint Service Specification Guides:

Air Vehicle		Air System	
Para #	Title	Para #	Title
3.1.1	Point Performance	3.1.1	Roles and Missions
3.1.1	Point Performance	3.1.5.1.1	Training Missions
3.1.1	Point Performance	3.1.5.1.2	Operational Deployment
3.1.1	Point Performance	3.1.5.1.3	Operational Missions in Peacetime
3.1.1	Point Performance	3.1.5.1.4	Base Escape
3.1.1	Point Performance	3.1.5.2.1	Combat Surge and Sustained
3.1.1	Point Performance	3.1.5.2.2	Air Alert, Loiter, Surveillance
3.1.1	Point Performance	3.1.5.2.3	Engagement from Ground/Deck Basing
3.1.1	Point Performance	3.1.5.2.4	Engagement from Loiter Location
3.1.1	Point Performance	3.1.6.2.1	Mission and One-on-One Survivability
3.1.1	Point Performance	3.1.6.2.2	Parked Aircraft and Ground Support Survivability
3.1.1	Point Performance	3.1.7.1.1	Air-to-Air Lethality
3.1.1	Point Performance	3.1.7.1.2	Air-to-Surface Lethality
3.1.1	Point Performance	3.1.7.2	Cargo Transport
3.1.1	Point Performance	3.1.7.3	Reconnaissance/Surveillance

Air Vehicle		Air System	
Para #	Title	Para #	Title
3.1.1	Point Performance	3.1.7.4	Aerial Refueling (Tanker)
3.1.1	Point Performance	3.1.7.5	System Reach
3.1.1.1	Flight Envelope	3.1.5.1.4	Base Escape
3.1.1.1	Flight Envelope	3.1.5.2.1	Combat Surge and Sustained
3.1.1.1	Flight Envelope	3.1.5.2.2	Air Alert, Loiter, Surveillance
3.1.1.1	Flight Envelope	3.1.5.2.3	Engagement from Ground/Deck Basing
3.1.1.1	Flight Envelope	3.1.5.2.4	Engagement from Loiter Location
3.1.1.1	Flight Envelope	3.1.6.2.1	Mission and One-on-One Survivability
3.1.1.1	Flight Envelope	3.1.7.1.1	Air-to-Air Lethality
3.1.1.1	Flight Envelope	3.1.7.1.2	Air-to-Surface Lethality
3.1.1.1	Flight Envelope	3.1.7.5	System Reach
3.1.1.1	Flight Envelope	3.1.1	Roles and Missions
3.1.1.1.1	Aerial Refueling Envelope	3.1.1	Roles and Missions
3.1.1.1.1	Aerial Refueling Envelope	3.1.3	Deployment and Mobilization
3.1.1.1.1	Aerial Refueling Envelope	3.1.5.1.1	Training Missions
3.1.1.1.1	Aerial Refueling Envelope	3.1.5.1.2	Operational Deployment
3.1.1.1.1	Aerial Refueling Envelope	3.1.5.1.3	Operational Missions in Peacetime
3.1.1.1.1	Aerial Refueling Envelope	3.1.5.2.1	Combat Surge and Sustained
3.1.1.1.1	Aerial Refueling Envelope	3.1.5.2.2	Air Alert, Loiter, Surveillance
3.1.1.1.1	Aerial Refueling Envelope	3.1.7.2	Cargo Transport
3.1.1.1.1	Aerial Refueling Envelope	3.1.7.4	Aerial Refueling (Tanker)
3.1.1.1.1	Aerial Refueling Envelope	3.1.7.5	System Reach
3.1.1.2	Ground Performance	3.1.1	Roles and Missions
3.1.1.2	Ground Performance	3.1.3	Deployment and Mobilization
3.1.1.2	Ground Performance	3.1.5.1.1	Training Missions
3.1.1.2	Ground Performance	3.1.5.1.2	Operational Deployment
3.1.1.2	Ground Performance	3.1.5.1.3	Operational Missions in Peacetime
3.1.1.2	Ground Performance	3.1.5.1.4	Base Escape
3.1.1.2	Ground Performance	3.1.5.2.1	Combat Surge and Sustained
3.1.1.2	Ground Performance	3.1.5.2.2	Air Alert, Loiter, Surveillance
3.1.1.2	Ground Performance	3.1.5.2.3	Engagement from Ground/Deck Basing
3.1.1.2	Ground Performance	3.1.5.4	Integrated Combat Turnaround Time (ICT)
3.1.1.2	Ground Performance	3.1.6.2.2	Parked Aircraft and Ground Support Survivability
3.1.2	Mission Profile Performance	3.1.1	Roles and Missions
3.1.2	Mission Profile Performance	3.1.2	Organization
3.1.2	Mission Profile Performance	3.1.3	Deployment and Mobilization
3.1.2	Mission Profile Performance	3.1.5.1.1	Training Missions

Air Vehicle		Air System	
Para #	Title	Para #	Title
3.1.2	Mission Profile Performance	3.1.5.1.2	Operational Deployment
3.1.2	Mission Profile Performance	3.1.5.1.3	Operational Missions in Peacetime
3.1.2	Mission Profile Performance	3.1.5.1.4	Base Escape
3.1.2	Mission Profile Performance	3.1.5.2.1	Combat Surge and Sustained
3.1.2	Mission Profile Performance	3.1.5.2.2	Air Alert, Loiter, Surveillance
3.1.2	Mission Profile Performance	3.1.5.2.3	Engagement from Ground/Deck Basing
3.1.2	Mission Profile Performance	3.1.5.2.4	Engagement from Loiter Location
3.1.2	Mission Profile Performance	3.1.6.2.1	Mission and One-on-One Survivability
3.1.2	Mission Profile Performance	3.1.7.1.1	Air-to-Air Lethality
3.1.2	Mission Profile Performance	3.1.7.1.2	Air-to-Surface Lethality
3.1.2	Mission Profile Performance	3.1.7.3	Reconnaissance/Surveillance
3.1.2	Mission Profile Performance	3.1.7.2	Cargo Transport
3.1.2	Mission Profile Performance	3.1.7.4	Aerial Refueling (Tanker)
3.1.2	Mission Profile Performance	3.1.7.5	System Reach
3.1.2.1	Threat Environment	3.1.1	Roles and Missions
3.1.2.1.1	Weapons Delivery	3.1.1	Roles and Missions
3.1.2.1.1	Weapons Delivery	3.1.2	Organization
3.1.2.1.1	Weapons Delivery	3.1.5.2.3	Engagement from Ground/Deck Basing
3.1.2.1.1	Weapons Delivery	3.1.5.2.4	Engagement from Loiter Location
3.1.2.1.1	Weapons Delivery	3.1.6.2.1	Mission and One-on-One Survivability
3.1.2.1.1	Weapons Delivery	3.1.7.1.1	Air-to-Air Lethality
3.1.2.1.1	Weapons Delivery	3.1.7.1.2	Air-to-Surface Lethality
3.1.2.1.1	Weapons Delivery	3.3.7.1	Weapons
3.1.3	Mission Planning	3.1.4	Mission Planning
3.1.3	Mission Planning	3.1.5.1.1	Training Missions
3.1.3	Mission Planning	3.1.5.1.2	Operational Deployment
3.1.3	Mission Planning	3.1.5.1.3	Operational Missions in Peacetime
3.1.3	Mission Planning	3.1.5.1.4	Base Escape
3.1.3	Mission Planning	3.1.5.2.1	Combat Surge and Sustained
3.1.3	Mission Planning	3.1.5.2.2	Air Alert, Loiter, Surveillance
3.1.3	Mission Planning	3.1.5.4	Integrated Combat Turnaround Time (ICT)
3.1.3	Mission Planning	3.1.6.2.1	Mission and One-on-One Survivability
3.1.3	Mission Planning	3.1.7.1.1	Air-to-Air Lethality
3.1.3	Mission Planning	3.1.7.1.2	Air-to Surface Lethality
3.1.3	Mission Planning	3.1.7.2	Cargo Transport

Air Vehicle		Air System	
Para #	Title	Para #	Title
3.1.3	Mission Planning	3.1.7.3	Reconnaissance/Surveillance
3.1.3	Mission Planning	3.1.7.4	Aerial Refueling (Tanker)
3.1.3	Mission Planning	3.4	Interfaces
3.1.4	Reliability	3.1.5.1.1	Training Missions
3.1.4	Reliability	3.1.5.1.2	Operational Deployment
3.1.4	Reliability	3.1.5.1.3	Operational Missions in Peacetime
3.1.4	Reliability	3.1.5.1.4	Base Escape
3.1.4	Reliability	3.1.5.2.1	Combat Surge and Sustained
3.1.4	Reliability	3.1.5.2.2	Air Alert, Loiter, Surveillance
3.1.4	Reliability	3.1.5.2.3	Engagement from Ground/Deck Basing
3.1.4	Reliability	3.1.5.2.4	Engagement from Loiter Location
3.1.4	Reliability	3.1.5.3.1	Availability
3.1.4	Reliability	3.1.6.1	Mission Reliability
3.1.4	Reliability	3.3.6	System Safety
3.1.4	Reliability	3.3.6.1	Air Vehicle Non-Combat Loss Rate
3.1.5	Maintainability	3.1.5.1.1	Training Missions
3.1.5	Maintainability	3.1.5.1.2	Operational Deployment
3.1.5	Maintainability	3.1.5.1.3	Operational Missions in Peacetime
3.1.5	Maintainability	3.1.5.1.4	Base Escape
3.1.5	Maintainability	3.1.5.2.1	Combat Surge and Sustained
3.1.5	Maintainability	3.1.5.2.2	Air Alert, Loiter, Surveillance
3.1.5	Maintainability	3.1.5.3.1	Availability
3.1.5	Maintainability	3.3.1.3	Manpower and Personnel
3.1.5	Maintainability	3.6.1	Maintenance Concept
3.1.6	Integrated Combat Turnaround Time	3.1.5.4	Integrated Combat Turnaround Time (ICT)
3.1.6	Integrated Combat Turnaround Time	3.3.1.3	Manpower and Personnel
3.1.6	Integrated Combat Turnaround Time	3.4.1.3	Common Support Equipment
3.1.7	Communication, Radio Navigation, and Identification	3.1.1	Roles and Missions
3.1.7	Communication, Radio Navigation, and Identification	3.1.4	Mission Planning
3.1.7	Communication, Radio Navigation, and Identification	3.1.5.1.1	Training Missions
3.1.7	Communication, Radio Navigation, and Identification	3.1.5.2.2	Air Alert, Loiter, Surveillance
3.1.7	Communication, Radio Navigation, and Identification	3.1.5.2.3	Engagement from Ground/Deck Basing
3.1.7	Communication, Radio Navigation, and Identification	3.1.5.2.4	Engagement from Loiter Location

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Para #	Title	Para #	Title
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3.1.7	Communication, Radio Navigation, and Identification	3.1.7.1.1	Air to Air Lethality
3.1.7	Communication, Radio Navigation, and Identification	3.1.7.1.2	Air to Surface Lethality
3.1.7	Communication, Radio Navigation, and Identification	3.1.7.3	Reconnaissance/Surveillance
3.1.7	Communication, Radio Navigation, and Identification	3.1.7.4	Aerial Refueling (Tanker)
3.1.7	Communication, Radio Navigation, and Identification	3.3.8	System Usage Information Collection and
3.1.7	Communication, Radio Navigation, and Identification	3.4	Interfaces
3.1.8.1.1.1	Radar Cross Section	3.1.6.2.1	Mission and One-on-One Survivability
3.1.8.1.1.1	Radar Cross Section	3.1.6.2.2	Parked Aircraft and Ground Support Survivability
3.1.8.1.1.1	Radar Cross Section	3.3.7.1	Weapons
3.1.8.1.1.1	Radar Cross Section	3.3.7.2	Sensor Pods
3.1.8.1.1.1	Radar Cross Section	3.3.7.4	Other Stores
3.1.8.1.1.2	Infrared Signature	3.1.6.2.1	Mission and One-on-One Survivability
3.1.8.1.1.2	Infrared Signature	3.1.6.2.2	Parked Aircraft and Ground Support Survivability
3.1.8.1.1.2	Infrared Signature	3.3.7.1	Weapons
3.1.8.1.1.2	Infrared Signature	3.3.7.2	Sensor Pods
3.1.8.1.1.2	Infrared Signature	3.3.7.4	Other Stores
3.1.8.1.1.3	Visual Signature	3.1.6.2.1	Mission and One-on-One Survivability
3.1.8.1.1.3	Visual Signature	3.1.6.2.2	Parked Aircraft and Ground Support Survivability
3.1.8.1.1.3	Visual Signature	3.3.7.1	Weapons
3.1.8.1.1.3	Visual Signature	3.3.7.2	Sensor Pods
3.1.8.1.1.3	Visual Signature	3.3.7.4	Other Stores
3.1.8.1.1.4	Acoustic Signature	3.1.6.2.1	Mission and One-on-One Survivability
3.1.8.1.1.4	Acoustic Signature	3.1.6.2.2	Parked Aircraft and Ground Support Survivability
3.1.8.1.1.5	Emission Control	3.1.6.2.1	Mission and One-on-One Survivability
3.1.8.1.1.5	Emission Control	3.1.6.2.2	Parked Aircraft and Ground Support Survivability
3.1.8.1.1.5	Emission Control	3.3.7.1	Weapons
3.1.8.1.1.5	Emission Control	3.3.7.2	Sensor Pods
3.1.8.1.1.5	Emission Control	3.3.7.4	Other Stores

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3.1.8.1.1.6	Electronic Protection	3.1.6.2.2	Parked Aircraft and Ground Support Survivability
3.1.8.1.1.6	Electronic Protection	3.3.7.1	Weapons
3.1.8.1.1.6	Electronic Protection	3.3.7.2	Sensor Pods
3.1.8.1.1.6	Electronic Protection	3.3.7.4	Other Stores
3.1.8.2.1	Threat Detection, Identification, Prioritization, Awareness, and Response	3.1.1	Roles and Missions
3.1.8.2.1	Threat Detection, Identification, Prioritization, Awareness, and Response	3.1.4	Mission Planning
3.1.8.2.1	Threat Detection, Identification, Prioritization, Awareness, and Response	3.1.5.2.3	Engagement from Ground/Deck Basing
3.1.8.2.1	Threat Detection, Identification, Prioritization, Awareness, and Response	3.1.5.2.4	Engagement from Loiter Location
3.1.8.2.1	Threat Detection, Identification, Prioritization, Awareness, and Response	3.1.6.2.1	Mission and One-on-One Survivability
3.1.8.2.1	Threat Detection, Identification, Prioritization, Awareness, and Response	3.1.7.1.1	Air to Air Lethality
3.1.8.2.1	Threat Detection, Identification, Prioritization, Awareness, and Response	3.1.7.1.2	Air-to Surface Lethality
3.1.8.2.2	Defensive Countermeasures	3.1.6.2.1	Mission and One-on-One Survivability
3.1.8.2.2	Defensive Countermeasures	3.1.1	Roles and Missions
3.1.8.2.2	Defensive Countermeasures	3.1.4	Mission Planning
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3.1.8.2.2	Defensive Countermeasures	3.1.5.2.4	Engagement from Loiter Location
3.1.8.2.2	Defensive Countermeasures	3.1.7.1.1	Air to Air Lethality
3.1.8.2.2	Defensive Countermeasures	3.1.7.1.2	Air-to Surface Lethality
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3.1.8.2.3	Terrain Following/Terrain Avoidance	3.1.6.2.1	Mission One on One Survivability
3.1.8.2.4	Ballistic Threat Survivability	3.1.6.2.1	Mission One on One Survivability
3.1.8.2.4	Ballistic Threat Survivability	3.1.6.2.2	Parked Aircraft and Ground Support Survivability

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3.1.8.2.4	Ballistic Threat Survivability	3.1.7.1.2	Air-to Surface Lethality
3.1.8.2.5.1	Electromagnetic Threat Survivability	3.1.6.2.1	Mission and One-on-One Survivability
3.1.8.2.5.1	Electromagnetic Threat Survivability	3.1.6.2.2	Parked Aircraft and Ground Support Survivability
3.1.8.2.5.1	Electromagnetic Threat Survivability	3.1.7.1.1	Air to Air Lethality
3.1.8.2.5.1	Electromagnetic Threat Survivability	3.1.7.1.2	Air to Surface Lethality
3.1.8.2.5.2	Laser Threat Survivability	3.1.6.2.1	Mission and One-on-One Survivability
3.1.8.2.5.2	Laser Threat Survivability	3.1.6.2.2	Parked Aircraft and Ground Support Survivability
3.1.8.2.5.2	Laser Threat Survivability	3.1.7.1.1	Air to Air Lethality
3.1.8.2.5.2	Laser Threat Survivability	3.1.7.1.2	Air to Surface Lethality
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3.1.8.2.6.1	Chemical and Biological Hardening	3.3.1.2	System Service Life
3.1.8.2.6.2	Chemical and Biological Personnel Protection	3.1.1	Roles and Missions
3.1.8.2.6.2	Chemical and Biological Personnel Protection	3.1.5.1.4	Base Escape
3.1.8.2.6.2	Chemical and Biological Personnel Protection	3.3.9	Human Systems
3.1.8.2.6.3	Chemical and Biological Decontamination	3.1.1	Roles and Missions
3.1.8.2.6.3	Chemical and Biological Decontamination	3.3.9	Human Systems
3.1.8.2.7	Nuclear Weapons Survivability	3.1.1	Roles and Missions
3.1.8.2.7	Nuclear Weapons Survivability	3.1.6.2.1	Mission and One-on-One Survivability
3.1.8.2.7	Nuclear Weapons Survivability	3.1.7.1.1	Air-to-Air Lethality
3.1.8.2.7	Nuclear Weapons Survivability	3.1.7.1.2	Air-to-Surface Lethality
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3.1.9.1	Target Detection, Track, Identification, and Designation	3.1.4	Mission Planning
3.1.9.1	Target Detection, Track, Identification, and Designation	3.1.5.2.3	Engagement from Ground/Deck Basing
3.1.9.1	Target Detection, Track, Identification, and Designation	3.1.5.2.4	Engagement from Loiter Location
3.1.9.1	Target Detection, Track, Identification, and Designation	3.1.6.2.1	Mission and One-on-One Survivability
3.1.9.1	Target Detection, Track, Identification, and Designation	3.1.7.1.1	Air-to-Air Lethality
3.1.9.1	Target Detection, Track, Identification, and Designation	3.1.7.1.2	Air-to-Surface Lethality
3.1.9.1	Target Detection, Track, Identification, and Designation	3.3.7.1	Weapons

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3.1.9.2	Integrated Earth/Space Reference Accuracy	3.1.1	Roles and Missions
3.1.9.2	Integrated Earth/Space Reference Accuracy	3.1.5.2.3	Engagement from Ground/Deck Basing
3.1.9.2	Integrated Earth/Space Reference Accuracy	3.1.5.2.4	Engagement from Loiter Location
3.1.9.2	Integrated Earth/Space Reference Accuracy	3.1.7.1.1	Air-to-Air Lethality
3.1.9.2	Integrated Earth/Space Reference Accuracy	3.1.7.1.2	Air-to-Surface Lethality
3.1.9.2	Integrated Earth/Space Reference Accuracy	3.1.7.2	Cargo Transport
3.1.9.2	Integrated Earth/Space Reference Accuracy	3.1.7.3	Reconnaissance/Surveillance
3.1.9.2	Integrated Earth/Space Reference Accuracy	3.1.7.4	Aerial Refueling (Tanker)
3.1.9.3	Air-to-Surface Accuracy	3.1.5.2.3	Engagement from Ground/Deck Basing
3.1.9.3	Air-to-Surface Accuracy	3.1.5.2.4	Engagement from Loiter Location
3.1.9.3	Air-to-Surface Accuracy	3.1.7.1.2	Air-to-Surface Lethality
3.1.9.3	Air-to-Surface Accuracy	3.3.7.1	Weapons
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3.1.9.4	Weapons Selection and Release Control	3.1.5.2.3	Engagement from Ground/Deck Basing
3.1.9.4	Weapons Selection and Release Control	3.1.5.2.4	Engagement from Loiter Location
3.1.9.4	Weapons Selection and Release Control	3.1.7.1.1	Air-to-Air Lethality
3.1.9.4	Weapons Selection and Release Control	3.1.7.1.2	Air-to-Surface Lethality
3.1.9.4	Weapons Selection and Release Control	3.3.7.1	Weapons
3.1.9.4	Weapons Selection and Release Control	3.3.7.2	Sensor Pods
3.1.9.5	Gun Accuracy and Control	3.1.5.2.3	Engagement from Ground/Deck Basing
3.1.9.5	Gun Accuracy and Control	3.1.5.2.4	Engagement from Loiter Location
3.1.9.5	Gun Accuracy and Control	3.1.7.1.1	Air-to-Air Lethality
3.1.9.5	Gun Accuracy and Control	3.1.7.1.2	Air-to-Surface Lethality
3.1.9.5	Gun Accuracy and Control	3.3.7.1	Weapons
3.1.9.5	Gun Accuracy and Control	3.3.7.2	Sensor Pods
3.1.10	Reserve Modes	3.1.8	Reserve Modes

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3.2.1	Electromagnetic Environmental Effects	3.3.4	Electromagnetic Environmental Effects (E3)
3.2.1	Electromagnetic Environmental Effects	3.1.1	Roles and Missions
3.2.2	Natural Climate	3.1.1	Roles and Missions
3.2.2	Natural Climate	3.2	Environment
3.2.3	Induced Environment	3.1.1	Roles and Missions
3.2.3	Induced Environment	3.2	Environment
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3.3.1.1	Propulsion, Fixed Wing	3.1.9	Lower-Tier Mandated Requirement
3.3.1.1.1	Engine Compatibility and Installation	3.1.9	Lower-Tier Mandated Requirement
3.3.1.1.1.1	Air Induction System	3.1.9	Lower-Tier Mandated Requirement
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3.3.3.1	Computer Hardware Reserve Capacity	3.3.1.1.1	Growth
3.3.3.2	Computer Hardware Extensibility	3.3.1.1	System Architecture
3.3.3.2	Computer Hardware Extensibility	3.3.1.1.1	Growth
3.3.4	Architecture	3.3.1.1	System Architecture
3.3.5	System Usage	3.1.5.1.1	Training Missions
3.3.5	System Usage	3.1.5.1.2	Operational Deployment
3.3.5	System Usage	3.1.5.1.3	Operational Missions in Peacetime
3.3.5	System Usage	3.1.5.1.4	Base Escape
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3.3.5	System Usage	3.1.5.2.3	Engagement from Ground/Deck Basing
3.3.5	System Usage	3.1.5.2.4	Engagement from Loiter Location
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3.3.5	System Usage	3.3.1.2	System Service Life
3.3.5.1	Service Life	3.3.1.2	Service Life
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3.3.5.1.1	Damage/Fault Tolerance	3.3.1.2	System Service Life

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3.3.5.1.1	Damage/Fault Tolerance	3.3.6	System Safety
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3.3.6.1	Asset Identification	3.3.1.4	Asset Identification
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3.3.7	Diagnostics and Health Management	3.1.6.1	Mission Reliability
3.3.7	Diagnostics and Health Management	3.3.6	System Safety
3.3.7	Diagnostics and Health Management	3.3.6.1	Air Vehicle Non Combat Loss Rate
3.3.7	Diagnostics and Health Management	3.3.8	System Usage Information Collection and Retrieval
3.3.7.1	Diagnostics Fault Detection and Fault Isolation	3.3.2	Diagnostics
3.3.7.1	Diagnostics Fault Detection and Fault Isolation	3.1.6.1	Mission Reliability
3.3.7.1	Diagnostics Fault Detection and Fault Isolation	3.3.6	System Safety
3.3.7.1	Diagnostics Fault Detection and Fault Isolation	3.3.6.1	Air Vehicle Non Combat Loss Rate
3.3.7.1	Diagnostics Fault Detection and Fault Isolation	3.3.8	System Usage Information Collection and Retrieval
3.3.8.1	Information Collection	3.3.8	System Usage Information Collection and Retrieval
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3.3.8.2	Crash Recording	3.3.8	System Usage Information Collection and Retrieval
3.3.9	Security	3.3.5	Security System
3.3.9	Security	3.3.8	System Usage Information Collection and Retrieval
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3.3.10	Safety	3.3.6	System Safety
3.3.10.1	Air Vehicle Noncombat Loss Rate	3.3.6.1	Air Vehicle Non Combat Loss Rate
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3.3.10.2.2	Energetics	3.3.6	System Safety
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3.3.11.1	Flying Qualities, Fixed Wing	3.3.6	System Safety
3.3.11.1	Flying Qualities, Fixed Wing	3.3.9	Human Systems
3.3.11.1.1	Primary Requirements for Air Vehicle States in Common Atmospheric Conditions	3.3.6	System Safety
3.3.11.1.1	Primary Requirements for Air Vehicle States in Common Atmospheric Conditions	3.3.9	Human Systems
3.3.11.1.1.1	Allowable Levels for Air Vehicle Normal States	3.3.6	System Safety
3.3.11.1.1.1	Allowable Levels for Air Vehicle Normal States	3.3.9	Human Systems
3.3.11.1.1.2	Allowable Levels for Air Vehicle Extreme States	3.3.6	System Safety
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3.3.11.1.1.3	Primary Requirements for Failure States	3.3.6	System Safety
3.3.11.1.1.3	Primary Requirements for Failure States	3.3.9	Human Systems
3.3.11.1.1.3.1	Probability of Encountering Degraded Levels of Flying Qualities Due to Failures While Operating Within the ROSH or ROTH	3.3.6	System Safety
3.3.11.1.1.3.1	Probability of Encountering Degraded Levels of Flying Qualities Due to Failures While Operating Within the ROSH or ROTH	3.3.9	Human Systems
3.3.11.1.1.3.2	Allowable Levels for Specific Air Vehicle Failure States	3.3.6	System Safety
3.3.11.1.1.3.2	Allowable Levels for Specific Air Vehicle Failure States	3.3.9	Human Systems
3.3.11.1.1.3.3	Failures Outside the ROTH	3.3.6	System Safety
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3.3.11.1.2	Flying Qualities Degradations in Atmospheric Disturbances	3.3.6	System Safety
3.3.11.1.2	Flying Qualities Degradations in Atmospheric Disturbances	3.3.9	Human Systems
3.3.11.1.3	Control Margins	3.3.6	System Safety
3.3.11.1.3	Control Margins	3.3.9	Human Systems
3.3.12	Growth Provisions	3.3.1.1.1	Growth

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3.4.1.2	Weapon and Store Loadouts	3.1.7.1.1	Air-to-Air Lethality
3.4.1.2	Weapon and Store Loadouts	3.3.7.1	Weapons
3.4.1.2	Weapon and Store Loadouts	3.3.7.2	Sensor Pods
3.4.1.2	Weapon and Store Loadouts	3.3.7.4	Other Stores
3.4.1.2	Weapon and Store Loadouts	3.3.6	System Safety
3.4.1.3	Gun Interface	3.3.6	System Safety
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3.4.1.3	Gun Interface	3.3.7.1	Weapons
3.4.1.3	Gun Interface	3.3.9	Human Systems
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3.4.2	Communication, Radio Navigation, and Identification Interfaces	3.1.2	Organization
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3.4.3.1.7	Interior Vision	3.3.9	Human Systems
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3.4.3.2	Maintainer/Vehicle Interface	3.3.1.3	Manpower and Personnel
3.4.3.2	Maintainer/Vehicle Interface	3.3.9	Human Systems

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AIR VEHICLE

JOINT SERVICE SPECIFICATION GUIDE

APPENDIX B

REFERENCED DOCUMENTS

B.1 SCOPE

B.1.1 Scope

This appendix identifies the documents referenced in the Air Vehicle JSSG. It is not intended to be a part of a program specification. Rather, it is provided to assist users of this specification guide in developing a program unique specification by identifying, in a single location, all the documents referenced in this guide. Applicable documents required in a program unique specification that may result from tailoring this guide, to the extent identified, should be defined in Section 2 of the completed, program-specific specification.

B.2 APPLICABLE DOCUMENTS

This section is not applicable to this appendix.

B.3 TABLE OF REFERENCES

The following table lists the documents referenced in the Air Vehicle JSSG and the location in which they are referenced:

Reference Name	Reference Location
Air Force Tech Order 00-25-172 Ground Servicing of Aircraft and Static Grounding/Bonding	3.4.6.1.1 Requirement Guidance 3.4.6.1.2 Requirement Guidance
Air Force Tech Order 1-1C-1-3 Air Refueling Procedures	3.1.1.1.1 Requirement Lessons Learned 3.4.6.2.1 Requirement Lessons Learned
Air Force Tech Order 1-1C-1-20, Aerial Refueling Procedures	3.1.1.1.1 Requirement Lessons Learned 3.4.6.2.1 Requirement Guidance 3.4.6.2.1 Requirement Lessons Learned
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Air Force Tech Order 1-1C-15-1-3 Chemical Warfare Decontamination, Detection and Disposal of Decontaminating Agents	3.1.8.2.6.3 Requirement Guidance
AFGS-87242A Flight Control System General Specification	3.3.11.1.1.3.1 Requirement Lessons Learned

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AFMCP 63-104 IWSM Configuration Management Guide	4.4.1.1 Verification Discussion
AFWAL-TR-81-3116 Equivalent System Verification and Evaluation of Augmentation Effects on Fighter Approach and Landing Flying Qualities	3.3.11.1.3 Requirement Lessons Learned
AIAA Paper 78-1500	3.3.11.1.3 Requirement Lessons Learned
Allied Publications AAP-4 NATO Standardization Agreements and Allied Publications	3.4 Requirement Guidance
Allied Tactical Publication (ATP) 56, Air-to-Air Refueling	3.1.1.1.1 Requirement Guidance 3.1.1.1.1 Requirement Lessons Learned 3.4.6.2.1 Requirement Guidance 3.4.6.2.2 Requirement Guidance
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Army Field Manual (FM) 3-5	3.1.8.2.6.3 Requirement Guidance
ARP 1420 Gas Turbine Inlet Flow Distortion Guidelines	3.3.1.1.1 Requirement Lessons Learned
ARP 1665 Definition of Pressure Surge Test and Measurement Methods for Receiver Aircraft	4.4.6.1.1 Verification Lessons Learned
ARP 1797 Aircraft and Aircraft Engine Fuel Pump Low Lubricity Fluid Endurance Test	4.4.11.2 Verification Lessons Learned
AS 1284 Standard Test Procedure and Limit Value for Shutoff Surge Pressure of Pressure Fuel Dispensing Systems	4.4.6.1.1 Verification Lessons Learned
ASTM D 910 Aviation Gasoline	3.4.11.3 Requirement Guidance
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ASTM D 1655 Aviation Turbine Fuels	3.4.11.1 Requirement Guidance 3.4.11.2 Requirement Guidance 3.4.11.2 Requirement Lessons Learned
ASTM D 4814 Automotive Gasoline	3.4.11.3 Requirement Guidance
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EUROCAE Standard ED 55 Minimum Operational Performance Specification for Flight Data Recorder Systems	4.3.8.2 Verification Lessons Learned
FAA-RD-75-123	3.3.11.1.2 Requirement Rationale
FAR Part 25 Airworthiness Standards: Transport Category Airplanes, Appendix C	3.3.1.1.1.1 Requirement Guidance 3.3.10.2.1 Requirement Guidance 3.3.11.1.1.3.1 Requirement Lessons Learned
Integrated Performance Based Business Environment Guide	6.2 Specification tree
ISO 45 Aircraft Pressure Refueling Connections	3.4.6.1.1 Requirement Guidance 3.4.6.1.2 Requirement Guidance
ISO 46 Aircraft Fuel Nozzle Grounding Plugs and Sockets	3.4.6.1.1 Requirement Guidance 3.4.6.1.2 Requirement Guidance
ISO 102 Gravity Filling Orifices	3.4.6.1.1 Requirement Guidance 3.4.6.1.2 Requirement Guidance

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JSSG-2007 Engines, Aircraft, Turbine	3.3.1.1.1.1 Requirement Guidance
JSSG-2010-5 Avionic Subsystem	4.4.3.1.6 Verification Discussion
MIL-A-8243 Anti-icing and Deicing-Defrosting Fluids	3.1.1 Requirement Guidance
MIL-A-8861 Airplane Strength and Rigidity Flight Loads	4.3.11.1.2 Verification Discussion 6.4.6 Flying qualities definitions
MIL-A-8863 Airplane Strength and Rigidity Ground Loads for Navy Acquired Airplanes	3.4.9 Requirement Guidance 3.4.9 Requirement Lessons Learned
MIL-C-81975 Coupling, Regulated, Aerial Pressure Refueling Type MA-3	4.2.3 Verification Discussion
MIL-DTL-5624 Turbine Fuel, Aviation, Grades JP-4, JP-5, and JP-5/JP-8 ST	3.4.11.1 Requirement Guidance 3.4.11.2 Requirement Lessons Learned 3.4.11.3 Requirement Guidance
MIL-DTL-83133 Turbine Fuels, Aviation, Kerosene Types, NATO F-34 (JP-8), NATO F-35, AND JP-8 + 100	3.4.11.1 Requirement Guidance 3.4.11.1 Requirement Lessons Learned
MIL-DTL-85110 Bar, Repeatable Release Holdback (RRHB), Aircraft Launching, General Requirements for	3.4.8 Requirement Guidance
MIL-DTL-85470 Inhibitor, Icing, Fuel System, High Flash NATO Code Number S-1745	3.4.11.1 Requirement Guidance
MIL-F-16884 (NATO F-76) Naval Distillate	3.4.11.3 Requirement Guidance
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MIL-F-9490D Flight Control Systems-Design Installation and Test of Piloted Aircraft, General Specification	6.4.6 Flying qualities definition 4.3.11.1.2 Verification Discussion
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MIL-HDBK-310 Global Climatic Data for Developing Military Procedures	3.2.2 Requirement Guidance 3.2.2 Requirement Lessons Learned 4.2.2 Natural climate verification 4.2.2 Verification Lessons Learned 3.3.1.1.1.1 Requirement Guidance
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MIL-N-18307 Nomenclature + Identification for Aeronautical Systems Including Joint Electronics Type Designated Systems + Associated Support Systems	3.3.6.1 Requirement Guidance
MIL-N-5877E Military Specification, Nozzle, Pressure Fuel Servicing	3.4.6.1.1 Requirement Guidance
MIL-P-15024 Plate, Identification	3.3.6.1 Requirement Guidance
MIL-PRF-23699 Lubricating Oil, Aircraft Turbine Engine, Synthetic Base, NATO Code Number O-156	3.1.1 Requirement Guidance
MIL-PRF-25017 Inhibitor, Corrosion/Lubricity Improver, Fuel Soluble	3.4.11.1 Requirement Guidance
MIL-PRF-25161	3.4.6.2.1 Requirement Lessons Learned
MIL-PRF-5624 Turbine Fuel, Aviation, Grades JP-4 and JP-5, and JP-5/JP-8 ST	3.1.1 Requirement Guidance
MIL-PRF-83282 Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Metric, NATO Code Number H-537	3.1.1 Requirement Guidance
MIL-STD-130 Identification Marking of U.S. Military Property	3.3.6.1 Requirement Guidance
MIL-STD-411 Aircrew Station Alerting Systems	3.4.3.1.6 Warnings, cautions, and advisories 4.4.3.1.6 Warnings, cautions, and advisories verification 4.4.3.1.6 Verification Discussion
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MIL-STD-1807 Crash Survivability of Aircraft Personnel (Release to other than DoD activity requires prior approval of ASC/ENOI, Wright-Patterson AFB OH 45433-6503)	3.3.10.2.1 Requirement Guidance
MIL-T-81259 Tie-Downs, Airframe Design, Requirements for	3.4.9 Requirement Guidance 3.4.9 Requirement Lessons Learned
MIL-T-83133 Fuel, Aviation, Turbine Engine, Requirements for	3.1.1 Requirement Guidance
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NAEC-MISC-06900 Rev D	3.4.8 Requirement Guidance
NAEC-MISC-O8784	3.4.8 Requirement Guidance
NAEC-MISC-OA136	3.4.8 Requirement Guidance
NATO AEP-7 NBC Defense Factors in Design, Testing & Acceptance of Military Equipment	3.1.8.2.6.2 Requirement Guidance

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NATO STANAG 1095 HOS Tiedown Fittings on Shipborne Aircraft	3.4.9 Requirement Guidance
NATO STANAG 2946 Forward Area refueling Equipment	3.4.6.1.1 Requirement Guidance 3.4.6.1.2 Requirement Guidance
NATO STANAG 2947 Technical Criteria for a Closed-Circuit Refueling System	3.4.6.1.1 Requirement Guidance 3.4.6.1.2 Requirement Guidance
NATO STANAG 3098 (ASSE) Aircraft Jacking	3.4.9 Requirement Guidance
NATO STANAG 3105 (ASSE) Pressure Refueling Connections and Defueling for Aircraft	3.4.6.1.1 Requirement Guidance 3.4.6.1.2 Requirement Guidance 3.4.9 Requirement Guidance
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NATO STANAG 3278 (ASSE) Towing Attachments on Aircraft	3.4.9 Requirement Guidance
NATO STANAG 3294 (ASSE) Aircraft Fuel Caps and Fuel Cap Access Covers	3.4.6.1.1 Requirement Guidance 3.4.9 Requirement Guidance
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NATO STANAG 3303 (AE) Connectors for 115/200 Volt, 400 Hz, 3 Phase, AC Servicing Power	3.4.9 Requirement Guidance
NATO STANAG 3315 (ASSE) Aircraft Cabin Pressurizing Test Connections	3.4.9 Requirement Guidance
NATO STANAG 3329 Numerals & Letters in Aircrew Stations	3.4.3 Requirement Guidance
NATO STANAG 3334 (ASSE) Defueling of Aircraft	3.4.9 Requirement Guidance
NATO STANAG 3370 Aircrew Station W, C, & A Signals	3.4.3 Requirement Guidance
NATO STANAG 3372 (ASSE) Low Pressure Air and Associated Electrical Connections for Aircraft Engine Starting	3.4.9 Requirement Guidance
NATO STANAG 3436 Colours & Markings Used to Denote Operating Ranges of Aircraft Instruments	3.4.3 Requirement Guidance

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NATO STANAG 3447 (ASSE) Aerial Refueling Equipment, Dimensional and Functional Characteristics	3.4.6.2.1 Requirement Guidance 3.4.6.2.1 Requirement Lessons Learned 3.4.6.2.2 Requirement Guidance 3.4.6.2.2 Requirement Lessons Learned 3.4.9 Requirement Guidance
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NATO STANAG 3547 (GGS) Characteristics of Replenishment Equipment for Liquid Nitrogen	3.4.9 Requirement Guidance
NATO STANAG 3595 (ASSE) Aircraft Fitting for Pressure Replenishment of Gas Turbine Engines with Oil	3.4.9 Requirement Guidance
NATO STANAG 3632 (AE) Aircraft and ground Support Equipment electrical Connections for Static Grounding	3.4.9 Requirement Guidance
NATO STANAG 3639 Aircrew Station Dimensional Design Factors	3.4.3 Requirement Guidance
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NATO STANAG 3847 Helicopter In-Flight refueling (HIFR) Equipment	3.4.6.1.1 Requirement Guidance
NATO STANAG 3869 Aircrew Station Control Panels	3.4.3 Requirement Guidance
NATO STANAG 3870 Emergency Escape/Evacuation Lighting	3.4.3 Requirement Guidance
NATO STANAG 3871 NATO Glossary of Aircraft Displays & Aircrew Stations Specialist terminology & Abbreviations	3.4.3 Requirement Guidance
NATO STANAG 3950 Helicopter Crew Seat Design	3.4.3 Requirement Guidance

Reference Name	Reference Location
NATO STANAG 3971 Air-to-Air Refueling	3.1.1.1.1 Requirement Guidance 3.1.1.1.1 Requirement Lessons Learned 3.4.6.2.1 Requirement Guidance 3.4.6.2.1 Requirement Lessons Learned 3.4.6.2.2 Requirement Guidance 3.4.6.2.2 Requirement Lessons Learned
NATO STANAG 3994 Application of Human Engineering to Advanced Crew Systems	3.4.3 Requirement Guidance
NATO STANAG 7041 Integrated HMDS for Rotary Wing Aircraft	3.4.3 Requirement Guidance
NATO STANAG 7042 Image Intensifier Displays in Aircraft	3.4.3 Requirement Guidance
NATO STANAG 7044 Mission Planning Station Interface design	3.4.3 Requirement Guidance
NATO STANAG 7080 Interactive Front Face	3.4.3 Requirement Guidance
NATO STANAG 7090 Diesel Fuel Oils	3.4.11.3 Requirement Guidance
NATO STANAG 7096 Location, Actuation & Shape of Airframe Controls	3.4.3 Requirement Guidance
NATO STANAG 7138 Aircraft Visual Display Units	3.4.3 Requirement Guidance
NATO STANAG 7139 Aircraft Engine Controls, Switches, Displays, Indicators, Gauges, & Arrangements	3.4.3 Requirement Guidance
NATO STANAG 7140 Aircraft Flight Instruments, Layout & Display	3.4.3 Requirement Guidance
NAVAIR 15-01-500	3.4.9 Requirement Guidance
NAVAIR A1-NBCDR-OPM-000 Naval Aviation NBC Defense Resource Manual	3.1.8.2.6.3 Requirement Guidance
NAVAIR NATOPS 00-80T-109 Air-to Air Refueling Manual	3.4.6.1.1 Requirement Guidance 3.4.6.1.2 Requirement Guidance
NAVAIR NATOPS 00-80T-110 Air-to-Air Refueling Manual	3.1.1.1.1 Requirement Lessons Learned 3.4.6.2.1 Requirement Lessons Learned 3.4.6.2.2 Requirement Lessons Learned
NAVPERS 18068D	3.4.3.2 Requirement Guidance
Performance Based Product Definition Guide	2.3 Guidance 3.3.4 Requirement Lessons Learned 6.2 Specification tree
RAND Report R-3604/2-AF	3.3.7.1 Requirement Lessons Learned
RTCA DO-208 Minimum Operational Performance Standard for Airborne Supplemental Navigation Equipment Using Global Positioning System (GPS)	3.1.9.2 Requirement Guidance
RTCA DO-236	3.1.9.2 Requirement Guidance
Society of Allied Weights Engineers Recommended Practices No.7 and 8	3.1.1 Requirement Guidance 3.3.6.2 Requirement Guidance 3.4.5.2 Requirement Guidance
System Threat Assessment Report (STAR)	3.1.2.1 Requirement Guidance 3.1.8.2.4 Requirement Guidance 3.1.8.2.5.1 Requirement Guidance 3.1.8.2.5.1 Requirement Lessons Learned 3.1.8.2.5.2 Requirement Guidance

AIR VEHICLE

JOINT SERVICE SPECIFICATION GUIDE

APPENDIX C

FLYING QUALITIES

C.1 SCOPE

C.1.1 Scope.

Section 3.3.11 of the Air Vehicle JSSG incorporates those top-level flying qualities requirements that are suitable for an air vehicle specification. This appendix contains amplifying design guidance to enable compliance with the top-level requirements found in Section 3.3.11.

C.1.2 Use of Appendix C.

The design guidance in this appendix is intended to bridge the gap between a specified qualitative Level of flying qualities and the designers' need to have a quantifiable, measurable set of parameters that will shape and size the resulting air vehicle. The resulting requirements are intended to assure flying qualities for adequate mission performance and flight safety regardless of the design implementation or flight control system augmentation. It is anticipated that this entire appendix will eventually be incorporated in MIL-HDBK-1797, Flying Qualities of Piloted Aircraft. The contractor and the procuring activity should utilize appropriate information from this appendix and from MIL-HDBK-1797 consistent with the specific acquisition.

C.2 APPLICABLE DOCUMENTS

C.2.1 Government documents.

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 listed in the latest issue of the Department of Defense Index of Specifications and Standards (DoDISS) and supplement thereto.

HANDBOOKS

DEPARTMENT OF DEFENSE

MIL-HDBK-1797	Flying Qualities of Piloted Aircraft

C.3 PERFORMANCE REQUIREMENTS

The following information is included to help define flying qualities requirements and verifications in the program-unique specification. Use of these requirements should assure adequate mission performance and flight safety. Table C-I is in a table of contents format that provides the user a linking tool to the requirements (digital viewers can click on the page number to hyperlink to the requirement).

TABLE C-I. Table of requirements.

C.3.1 Control power.
For all normal and extreme states, aerodynamic control power, control surface rate, and hinge moment capability shall be sufficient to assure safety throughout the combined range of all attainable AOAs (both positive and negative) and sideslip. For all failure states and flight conditions, control margins shall be such that control can be maintained long enough to fly out of atmospheric disturbances, all flight phases can be terminated safely, and a waveoff (go-around) can be accomplished successfully.

REQUIREMENT RATIONALE (C.3.1)

This overall requirement is intended to assure adequate control for safety in any situation not otherwise covered in this specification. It is intended to permit recovery from unusual situations in, and even beyond, the RORH, on the grounds that if a condition is attainable, someday it will be attained. Experience has shown that to be a reasonable assumption.

REQUIREMENT GUIDANCE (C.3.1)

To Be Prepared

REQUIREMENT LESSONS LEARNED (C.3.1)

To attain performance benefits, we no longer require control-surface-fixed stability. Whatever the cause, control saturation can be catastrophic in a basically unstable air vehicle. Then control deflection for recovery, whether commanded by the pilot or automatically, is just not available. This differs from the stable case, in which if the deflection limit is reached for trim, full control authority is available for recovery. Control rate limiting can also induce instability if the basic airframe is unstable. This requirement is intended to require full consideration of all the implications of relaxed static stability and other Control-Configured Vehicle (CCV) concepts.

In considering how much margin of control should be required there is no general quantitative answer, but it is possible to enumerate some cases to consider. Certainly there should be sufficient control authority to pitch the air vehicle out of any trim point to lower the AOA from any attainable value. That is, with full nose-down control the pitching moment should be at least a little negative at the most critical attainable AOA, for a c.g. on the aft limit and nominal trim setting. Attainable AOA is another issue in itself; but lacking intolerable buffet or a limiter that is effective in every conceivable situation, angles to at least 90 degrees should be considered. Control margin is also necessary at negative AOA.

The flight task will dictate some minimum amount of nose-down control capability. Air combat maneuvering certainly imposes such a requirement, and so do terminal-area operations including landing flare out. Then, there should be some capability to counter atmospheric disturbances while maneuvering; counter c.g. movements due to fuel slosh while accelerating, diving, or climbing; stop rotation at the take-off attitude; etc. Roll inertial coupling has been a critical factor for many slender air vehicles.

In addition to conventional control modes, a CCV's direct-force controls can offer a number of new possibilities ranging from independent fuselage aiming to constant-attitude landing flares. The additional variables must be accounted for to assure adequate sizing of the control surfaces, and priorities may need to be established. The effectiveness of thrust vectoring varies with airspeed and altitude, and of course with the commanded thrust level; engine flameout or stall may be a consideration.

The instabilities and complications resulting from these factors can probably be rectified by stability augmentation if and only if control effectiveness is adequate. The controllability margin conventionally provided by static stability must be translated for CCV's into margins of controllability authority and rate. Control must be adequate for the combined tasks of trim (establishing the operating point), maneuvering, stabilization (regulation against disturbances), and handling of failures (flight control system, propulsion, etc.).

3.6 precludes dangerous single failures. After the first failure it may be advisable to constrict flight envelopes for some assurance of flight safety in case, say, a second hydraulic system should fail. The contractor will need to weight the expected frequency and operational consequences of such measures against predicted benefits.

Excessive stability, as well as excessive instability of the basic airframe, is of concern with respect to available control authority and rate. For example, large stable C_{l_β} increases the roll control power needed to counteract gusts.

It is well known that hinge moments can limit both deflection and rate of control surfaces. When using a surface for control in two axes, as with a horizontal stabilizer deflected symmetrically for pitching and differentially for rolling, priorities or combined limits must be set to assure safety (AIAA Paper 78-1500). Other demands on the hydraulic system can reduce control capability at times. Aeroelasticity can reduce control effectiveness directly, as well as alter the air vehicle stability. For the F-16, full nose-down control put in by stability augmentation has to be overridden in order to rock out of the locked-in deep stall. Control surfaces stall at an incidence somewhat less than 90 degrees; and if control is supplemented by thrust vectoring, for example, one must consider the control force or moment available in normal operation, the effect on forward thrust, and the possibility of flameout, as well as aerodynamic interference effects. All the possible interactions of active control must be taken into account.

Encountering the wake vortex of another air vehicle can be an extremely upsetting experience. These encounters are not uncommon in practice or real combat, and also may occur in the terminal area and elsewhere; prediction is difficult. Other atmospheric disturbances can be severe, too; jetstreams, storms, wakes of buildings, etc., as well as gusts and wind shears.

The amount of control capability at extreme AOAs, positive and negative, must be enough to recover from situations that are not otherwise catastrophic. Avoidance of a locked-in deep stall has been known to limit the allowable relaxation of static stability. Also, control must be sufficient to counter the worst dynamic pitch-up tendency below stall or limit AOA. Propulsion and flight control system failure transients must be considered, along with possibly degraded control authority and rate after failure: spin/post-stall gyration susceptibility and characteristics may well be affected. The designer must allow for fuel system failure or mismanagement.

The range of maneuvers considered should account for both the stress of combat and the range of proficiency of service pilots. For example, in 1919 the British traced a number of losses of unstable air vehicles to control authority insufficient to complete a loop that had flattened on top (ARC R&M No. 917). Thus nose-up capability at negative AOAs can also be important. Poorly executed maneuvers may make greater demands on the flight control system for departure prevention or recovery. For CCVs as well as conventional air vehicles, limiters can help greatly, but their effectiveness and certainty of operation need to be considered. Spins attained in the F-15 and F-16 attest to the possibility of defeating limiters. AFWAL-TR-81-3116 describes the A-7 departure boundary's closing in with increasing sideslip angle; angular rates also affect departure boundaries. Rapid rolling sometimes creates inertial coupling which can put great demands on pitch control; nose-down pitching seems to accentuate the divergence tendency.

External stores change both c.g. and pitching moment (C_{m_0} and C_{m_α}). Experience with past air vehicles indicates a firm need to allow some margin to account for unforeseen store loadings. With relaxed static stability this can determine not only the safety but the possibility of flight with stores not considered in the design process.

Uncertainties exist in the design stage. Nonlinear aerodynamics, particularly hard to predict even from wind tunnel tests, are almost certain to determine the critical conditions. The c.g., too, may not come out as desired, and in service, the c.g. location is only known with limited accuracy. There are also possible malfunctions and mismanagement in fuel usage to consider. We have even seen recent cases (e.g., F-111 and F-16) of misleading wind tunnel tests of basic static stability. Aeroelasticity and dynamic control effectiveness (e.g., F-15) can also reduce control margins.

Asymmetric loadings need to be considered. A critical case for the L-19 (subsequently known as the O-1) was the addition of a wire-laying mission involving carriage of a large reel under one wing. Some air vehicles – F-15 is a recent example – have been prone to develop significant fuel asymmetries due to prolonged inadvertent small sideslipping. Dive pullouts (n greater than 1) will accentuate the effects of loading asymmetries. Some F-100s were lost from asymmetric operation of leading edge slats (non-powered, aerodynamically operated on their own, without pilot action) in dive-bombing pullouts.

Reconfigurable flight control systems add a new dimension to tracking and managing the available control power.

The control margin requirements must be met with aerodynamic control power only, without the use of other effectors, such as thrust vectoring. This approach was chosen because experience to date with current technology inlets and engines operating at the distortion levels typical of high AOA at low speed dictates caution, due to the considerable uncertainty about reliability and dependability for use to stabilize and control the vehicle. Throttle usage is also a factor. While this requirement does not preclude the application of thrust vectoring for low-speed agility and supermaneuverability performance enhancements in the future, it does reinforce the position that current technology engines/inlets should not be relied upon as the only means to assure flight safety, prevent loss of control, or provide recovery capability anywhere in the flight envelope. Should future technology advancements provide demonstrated engine/inlet reliability at low speeds and high AOAs, the procuring activity may allow this requirement to be modified for multiple engine air vehicles such that thrust vectoring with one engine out may be used to meet it.

C.4.1 Control power verification.

Verification shall be by analysis and by simulation or flight test in the performance of the tasks of 4.3.13.1.1, 4.3.13.1.2, 4.3.13.1.3.2, and 4.3.13.1.3.3 under various levels of atmospheric disturbances. These tasks will be flown by test pilots at specific flight conditions throughout the ROSH and ROTH. The specific flight conditions to be evaluated shall be the most common operating conditions, any operating conditions critical to the mission of the air vehicle, and any conditions determined by analysis or simulation to be worse than the Level of flying qualities required. This requirement applies to the prevention of loss of control and to recovery from any situation, including deep stall trim conditions, for all maneuvering, including pertinent effects of factors such as pilot strength, regions of control-surface-fixed instability, inertial coupling, fuel slosh, the influence of symmetric and asymmetric stores, stall/post-stall/spin characteristics (3.13), atmospheric disturbances (3.3.13.2), and air vehicle failure states (3.3.13.1.3 through 3.3.13.1.3.3; failure transients and maneuvering flight appropriate to the failure state are to be included). For conditions which are considered too dangerous to test in flight, verification can be shown in a manned simulation. Proof of compliance in these demonstration tasks will consist of pilot comments and C-H ratings. The comments and ratings shall indicate that the flying qualities are no worse than the required Level of flying qualities for each combination of air vehicle state, flight phase, and level of atmospheric disturbance.

VERIFICATION RATIONALE (4.1)

This is a flight safety item. Analysis and simulation should proceed or accompany careful build-up to suspected critical flight conditions.

VERIFICATION GUIDANCE (4.1)

In dangerous cases we do not intend to show compliance with this requirement through flight demonstration. “Combined range of all attainable AOAs and sideslip” may even extend beyond the RORH, except for certain highly maneuverable fighter and trainer air vehicles. Flight test bounds will be established according to such requirements as former MIL-F-83691. For extreme flight conditions a combination of model testing – wind tunnel, free-flight if necessary, and hardware – and analysis will often be adequate. These extremes should be investigated in some way, whether or not the air vehicle incorporates a limiter. The scope of analysis, simulation, and testing needs careful consideration at the outset of a program. Then the progress must be monitored for possible additional troubles.

VERIFICATION LESSONS LEARNED (4.1)

AFWAL-TR-87-3018 gives guidance on determining control deflection and rate margins and calculating the deflection-saturated departure boundary in the conceptual and preliminary design stages, based on a reduced-order system with full-state feedback. At high speed and high dynamic pressure, the system bandwidth required is high, increasing the importance of high-frequency control system modes, structural modes, and system noise amplification. At low speed and low dynamic pressure, design risks are related to the limited ability of aerodynamic control surfaces to generate control moments. The lack of stabilizing control moments beyond some AOA or control-surface rate limits, will compromise transient responsiveness. Describing function analysis treats control limiting as a gain reduction, which in general lessens the stabilizing effect of feedbacks. Statistically-based margins for gusts reduce, but do not eliminate, the possibility of inadequate control margin.

Figure C-1 indicates some critical parameters in the response of an unstable system to a step command. Factors influencing some control margin increments may be seen in table C-II. To these margins must be added another nose-down control increment to counter the pitch-out tendency while rolling about the x stability axis (flightpath). As a first cut,

$$\left|\Delta\delta\right| = \left|\frac{I_x - I_z}{2M_\delta I_y} \cdot p^2 \cdot \sin 2\alpha\right|$$

$$\left|\dot{\delta}\right| = \left|\frac{I_x - I_z}{M_\delta I_y} \cdot p \cdot \dot{p} \cdot \sin 2\alpha\right|$$

where p is the stability-axis roll rate (about the flightpath). Figure C-2 shows in concept the margins that are needed: $\Delta\delta_{marg}$ is the sum of turbulence and sensor noise components, $\Delta\delta_{tran}$ provides the pitching acceleration to meet the CAP requirement, and $\Delta\delta_{pr}$ can cancel the inertial pitching moment from rolling. Unless deactivated whenever saturation is encountered, an integrator in the flight control system tends to run away, leading to loss of control.

Similar considerations, also treated in AFWAL-TR-87-3018, apply to any basic airframe having static directional instability.

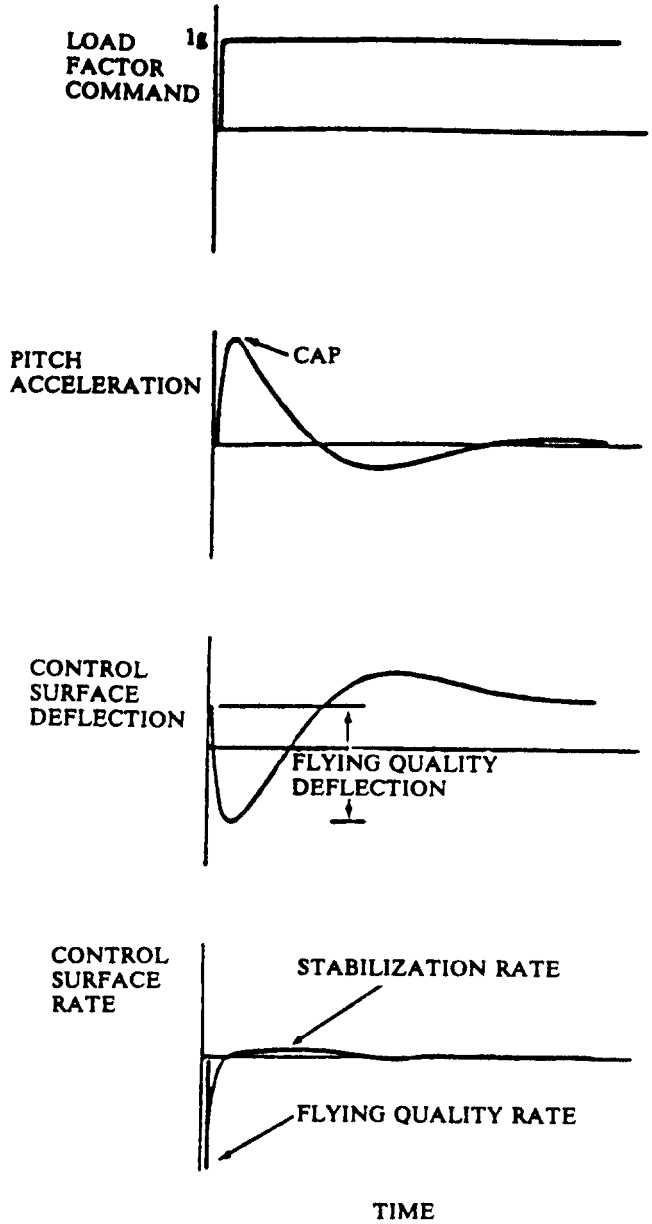

FIGURE C-1. Control surface requirements.

TABLE C-II. Control margin increment.

Flying Quality	$\Delta\delta_{FQ}/\Delta n_c = 57.3\ CAP'/M_\delta$ deg/g (for $T_{eff} \le 0.05$)
Stabilization	$\Delta\delta_{stab} / \Delta n_c = 57.3 \frac{g}{U_0} \cdot \frac{1/T_{sp_1} \cdot 1/T_{sp_2}}{M_\delta \cdot 1/T_{\theta_2}}$ deg/g (linear, 2DOF)
Turbulence	σ_δ/σ_w function of M_w, M_δ, $\omega_{sp_{cl}}$, $\zeta_{sp_{cl}}$, structural modes
	- most severe at low $\bar{q}$
	- $3\sigma_\delta$ and σ_w for severe turbulence recommended
Sensor noise	σ_δ/σ_s function of K_s, K_F, ω_s, $1/T_a$, $\omega_{sp_{cl}}$, $\zeta_{sp_{cl}}$, $\omega^2_{sp_{ol}}$
Flying Quality	$\dot{\delta}_{FQ}/n_c = 57.3\ CAP/(M_\delta \cdot T_{eff})$ for desired CAP
Stabilization	$\dot{\delta}_{stab}/n_c < \dot{\delta}_{FQ}/n_c$ if FCS stability margins OK & $1/T_{eff} > \omega_c$
	$\dot{\delta}_{stab}/n_c$ function of $1/T_{eff}$, $1/T_{sp_2}$, $\omega_{sp_{cl}}$, $\zeta_{sp_{cl}}$
Turbulence	$\sigma_{\dot{\delta}}/\sigma_w$ function of $1/T_a$, $\omega_{sp_{cl}}$, $\zeta_{sp_{cl}}$, M_δ
	- most severe at low $\bar{q}$
	- $3\sigma_{\dot{\delta}}$ recommended for control margin
Sensor noise	$\sigma_{\dot{\delta}}/\sigma_s = K_s K_F \cdot fn(\omega_s$, $1/T_a$ and, for low $\omega_{sp_{cl}}$: $\omega^2_{sp_{ol}}$, $\omega_{sp_{cl}}$, $\zeta_{sp_{cl}})$
	- these parameters are not all independent
	- $3\sigma_{\dot{\delta}}$ recommended for control margin

Δn_c is the commanded increment of normal acceleration
$1/T_2$ is the unstable pole of the transfer function (negative; 1/sec)
$\omega^2_{sp_{ol}}$ is the 2-deg-of-freedom product of the poles, 1/sec^2
$\omega_{sp_{cl}}$ and $\zeta_{sp_{cl}}$ are the closed-loop frequency and damping ratio of the short-period mode
CAP is $\dot{q}_0/\Delta n_\infty$, CAP′ is $\dot{q}_{max}/\Delta n_\infty$
ω_s is the sensor bandwidth
K_s, K_F are the sensor and forward-loop gains
σ_s, σ_w are the rms intensities of sensor noise and vertical gusts
ω_c is the crossover frequency of the $\dot{\delta}/n_c$ transfer function
T_{eff} is the effective time constant of command-path plus forward-path control-loop elements (such as prefilters and actuators)
T_a is the time constant of the actuator ram

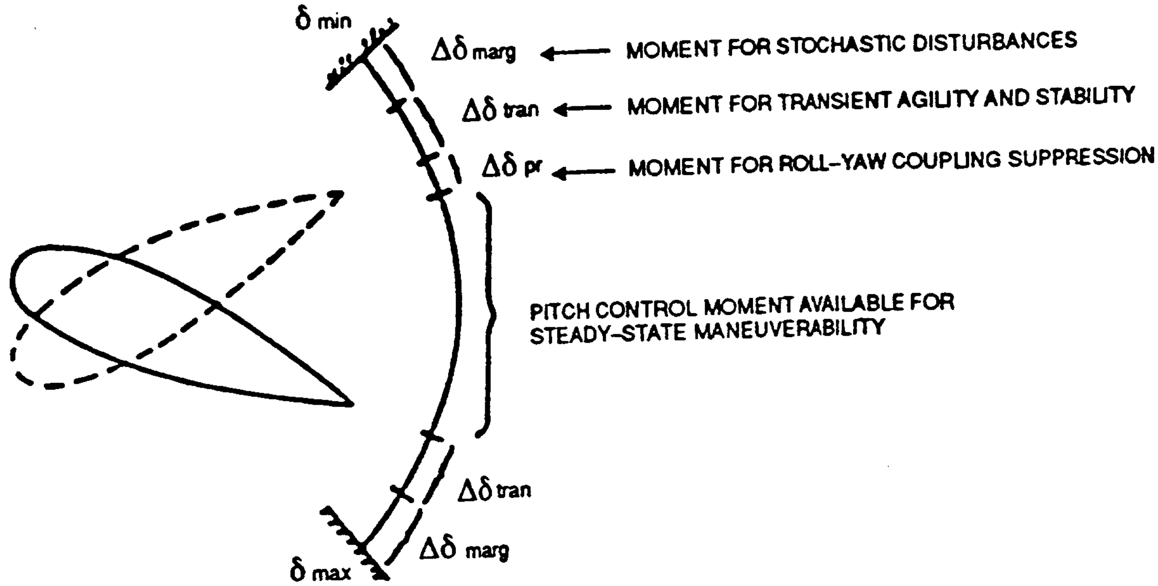

FIGURE C-2. Control margin requirements.

While flight test risk must be bounded, it is necessary to assure by some means that any dangerous conditions are found and evaluated before service pilots and air vehicles are lost through surprise encounters, with no known avoidance or recovery technique. Flight experience can be summarized by Murphy's Law. Therefore, it is better for highly skilled flight test pilots to find any serious glitches under controlled conditions rather than to wait for some less experienced operational pilots to find them in service use.

During F/A-18 high-AOA/stall testing, an AOA hang-up phenomenon was observed (at 50-60 deg AOA) which was very similar to that described in 3.3.13.15.4.1 Lessons Learned with regard to the F-16 deep stall. At operational aft c.g.'s and high AOA, delayed recoveries were experienced in the F/A-18 due to weak nose-down pitch restoring moments, even with full forward stick. Based upon the F/A-18 test experience a pitch restoring (nose-down) moment coefficient magnitude of at least 0.2 (i.e., $C_m \leq -0.2$) should be available for the most longitudinally unstable loading and aft c.g. combination expected to exist on Class IV air vehicles. Analysis of the F/A-18 test data from high-AOA post-stall gyrations shows that the AOA hang-up phenomenon was further aggravated by uncommanded roll rate and yaw rate oscillations and resultant nose-up pitching moments. Flight test results indicate that these oscillations could generate pitching moments approximately equivalent to a change in pitching moment coefficient of +0.1, which significantly opposed natural aerodynamic pitch restoring moments. Occasionally F/A-18 recoveries from high-AOA hang-ups were significantly delayed because of accompanying roll/yaw rate oscillations when c.g./loading/AOA conditions caused C_m (with full nose-down control input) to be greater than approximately -0.2. This suggests that for Class IV air vehicles a pitch recovery criterion could be that the pitch recovery control produce a net pitch restoring moment coefficient magnitude not less than 0.1 ($C_m \leq -0.1$), which yields approximately 15-20 deg/sec^2 nose down at low airspeed.

C.3.1.1 Pitch axis control margin

Aerodynamic control power, control surface rate, and hinge moment capability shall be sufficient to provide for safe recovery throughout the range of attainable angles of attack to prevent the occurrence of deep stall and enhance maneuverability for tactical utility. For all normal states, the air vehicle shall exhibit no deep stall trim point within the center of gravity limits of the air vehicle, and shall have no objectionable nose-up or nose-down recovery characteristics, such as positive or negative AOA hang–up.

REQUIREMENT RATIONALE (3.1.1)

The amount of pitching moment available is critical to tactical maneuverability and safe recovery from high angle of attack flight conditions. The vortex lift augmentation and relaxed static stability design features have led to improved performance, maneuverability, and agility but have also resulted in inadequate nosedown pitch control power for high AOA recovery at some conditions. The Navy and USAF have experienced numerous incidents and accidents in air vehicles that have developed high angle of attack hangup or deep stall and were unable to recover because the nose-down pitching moment available was insufficient to overcome the established conditions.

REQUIREMENT GUIDANCE (3.1.1)

An overly stringent requirement for longitudinal control margin may result in excessive weight and supersonic performance penalties, whereas one which is too lax could lead to low-speed high angle of attack controllability problems and degraded maneuvering capability. The level of static pitching moment coefficient is important throughout the angle of attack range but especially at the pinch point where pitching moment is at a minimum.

The effects of factors such as pilot strength, regions of control-surface-fixed instability, inertial and kinematic coupling, symmetric and asymmetric stores, atmospheric disturbances, failure transients due to center of gravity control malfunction, or failures in the propulsion, flight control and other integrated systems, should also be factored into the guideline.

Extensive simulation and flight testing by NASA and the Navy resulted in the development of figures of merit to guide the design for nose-down control capability. This joint effort determined the desired values for nosedown performance with gear and flaps retracted, in 1g flight, idle power, and dynamic pressure for stall.

REQUIREMENT LESSONS LEARNED (3.1.1)

Results of the Navy and NASA Langley Research Center pitch control margin simulation studies were validated in flight. The figures of merit that relate pilot cueing and qualitative assessment of high angle of attack nosedown recovery to quantitative measures were confirmed to be short term response in the form of pitch acceleration and pitch rate. During the NASA simulation studies, it was determined by the evaluation pilots that pitch acceleration was the most strongly perceived nosedown response cue. In the absence of significant angular rates, pitch acceleration is strongly related to the pitch control power due to the direct proportionality to static pitching moment. Pitch acceleration was considered to be the most important figure of merit in quantifying longitudinal control margin requirements since acceleration was readily perceived by the pilots during a pushover recovery from high angle of attack within the first second of the recovery. Pilot comments also indicated that in addition to initial pitch acceleration, pitch rate approximately two seconds after the recovery input was useful in the pitch recovery rating process.

C.4.1.1 Pitch axis control margin verification.

Pitch control margin should be demonstrated during flight test. Nose down acceleration and pitch rate capability should be measured at the minimum pitching moment point with full forward longitudinal control stick command, with normal trim, at aft CG locations, flight conditions for low fuel state, and controls deflected to maintain stability. Maneuvers that also have some utility for assessing pitch control margin include pushovers with initial nose up pitch rate and recoveries from zoom climb and rolling conditions.

VERIFICATION RATIONALE (4.1.1)

During the joint NASA and Navy test program, fundamental types of maneuvers were performed and evaluated during piloted simulation and flight test. The maneuvers were open-loop such that specific recovery conditions were not targeted for capture. The pushover from 1g stabilized, trimmed, wings-level, high angle of attack allows for direct assessment of the nosedown control moment available over an angle of attack range, while minimizing the thrust and performance effects.

VERIFICATION GUIDANCE (4.1.1)

Use of advanced propulsive and aerodynamic control effectors will aid in achieving the control moments to meet maneuvering requirements. Control power for verification may be derived from aerodynamic control surfaces, thrust vectoring and reaction-type control devices. Additionally, control power/control margin should be verified, in environmentally-calm conditions, adequate to maintain or recover control following any failure and to ensure that the flight phase can be terminated. Results of the Navy and NASA Langley Research Center pitch control margin simulation and flight test studies proved that high angle of attack pitch control margin can be demonstrated using a stabilized pushover method from 1g stabilized trim wings-level flight at high angles of attack, minimizing the thrust and performance effects. A nosedown command applied at initial conditions at which the pitch attitude or the flight path angle is changing results in changes in angle of attack that are not due solely to the nosedown moment generated by the application of controls. With residual pitch attitude or flight path angle rates, the pilot technique and resulting motion are more complex, which reduces the repeatability of the maneuver and complicates the analysis.

VERIFICATION LESSONS LEARNED (4.1.1)

During the NASA/Navy studies, simulation and flight test results for linear pitch acceleration were compared and found to correlate well. However, at aft center of gravity locations with nonlinearities in pitch acceleration, qualitative flight test data diverged from predicted simulation trends due to motion cue effects and increased pilot sensitivity to degraded pitch response. Flight tests also revealed that extensive workload was required to stabilize the air vehicle at the specified initial conditions of 1g, stabilized, trim at high angles of attack. Since the simulation tests used preset conditions, the pilots were not required to perform the maneuver setups during the piloted simulation portion of the evaluation. When the maneuvers were duplicated during flight tests, the pilots discovered establishing the required angle of attack and 15 degree pitch attitude was very difficult because the pilot had to "close the loop" on trim airspeed with the throttles to stabilize the flight path angle.

C.3.1.2 Pitch axis control power in unaccelerated flight.

Pitch control effectiveness shall not limit the ability to attain and hold any speed from V_S to V_{max} in steady 1-g flight at any altitude within the ROTH.

REQUIREMENT RATIONALE (3.1.2)

This requirement is intended to insure that the pilot can maintain equilibrium level flight throughout the flight envelope by normal means.

REQUIREMENT GUIDANCE (3.1.2)

Controllability at speeds down to the 1-g stall speed is generally deemed necessary for safety, as well as full utilization, of maneuvering air vehicles such as the military use. V_{max}, the high-speed boundary of the ROTH, must be at least $V_{o_{max}}$; beyond that, it may be set by the contractor.

REQUIREMENT LESSONS LEARNED (3.1.2)

See MIL-HDBK-1797.

C.4.1.2 Pitch axis control power in unaccelerated flight verification.

Verification shall be by analysis, simulation, and flight test.

VERIFICATION RATIONALE (4.1.2)

Operational flight test will help reveal any deficiencies in pitch control power.

VERIFICATION GUIDANCE (4.1.2)

The controls are to be used in their normal manner, and sideslip minimized. It is important to explore all corners of the V-h ROTH. For example, a transonic tuck or high-speed dives can be critical due to combined aeroelastic and Mach number effects. Extremes of static stability or instability (Mach number, AOA, c.g.) will be critical. Also, hinge moments may limit control deflection and aeroelastic deformations may affect controllability where, as in 1-g equilibrium level flight, net forces and moments are zero.

VERIFICATION LESSONS LEARNED (4.1.2)

See MIL-HDBK-1797.

C.3.1.3 Pitch axis control power in maneuvering flight.

Within the ROSH, it shall be possible, by use of the pitch control alone, to achieve the load factors of table C-III. This maneuvering capability is required at constant altitude at the 1-g trim speed and, with trim and throttle settings not changed by the crew, over a range about the trim speed the lesser of ±15% or ±50 kt EAS (except where limited by the boundaries of the ROSH).

TABLE C-III. Required load factor ranges for maneuvering flight.

Level	Load factor range
1	
2	
3	

REQUIREMENT RATIONALE (3.1.3)

The pitch axis controller must be sufficiently powerful to produce an adequate range of load factors for maneuvering. Fixed-wing air vehicles generally use the pitch controller to affect flight-path changes.

REQUIREMENT GUIDANCE (3.1.3)

Recommended values for C-I:

Level	Load factor range
Levels 1 and 2	n_{o-} to n_{o+}
Level 3	From n = 0.5 g to the lower of: a) n_{o+}, or b) $n = 2.0$ g for $n_{o+} \leq 3$ g $= 0.5(n_{o+} + 1)$ for $n_{o+} > 3$ g

REQUIREMENT LESSONS LEARNED (3.1.3)

See MIL-HDBK-1797.

C.4.1.3 Pitch axis control power in maneuvering flight verification.

Verification shall be by analysis, simulation, and flight test.

VERIFICATION RATIONALE (4.3)

This is a flight safety item. Analysis and simulation should proceed or accompany careful build-up to suspected critical flight conditions.

VERIFICATION GUIDANCE (4.3)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.3)

See MIL-HDBK-1797.

C.3.1.4 Longitudinal control for take-off.

The effectiveness of the pitch control shall not restrict the take-off performance of the air vehicle and shall be sufficient to prevent overrotation during all types of take-off. During __(1)__, at __(2)__, pitch control effectiveness shall be sufficient to __(3)__. These requirements shall be met on hard-surface runways. In the event that the air vehicle has a mission requirement for operation from unprepared fields, these requirements shall be met on such fields also. Satisfactory take-offs shall not depend upon use of the trimmer control during take-off or on complicated control manipulation by the pilot.

REQUIREMENT RATIONALE (3.1.4)

The requirement is intended to regulate against air vehicles that exhibit no apparent pitch response to commands during the take-off roll until flying speed is reached (V_{min}). These air vehicles give no assurance that rotation will be forthcoming, but then tend to “pop off”, resulting in overrotation and a necessity for immediate control reversal to avoid stall.

REQUIREMENT GUIDANCE (3.1.4)

Blanks 1-3. Recommended values:

Air Vehicle Class	Blank 1	Blank 2	Blank 3
Nosewheel air vehicles, all Classes	the take-off roll	0.9 V_{min}	obtain the pitch attitude which will result in lift-off at V_{min}(TO)
Tailwheel air vehicles, Class I	the take-off roll	0.5 V_S(TO)	maintain any pitch attitude up to that for a level thrust-line
Tailwheel air vehicles, Classes II, III, and IV	the take-off roll	V_S(TO)	maintain any pitch attitude up to that for a level thrust-line
Catapult-launched air vehicles	catapult take-offs	speeds from $V_{c_{min}}$ (CT) to $V_{c_{min}}$(CT) + 30 kts	prevent the air vehicle from pitching up or down to undesirable attitudes in catapult take-offs

REQUIREMENT LESSONS LEARNED (3.1.4)

See MIL-HDBK-1797.

C.4.1.4 Longitudinal control for take-off verification.

Verification shall be by analysis, simulation, and flight test.

VERIFICATION RATIONALE (4.1.4)

This is a flight safety item. Analysis and simulation should proceed or accompany careful build-up to suspected critical flight conditions.

VERIFICATION GUIDANCE (4.1.4)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.1.4)

See MIL-HDBK-1797.

C.3.1.5 Longitudinal control in landing.

For Levels 1 and 2, the pitch control shall be sufficiently effective in the landing flight phase in close proximity to the ground that, in calm air, during landing flare and rollout with the air vehicle trimmed for the minimum recommended approach speed [not to exceed 1.3 $V_S(L)$]:

a. The geometry-limited touchdown can be achieved at touchdown, or alternatively
b. The lower of $V_S(L)$ or the guaranteed minimum landing speed [$V_{min}(L)$] can be achieved when flaring from shallow (γ = -3 deg) and steep (γ = -6 deg) approaches, and the __(1)__ can be gently lowered to the ground at speeds down to __(2)__. The pitch control forces required to meet these requirements shall be pull forces and shall not exceed __(3)__.

REQUIREMENT RATIONALE (3.1.5)

This requirement insures that the air vehicle can be pitched up sufficiently, in ground effect, to achieve the guaranteed minimum landing speed. It also insures that the nosewheel or tailwheel can be gently lowered to the ground during landing rollout.

REQUIREMENT GUIDANCE (3.1.5)

Blanks 1 and 2. Recommended values:

Landing gear configuration	Air Vehicle Class	Blank 1	Blank 2
Nosewheel	All	nosewheel	0.9 $V_{min}(L)$
Tailwheel	Class I	tailwheel	0.5 $V_{min}(L)$
	Classes II, III, and IV	tailwheel	0.75 $V_{min}(L)$

Blank 3. For Classes I, II-C, and IV: 35 pounds
For Classes II-L and III: 50 pounds

REQUIREMENT LESSONS LEARNED (3.1.5)

See MIL-HDBK-1797.

C.4.1.5 Longitudinal control in landing verification.

Verification shall be by analysis, simulation, and flight test.

VERIFICATION RATIONALE (4.1.5)

This is a flight safety item. Analysis and simulation should proceed or accompany careful build-up to suspected critical flight conditions.

VERIFICATION GUIDANCE (4.1.5)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.1.5)

See MIL-HDBK-1797.

C.3.1.6 Flight path control power.

The designated flight path controller shall be capable of producing the steady-state flight path angle changes given in table C-IV following full actuation of the controller. It shall be possible to achieve these flight path angle changes without changing the trim airspeed for the approach flight condition and without reconfiguring the air vehicle.

TABLE C-IV. Minimum flight path control power.

Flight Phase	Level	Minimum flight path angle changes (measured from γ_{TRIM})	
		$\Delta\gamma$ Up	$\Delta\gamma$ Down
PA	1		
	2		
	3		
L	1		
	2		
	3		

REQUIREMENT RATIONALE (3.1.6)

For most current STOL designs, flight path is primarily controlled with throttle. For such cases, the requirement applies directly to the limits of travel for the thrust controller. For configurations which are augmented so that flight path is controlled exclusively with attitude (such as the Boeing YC-15), the requirements of this section apply except that the limits apply to attitude control rather than throttle. The use of a separate auxiliary cockpit controller (such as spoilers) is considered to be a way of reconfiguring the air vehicle and therefore does not apply.

REQUIREMENT GUIDANCE (3.1.6)

Recommend values for table C-IV:

Flight Phase	Level	Minimum flight path angle changes (measured from γ_{TRIM})	
		$\Delta\gamma$ Up	$\Delta\gamma$ Down
PA	1	4°	-4°
	2	2°	-2°
	3	2°	-2°
L	1	6.5° or $\Delta\gamma$ which gives γ = 1.5°, whichever is greater	-4°
	2	4° or $\Delta\gamma$ which gives γ = -1°, whichever is greater	-2°
	3	4° or $\Delta\gamma$ which gives γ = -1°, whichever is greater	-2°

REQUIREMENT LESSONS LEARNED (3.1.6)

See MIL-HDBK-1797 and AFWAL-TR-83-3059.

C.4.1.6 Flight path control power verification.

Verification shall be by analysis, simulation, and flight test.

VERIFICATION RATIONALE (4.1.6)

This is a flight safety item. Analysis and simulation should proceed or accompany careful build-up to suspected critical flight conditions.

VERIFICATION GUIDANCE (4.1.6)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.1.6)

See MIL-HDBK-1797.

C.3.1.7 Roll performance.

For full roll commands to the right and to the left, initiated abruptly both from steady, coordinated (zero lateral acceleration) bank angles and from wings-level flight, the time to bank shall be no more than the limits in table C-V, with time measured from the initiation of control force application. Requirements 3.1.7 through 3.1.7.2 apply throughout the applicable speed-altitude-load factor envelopes, except that the structural limits on combined rolling and normal acceleration need not be exceeded. Pitch control shall be held fixed throughout the maneuver and __(1)__ ; but otherwise, yaw control pedals may be used to reduce sideslip that retards roll rate (not to produce sideslip that augments roll rate) if such control inputs are simple, easily coordinated with roll control inputs, and consistent with piloting techniques for the mission.. For flight phase TO, the time required to bank may be increased proportional to the ratio of the rolling moment of inertia at take-off to the largest rolling moment of inertia at landing for weights up to the maximum authorized landing weight. __(3)__

TABLE C-V. Roll performance.

Level	Speed Range	Time to achieve the stated bank angle change (seconds)		
		Category A	Category B	Category C
1				
2				
3				

C.3.1.7.1 Additional roll requirements for Class IV air vehicles.

In flight phase CO, the time to bank during 360° rolls initiated at 1-g shall be no more than the limits in table C-VI. In flight phase CO, the time to bank for rolls initiated from coordinated turns, keeping approximately constant normal load factor, at load factors between $0.8n_{o-}$ and $0.8n_{o+}$, shall be no more than the limits in table C-VII. At load factors beyond this range, the change in bank angle shall always be in the direction of the roll control command, and the change in bank angle after 1 second shall be greater than 0.0 deg. The requirements in flight phase GA with large complements of external stores may be relaxed from those specified in table C-VI;

however, for any expected external loading the time to bank shall be no more than the limits in table C-VII for rolls initiated from coordinated turns, keeping approximately constant normal load factor, at load factors between $0.8n_{o-}$ and $0.8n_{o+}$.

TABLE C-VI. Flight phase CO roll performance in 360° rolls.

Level	Speed Range	Time to achieve the stated bank angle change (seconds)			
		30°	90°	180°	360°
1	$V_{o_{min}} \leq V < V_{o_{min}} + 20$ kts				
	$V_{o_{min}} + 20$ kts $\leq V < 1.4V_{o_{min}}$				
	$1.4V_{o_{min}} \leq V < 0.7V_{o_{max}}$				
	$0.7V_{o_{max}} \leq V \leq V_{o_{max}}$				
2	$V_{min} \leq V < V_{min} + 20$ kts				
	$V_{min} + 20$ kts $\leq V < 1.4V_{min}$				
	$1.4V_{min} \leq V < 0.7V_{max}$				
	$0.7V_{max} \leq V \leq V_{max}$				
3	$V_{min} \leq V < V_{min} + 20$ kts				
	$V_{min} + 20$ kts $\leq V < 1.4V_{min}$				
	$1.4V_{min} \leq V < 0.7V_{max}$				
	$0.7V_{max} \leq V \leq V_{max}$				

TABLE C-VII. Flight phase CO loaded roll performance.

Level	Speed Range	Time to achieve the stated bank angle change (seconds)			
		30°	50°	90°	180°
1	$V_{o_{min}} \leq V < V_{o_{min}} + 20$ kts				
	$V_{o_{min}} + 20$ kts $\leq V < 1.4V_{o_{min}}$				
	$1.4V_{o_{min}} \leq V < 0.7V_{o_{max}}$				
	$0.7V_{o_{max}} \leq V \leq V_{o_{max}}$				
2	$V_{min} \leq V < V_{min} + 20$ kts				
	$V_{min} + 20$ kts $\leq V < 1.4V_{min}$				
	$1.4V_{min} \leq V < 0.7V_{max}$				
	$0.7V_{max} \leq V \leq V_{max}$				
3	$V_{min} \leq V < V_{min} + 20$ kts				
	$V_{min} + 20$ kts $\leq V < 1.4V_{min}$				
	$1.4V_{min} \leq V < 0.7V_{max}$				
	$0.7V_{max} \leq V \leq V_{max}$				

TABLE C-VIII. Flight phase GA loaded roll performance.

Level	Speed Range	Time to achieve the stated bank angle change (seconds)			
		30°	50°	90°	180°
1	$V_{o_{min}} \leq V < V_{o_{min}}$ + 20 kts				
	$V_{o_{min}}$+ 20 kts $\leq V < 1.4V_{o_{min}}$				
	$1.4V_{o_{min}} \leq V < 0.7V_{o_{max}}$				
	$0.7V_{o_{max}} \leq V \leq V_{o_{max}}$				
2	$V_{min} \leq V < V_{min}$ + 20 kts				
	V_{min} + 20 kts $\leq V < 1.4V_{min}$				
	$1.4V_{min} \leq V < 0.7V_{max}$				
	$0.7V_{max} \leq V \leq V_{max}$				
3	$V_{min} \leq V < V_{min}$ + 20 kts				
	V_{min} + 20 kts $\leq V < 1.4V_{min}$				
	$1.4V_{min} \leq V < 0.7V_{max}$				
	$0.7V_{max} \leq V \leq V_{max}$				

C.3.1.7.2 Roll termination.

Clean and with symmetric and asymmetric air-to-air and air-to-ground loadings, after achieving the bank angle changes specified in 3.1.7, abrupt lateral control inputs used to terminate the roll maneuvers shall not cause air vehicle motions which result in loss of control, stall, or exceedance of structural limits.

REQUIREMENT RATIONALE (3.1.7 through 3.1.7.2)

Roll power is specified in terms of bank angle change in a given time, a form related to operational use of the air vehicle, to allow necessary maneuvering and attitude regulation.

REQUIREMENT GUIDANCE (3.7 through 3.7.2)

Recommended values for table C-V for Class I air vehicles:

Level	Speed Range	Time to achieve the stated bank angle change (seconds)		
		Category A	Category B	Category C
		60°	60°	30°
1	$V_{o_{min}} \leq V < V_{o_{max}}$	1.3	1.7	1.3
2	$V_{min} \leq V \leq V_{max}$	1.7	2.5	1.8
3	$V_{min} \leq V \leq V_{max}$	2.6	3.4	2.6

Recommended values for table C-V for Class II-L air vehicles:

Level	Speed Range	Time to achieve the stated bank angle change (seconds)		
		Category A	Category B	Category C
		45°	45°	30°
1	$V_{o_{min}} \le V < V_{o_{max}}$	1.4	1.9	1.8
2	$V_{min} \le V \le V_{max}$	1.9	2.8	2.5
3	$V_{min} \le V \le V_{max}$	2.8	3.8	3.6

Recommended values for table C-V for Class II-C air vehicles:

Level	Speed Range	Time to achieve the stated bank angle change (seconds)		
		Category A	Category B	Category C
		45°	45°	25°
1	$V_{o_{min}} \le V < V_{o_{max}}$	1.4	1.9	1.0
2	$V_{min} \le V \le V_{max}$	1.9	2.8	1.5
3	$V_{min} \le V \le V_{max}$	2.8	3.8	2.0

Recommended values for table C-V for Class III air vehicles:

Level	Speed Range	Time to achieve stated bank angle change (seconds)		
		Category A	Category B	Category C
		30°	30°	30°
1	$V_{o_{min}} \le V < 1.8V_{o_{min}}$	1.8	2.3	2.5
	$1.8V_{o_{min}} \le V < 0.7V_{o_{max}}$	1.5	2.0	2.5
	$0.7V_{o_{max}} \le V \le V_{o_{max}}$	2.0	2.3	2.5
2	$V_{min} \le V < 1.8V_{min}$	2.4	3.9	4.0
	$1.8V_{min} \le V < 0.7V_{max}$	2.0	3.3	4.0
	$0.7V_{max} \le V \le V_{max}$	2.5	3.9	4.0
3	$V_{min} \le V \le V_{max}$	3.0	5.0	6.0

Recommended values for table C-V for Class IV air vehicles:

Level	Speed Range	Time to achieve the stated bank angle change (seconds)				
		Category A			Category B	Category C
		30°	50°	90°	90°	30°
1	$V_{o_{min}} \leq V < V_{o_{min}} + 20$ kts	1.1			2.0	1.1
	$V_{o_{min}} + 20$ kts $\leq V < 1.4V_{o_{min}}$	1.1			1.7	1.1
	$1.4V_{o_{min}} \leq V < 0.7V_{o_{max}}$			1.3	1.7	1.1
	$0.7V_{o_{max}} \leq V \leq V_{o_{max}}$		1.1		1.7	1.1
2	$V_{min} \leq V < V_{min} + 20$ kts	1.6			2.8	1.3
	$V_{min} + 20$ kts $\leq V < 1.4V_{min}$	1.5			2.5	1.3
	$1.4V_{min} \leq V < 0.7V_{max}$			1.7	2.5	1.3
	$0.7V_{max} \leq V \leq V_{max}$		1.3		2.5	1.3
3	$V_{min} \leq V < V_{min} + 20$ kts	2.6			3.7	2.0
	$V_{min} + 20$ kts $\leq V < 1.4V_{min}$	2.0			3.4	2.0
	$1.4V_{min} \leq V < 0.7V_{max}$			2.6	3.4	2.0
	$0.7V_{max} \leq V \leq V_{max}$		2.6		3.4	2.0

Blank 1. For Class IV-L air vehicles: yaw control pedals shall remain free for Level 1

For Class IV-C air vehicles: yaw control pedals shall remain free for Level 1 in all Flight phase categories and for Level 2 in flight phase Category C

For all other carrier-based air vehicles: yaw control pedals shall remain free for Level 1 and Level 2 in Category C flight phases

For all other Classes of air vehicles: Not applicable

Note that Requirement 3.1.7.1 applies only for Class IV air vehicles and should be deleted if the vehicle under consideration is not a Class IV air vehicle.

Recommended values for table C-VI:

Level	Speed Range	Time to achieve the stated bank angle change (seconds)			
		30°	90°	180°	360°
1	$V_{o_{min}} \leq V < V_{o_{min}}$ + 20 kts	1.0			
	$V_{o_{min}}$+ 20 kts $\leq V < 1.4V_{o_{min}}$		1.4	2.3	4.1
	$1.4V_{o_{min}} \leq V < 0.7V_{o_{max}}$		1.0	1.6	2.8
	$0.7V_{o_{max}} \leq V \leq V_{o_{max}}$		1.4	2.3	4.1
2	$V_{min} \leq V < V_{min}$ + 20 kts	1.6			
	V_{min} + 20 kts $\leq V < 1.4V_{min}$	1.3			
	$1.4V_{min} \leq V < 0.7V_{max}$		1.3	2.0	3.4
	$0.7V_{max} \leq V \leq V_{max}$		1.7	2.6	4.4
3	$V_{min} \leq V < V_{min}$ + 20 kts	2.5			
	V_{min} + 20 kts $\leq V < 1.4V_{min}$	2.0			
	$1.4V_{min} \leq V < 0.7V_{max}$		1.7	3.0	
	$0.7V_{max} \leq V \leq V_{max}$		2.1		

Recommended values for table C-VI:

Level	Speed Range	Time to achieve the stated bank angle change (seconds)			
		30°	50°	90°	180°
1	$V_{o_{min}} \leq V < V_{o_{min}}$ + 20 kts	1.0			
	$V_{o_{min}}$+ 20 kts $\leq V < 1.4V_{o_{min}}$		1.1		
	$1.4V_{o_{min}} \leq V < 0.7V_{o_{max}}$			1.1	2.2
	$0.7V_{o_{max}} \leq V \leq V_{o_{max}}$		1.0		
2	$V_{min} \leq V < V_{min}$ + 20 kts	1.6			
	V_{min} + 20 kts $\leq V < 1.4V_{min}$	1.3			
	$1.4V_{min} \leq V < 0.7V_{max}$			1.4	2.8
	$0.7V_{max} \leq V \leq V_{max}$		1.4		
3	$V_{min} \leq V < V_{min}$ + 20 kts	2.5			
	V_{min} + 20 kts $\leq V < 1.4V_{min}$	2.0			
	$1.4V_{min} \leq V < 0.7V_{max}$			1.7	3.4
	$0.7V_{max} \leq V \leq V_{max}$		1.7		

Recommended values for table C-VI:

Level	Speed Range	Time to achieve the stated bank angle change (seconds)			
		30°	50°	90°	180°
1	$V_{o_{min}} \leq V < V_{o_{min}}$ + 20 kts	1.5			
	$V_{o_{min}}$ + 20 kts $\leq V < 1.4V_{o_{min}}$		1.7		
	$1.4V_{o_{min}} \leq V < 0.7V_{o_{max}}$			1.7	3.0
	$0.7V_{o_{max}} \leq V \leq V_{o_{max}}$		1.5		
2	$V_{min} \leq V < V_{min}$ + 20 kts	2.8			
	V_{min} + 20 kts $\leq V < 1.4V_{min}$	2.2			
	$1.4V_{min} \leq V < 0.7V_{max}$			2.4	4.2
	$0.7V_{max} \leq V \leq V_{max}$		2.4		
3	$V_{min} \leq V < V_{min}$ + 20 kts	4.4			
	V_{min} + 20 kts $\leq V < 1.4V_{min}$	3.8			
	$1.4V_{min} \leq V < 0.7V_{max}$			3.4	6.0
	$0.7V_{max} \leq V \leq V_{max}$		3.4		

REQUIREMENT LESSONS LEARNED (3.1.7 through 3.1.7.2)

See MIL-HDBK-1797.

C.4.1.7 Roll performance verification.

Verification shall be by analysis, simulation, and flight test.

VERIFICATION RATIONALE (4.1.7)

This is a flight safety item. Analysis and simulation should proceed or accompany careful build-up to suspected critical flight conditions.

VERIFICATION GUIDANCE (4.1.7)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.1.7)

See MIL-HDBK-1797.

C.3.1.8 Cross-axis coupling in roll maneuvers.

In yaw-control-free, pitch-control-fixed maximum performance rolls through __(1)__ and rolls which are checked at a given bank angle, entered from straight flight or from turns, pushovers, or pullups ranging from 0g to $0.8n_L$, the resulting yaw or pitch motions and sideslip or angle of attack changes shall neither exceed structural limits nor cause other dangerous flight conditions such as uncontrollable motions or roll autorotation. During combat type maneuvers involving rolls through angles up to __(2)__ and rolls which are checked at a given bank angle, the yawing and pitching shall not be so severe as to impair the tactical effectiveness of the maneuver. Rudder pedal inputs used to roll the air vehicle with lateral control fixed, or when used in a coordinated manner with lateral control inputs, shall not result in departures in pitch, roll, or yaw. These requirements define Levels 1 and 2.

REQUIREMENT RATIONALE (3.1.8)

Both aerodynamic and inertial cross-coupling of pitch and yaw motions with rolling are common for modern air vehicles. The ensuing motions can be violent in nature, leading to prolonged loss of control.

REQUIREMENT GUIDANCE (3.1.8)

Blanks 1 and 2: Class I and Class IV: 360 degrees
Class II and Class III: 120 degrees

REQUIREMENT LESSONS LEARNED (3.1.8)

See MIL-HDBK-1797.

C.4.1.8 Cross-axis coupling in roll maneuvers verification.

Verification shall be by analysis, simulation, and flight test.

VERIFICATION RATIONALE (4.1.8)

See **C.4**.3.1 Verification Rationale.

VERIFICATION GUIDANCE (4.1.8)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.1.8)

See MIL-HDBK-1797.

C.3.1.9 Directional control with speed changes.

When initially trimmed directionally with symmetric power, the trim change with speed shall be such that wings-level straight flight can be maintained over a speed range of __(1)__ of the trim speed or __(2)__, whichever is less, (except where limited by the boundaries of the ROTH) with yaw control pedal forces not greater than the values of table C-IX without retrimming.

TABLE C-IX. Maximum pedal force during speed changes.

Level	Maximum pedal force (pounds)
1	
2	
3	

REQUIREMENT RATIONALE (3.1.9)

This requirement is to insure that speed effects on yawing moment are not unduly distracting.

REQUIREMENT GUIDANCE (3.1.9)

Blank 1. ±30%
Blank 2. ±100 kt equivalent airspeed

Recommendations for table C-IX:

Propulsion Type	Level	Maximum pedal force (pounds)
Propeller	1 and 2	100
	3	180
All others	1 and 2	40
	3	180

REQUIREMENT LESSONS LEARNED (3.1.9)

See MIL-HDBK-1797.

C.4.1.9 Directional control with speed changes verification.
Verification shall be by analysis, simulation, and flight test.

VERIFICATION RATIONALE (4.1.9)

See **C.4**.3.1 Verification Rationale.

VERIFICATION GUIDANCE (4.1.9)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.1.9)

See MIL-HDBK-1797.

C.3.1.10 Directional control in wave-off (go-around).
The response to thrust, configuration, and airspeed change shall be such that the pilot can maintain straight flight during wave-off (go-around) initiated at speeds down to V_S(PA) with yaw control pedal forces not exceeding the values in table C-X when trimmed at $V_{o_{min}}$(PA). Bank angles up to __(1)__ are permitted for all Levels.

TABLE C-X. Maximum yaw control force for wave-off (go-around).

Level	Maximum pedal force (pounds)
1	
2	
3	

REQUIREMENT RATIONALE (3.1.10)

The possibility of large, transient yaw pedal forces being needed on initiation of go-arounds necessitates a limit.

REQUIREMENT GUIDANCE (3.1.10)

Recommended values for C-VIII:

Air Vehicle Class	Level	Maximum pedal force (pounds)
Propeller-driven Class IV and all propeller-driven carrier-based air vehicles	1 and 2	100
	3	180
All others	1 and 2	40
	3	180

Blank 1. Recommended value: 5 degrees

REQUIREMENT LESSONS LEARNED (3.1.10)

See MIL-HDBK-1797.

C.4.1.10 Directional control in wave-off (go-around) verification.

Verification shall be by analysis, simulation, and flight test.

VERIFICATION RATIONALE (4.1.10)

This is a flight safety item. Analysis and simulation should proceed or accompany careful build-up to suspected critical flight conditions.

VERIFICATION GUIDANCE (4.1.10)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.1.10)

See MIL-HDBK-1797.

C.3.1.11 Lateral-directional control in crosswinds.

It shall be possible to take-off and land with normal pilot skill and technique in 90-degree crosswinds, from either side, of velocities up to those specified in table C-XI. Roll control force shall not exceed the limits of table C-XII, and yaw control pedal forces shall not exceed __(1)__ for Level 1 or __(2)__ for Levels 2 and 3.

TABLE C-XI. Crosswind velocity.

Level	Crosswind
1	
2	
3	

TABLE C-XII. Maximum roll control force.

Level	Flight Phase Category	Maximum force (pounds)
1	A and B	
	C	
2	A and B	
	C	
3	All	

C.3.1.11.1 Final approach in crosswinds.

Yaw-and-roll control power shall be adequate to maintain wings level with at least __(3)__ of sideslip in the power approach with yaw control pedal forces not exceeding the values specified in 3.1.11. For Level 1, roll control shall not exceed either __(4)__ of force or __(5)__ of control power available to the pilot. For Levels 2 and 3, roll control force shall not exceed __(6)__.

C.3.1.11.2 Take-off run and landing rollout in crosswinds.

Yaw and roll control power, in conjunction with other normal means of control, shall be adequate to maintain a straight path on the ground or other landing surface during take-off run and landing rollout in calm air and in crosswinds up to the values in table C-XI, with cockpit control forces not exceeding the values specified in 3.1.11. This requirement applies on __(7)__ runways. Aerodynamic control power alone shall be sufficient to maintain control at all airspeeds above __(8)__. For very slippery runways, these requirements need not apply for crosswind components at which the force tending to blow the air vehicle off the runway exceeds the opposing tire-runway frictional forces with the tires supporting all of the air vehicle's weight.

C.3.1.11.3 Additional take-off run and landing rollout requirements for carrier-based vehicles.

All carrier-based air vehicles shall be capable of maintaining a straight path on the ground without the use of wheel brakes, at airspeeds of __(9)__and above, during take-offs and landings in a 90-degree crosswind of at least __(10)__, with cockpit control forces not exceeding the values specified in 3.1.11.

C.3.1.11.4 Taxiing wind speed limits.

It shall be possible to taxi on a dry surface at any angle to a __(11)__ wind.

REQUIREMENT RATIONALE (3.1.11 through 3.1.11.4)

Control power must be available for maneuvering and countering atmospheric disturbances while sideslipping, in the air and on the ground while getting to and from the runway. This requirement assures good yaw-axis flying qualities in crosswind take-offs and landings.

REQUIREMENT GUIDANCE (3.1.11 through 3.1.11.4)

For these requirements, crosswind values should be assumed to be invariant with altitude.

Recommended values for table C-XI:

Level	Class	Crosswind
1 and 2	I	20 kts
	II, III, and IV	30 kts
	Water-based air vehicles	20 kts
3	All	50% of the values for Levels 1 and 2

Recommended values for table C-XII:

Level	Class	Flight Phase Category	Maximum force (pounds)		
			Centerstick	Wheel	Sidestick
1	I, II-C, and IV	A and B	20	40	Forces should not be so large or so small as to be objectionable to the pilot
		C	20	20	
	II-L and III	A and B	25	50	
		C	25	25	
2	I, II-C, and IV	A and B	30	60	
		C	20	20	
	II-L and III	A and B	30	60	
		C	30	30	
3	All	All	35	70	

Recommended values for blanks in 3.1.11:
Blank 1. 100 pounds
Blank 2. 180 pounds

Requirement 3.1.11.1 does not apply for land-based air vehicles equipped with crosswind landing gear or otherwise constructed to land in a large crabbed attitude. For all other air vehicles the recommended values are:
Blank 3. 10 degrees
Blank 4. 10 pounds
Blank 5. 75%
Blank 6. 20 pounds

Recommended values for blanks in 3.1.11.2:
Blank 7. All air vehicles: dry and wet
Air vehicles intended to operate in snow and ice: dry, wet, snow-packed, and icy
Blank 8. For Class IV air vehicles: 50 kts
Class I, Class II, and Class III air vehicles: 30 kts

Note that 3.1.11.3 only applies for carrier-based air vehicles:
Blank 9. 30 kts
Blank 10. $0.10V_S(L)$

Recommended values for 3.1.11.4:

Blank 11. For Class I air vehicles: 35-kt
For Class II, III, and IV air vehicles: 45-kt

REQUIREMENT LESSONS LEARNED (3.1.11 through 3.1.11.4)

See MIL-HDBK-1797.

C.4.1.11 Lateral-directional control in crosswinds verification.

Verification shall be by analysis, simulation, and flight test.

VERIFICATION RATIONALE (4.1.11)

This is a flight safety item. Analysis and simulation should proceed or accompany careful build-up to suspected critical flight conditions.

VERIFICATION GUIDANCE (4.1.11)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.1.11)

See MIL-HDBK-1797.

C3.1.12 Lateral-directional control with asymmetric thrust.

Following sudden asymmetric loss of thrust from any factor, the air vehicle shall be safely controllable in the crosswinds of table C-XI from the unfavorable direction. Requirements 3.1.12 through 3.1.12.6 shall be met for the appropriate flight phases when any single failure or malperformance of the propulsive system including inlet, exhaust, engines, propellers, or drives causes loss of thrust on one or more engines or propellers. Also, the effect of the failure or malperformance on all subsystems powered or driven by the failed propulsive system shall be included when meeting these requirements.

C.3.1.12.1 Thrust loss during take-off run.

It shall be possible for the pilot to maintain control of the air vehicle on the take-off surface following sudden asymmetric loss of thrust from the most critical propulsive source, allowing a realistic time delay of at least __(1)__ between the failure and initiation of pilot corrective action (3.6). Thereafter it shall be possible to achieve and maintain a straight path on the take-off surface without a deviation of more than __(2)__ from the path originally intended, with yaw control pedal forces not exceeding __(3)__. For the continued take-off, the requirement shall be met when thrust is lost at speeds from the refusal speed (based on the shortest runway from which the air vehicle is designed to operate) to the maximum take-off speed with take-off thrust maintained on the operative engine(s), using only controls not dependent upon friction against the take-off surface or upon release of the pitch, roll, yaw, or throttle controls. For the aborted take-off, the requirement shall be met at all speeds below the maximum take-off speed; however, additional controls such as nosewheel steering and differential braking may be used. Automatic devices which normally operate in the event of a thrust failure may be used in either case.

C.3.1.12.2 Thrust loss after take-off.

After liftoff, it shall be possible for the pilot to achieve straight flight without a change in selected configuration following sudden asymmetric loss of thrust from the most critical factor at speeds from V_{min}(TO) to V_{max}(TO), allowing a realistic time delay of at least __(4)__ between the failure and initiation of pilot corrective action (3.6). Thereafter, the pilot shall be able to maintain straight flight throughout the climbout and to perform __(5)__ banked turns with and against the inoperative propulsive unit. The yaw-control-pedal force required to maintain straight flight with asymmetric thrust shall not exceed __(6)__. Roll control shall not exceed either the force limits specified in table C-XII or __(7)__ of available roll control power, with take-off thrust maintained on the operative engine(s) and trim at normal setting for take-off with symmetric thrust. Automatic devices which normally operate in the event of a thrust failure may be used, and the air vehicle may be banked up to __(8)__ away from the inoperative engine.

C.3.1.12.3 Waveoff (go-around).

At any airspeed down to V_{min}(L) it shall be possible to achieve and maintain steady, straight flight with waveoff (go-around) thrust on the remaining engine(s) following sudden asymmetric loss of thrust from the most critical factor. Configuration changes within the capability of the crew while retaining control of the air vehicle, and automatic devices that normally operate in the event of a propulsion failure, may be used.

C.3.1.12.4 Transient effects.

The air vehicle motions following sudden asymmetric loss of thrust shall be such that dangerous conditions can be avoided by pilot corrective action, allowing a realistic time delay of at least __(9)__ between the failure and initiation of pilot corrective action (3.6).

C.3.1.12.5 Yaw controls free.

The static directional stability shall be such that at all speeds above $1.4V_{min}$, with asymmetric loss of thrust from the most critical propulsive source while the other engine(s) develop normal rated thrust, the air vehicle with yaw-control-pedals free can be balanced directionally in steady straight flight. The trim settings shall be those required for wings-level straight flight prior to the failure. Roll control forces shall not exceed the Level 2 upper limits specified in table C-XII for Levels 1 and 2 and shall not exceed the Level 3 upper limits for Level 3.

C.3.1.12.6 Two-engine failures in multi-engine air vehicles (more than two engines).

At the one-engine-out speed for maximum range with any engine initially failed, it shall be possible upon failure of the most critical remaining engine to stop the transient motion and thereafter to maintain straight flight from that speed to the speed for maximum range with both engines failed. In addition, it shall be possible to effect a safe recovery at any service speed above $V_{o_{min}}$(CL) following sudden simultaneous failure of the two most critical failing engines.

REQUIREMENT RATIONALE (3.1.12 through 3.1.12.6)

The transient and steady-state effects of asymmetric thrust must be limited to amounts which can be compensated by pilot control action.

REQUIREMENT GUIDANCE (3.1.12 through 3.1.12.6)

Recommended values for blanks in 3.1.12.1:

Blank 1. 1 second
Blank 2. 30 feet
Blank 3. 180 pounds

Recommended values for blanks in 3.1.12.2:

Blank 4. 1 second
Blank 5. 20-degree
Blank 6. 180 pounds
Blank 7. 75%
Blank 8. 5 degrees

Recommended value for blank in 3.1.12.4.

Blank 9. 1 second

Requirement 3.1.12.6 only applies to multi-engine air vehicles.

REQUIREMENT LESSONS LEARNED (3.1.12 through 3.1.12.6)

See MIL-HDBK-1797.

C.4.1.12 Lateral-directional control with asymmetric thrust verification.

Verification shall be by analysis, simulation, and flight test.

VERIFICATION RATIONALE (4.1.12)

This is a flight safety item. Analysis and simulation should proceed or accompany careful build-up to suspected critical flight conditions.

VERIFICATION GUIDANCE (4.1.12)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.1.12)

See MIL-HDBK-1797.

C.3.1.13 Lateral-directional control with asymmetric loads.

When initially trimmed with each expected asymmetric loading (including hung stores and all asymmetries in normal operation) at any speed in the ROSH, it shall be possible to maintain a straight flight path throughout the ROSH with yaw-control-pedal forces not greater than __(1)__ for Levels 1 and 2 and not greater than __(2)__ for Level 3, without retrimming. For Category A flight phases, with any expected asymmetric loading, roll control power shall be sufficient to hold the wings level at the maximum load factors specified in 3.1.3 with adequate control margin (3.3.13.3).

REQUIREMENT RATIONALE (3.1.13)

This requirement is necessary for service employment. It has flight safety implications.

REQUIREMENT GUIDANCE (3.1.13)

Blank 1.: 100 pounds
Blank 2. 180 pounds

REQUIREMENT LESSONS LEARNED (3.1.13)

See MIL-HDBK-1797.

C.4.1.13 Lateral-directional control with asymmetric loads verification.

Verification shall be by analysis, simulation, and flight test.

VERIFICATION RATIONALE (4.1.13)

This is a flight safety item. Analysis and simulation should proceed or accompany careful build-up to suspected critical flight conditions.

VERIFICATION GUIDANCE (4.1.13)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.1.13)

See MIL-HDBK-1797.

C.3.1.14 Lateral-directional control in dives and pullouts.

Yaw and roll control power shall be adequate to maintain wings level and zero sideslip, without retrimming, in dives to all attainable speeds throughout the RORH and in subsequent pullouts. In the ROTH, roll control forces shall not exceed __(1)__, and yaw control pedal forces shall not exceed __(2)__.

REQUIREMENT RATIONALE (3.1.14)

For safety, roll control power must be adequate to perform any dive maneuvers, not only within the ROTH but also throughout the RORH. Excessive roll control forces in intended symmetric dives and pullouts increase the difficulty of maintaining symmetric flight. Excessive yaw in dives presents both control and structural problems, so any required rudder pedal forces must be within the pilot's capability.

REQUIREMENT GUIDANCE (3.1.14)

Blank 1.: For propeller-driven air vehicles: 20 pounds
For other air vehicles: 10 pounds
Blank 2. For propeller-driven air vehicles: 180 pounds
For other air vehicles: 50 pounds

REQUIREMENT LESSONS LEARNED (3.1.14)

See MIL-HDBK-1797.

C.4.1.14 Lateral-directional control in dives and pullouts verification.
Verification shall be by analysis, simulation, and flight test.

VERIFICATION RATIONALE (4.1.14)

This is a flight safety item. Analysis and simulation should proceed or accompany careful build-up to suspected critical flight conditions.

VERIFICATION GUIDANCE (4.1.14)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.1.14)

See MIL-HDBK-1797.

C.3.2 Dangerous flight conditions.
When approaching dangerous flight conditions at which the air vehicle should not be flown, it shall be possible by clearly discernible means for the pilot to recognize the impending dangers and take preventive action.

C.3.2.1 Dangerous flight conditions following failures.
Whenever failures occur that require or limit any flight crew action or decision concerning flying the air vehicle, the crew member concerned shall be given immediate and easily interpreted indication.

C.3.2.2 Warning and indication.
Warning and indication of approach to a dangerous condition shall be clear and unambiguous.

C.3.2.3 Devices for indication, warning, prevention, and recovery.
As a minimum, special devices incorporated to eliminate dangerous flight conditions shall perform their functions whenever needed but shall not limit the air vehicle's ability to perform the operational maneuvers required of it.

C.3.2.3.1 Operation of devices for indication, warning, prevention, and recovery.
Neither normal nor inadvertent operation of such devices shall create a hazard to the air vehicle.

C.3.2.3.2 Nuisance operation of devices for indication, warning, prevention, and recovery.
For Levels 1 and 2, nuisance operation of these devices shall not be possible.

C.3.2.3.3 Failure of devices for indication, warning, prevention, and recovery.
Functional failure of these devices shall be indicated to the pilot.

REQUIREMENT RATIONALE (3.2 through 3.2.3.3)

Approach to any dangerous flight condition must be clearly apparent to the pilot with sufficient margin (time, control power, etc.) to avoid loss of control. That, together with limiting the frequency of encounter, is the essence of flight safety as it involves flying qualities.

REQUIREMENT GUIDANCE (3.2 through 3.2.3.3)

To Be Prepared

REQUIREMENT LESSONS LEARNED (3.2 through 3.2.3.3)

The need for warning may not become apparent until late in the development program (or after it), and each such device will generally have to be tailored to a specific set of conditions. These requirements clearly apply to stall warning and prevention devices, as well as to other types.

Certain failures may require restriction of the flight envelope in order to assure safety after the failure, or in the event of a subsequent failure. The flight crew needs to be made aware when such a situation exists.

One possible source of danger is the use of special, unconventional control modes for certain tasks. Under stress, a pilot may forget and revert to the normal technique or exceed a limit. For example, a yaw-pointing mode might generate excessive sideslip at low dynamic pressure or too much lateral acceleration at high dynamic pressure. Also, partially or fully automatic modes of flight need to be examined for possible hazards.

Normally, a reasonably reliable limiter or warning need not be redundant. If the pilot knows that the device is inoperative, he can stay well clear of the danger. Nuisance operation not only interferes with mission performance; it breeds disregard or disconnection. Reliance is placed on the flight control system requirements and other requirements to assure sufficient reliability of these devices, warning of their failure, and checkout provisions.
Requirement 3.2.3 is designed to discourage prevention devices that create more problems than they solve.

Stall limiters have proved to be of significant help, as with the F-101B Boundary Control System and the F-16 stall, load factor, and roll limiter, which allow carefree maneuvering up to the set limits. However, an undefeatable limiter is hard to design. If a dangerous pitch-up or locked-in deep stall lurks beyond, some pilot will encounter it. Indeed pilots would rather bend the wings than hit the ground, so a soft limiter may be in order. On the other hand, makers and flyers of air vehicles with no post-stall limitations (e.g., T-38/F-5, F-15) find these extreme AOAs useful occasionally in air combat.

Several C-133 losses over oceans are conjectured to have resulted from starting long-range cruise too close to stall, with no stall warning and a severe roll-off in a power-on stall. The artificial stall warning often was turned off because it was not reliable.

F-16s have been lost in ground attack runs because of deteriorated aerodynamics with external stores. The fix was to change the limits when air-to-ground stores are carried. Although the F-16 uses a pilot-operated switch, this can be done automatically, so that the pilot does not have to remember to switch.

Sensors critical to air vehicle safety should be designed and located for adequate sensing of the appropriate parameters and minimization of exposure to conditions which could produce spurious indications. During development of a ground proximity warning system using an F/A-18 manned flight simulator, the system produced occasional spurious warnings, falsely indicating close proximity to the ground when the condition did not actually exist. The development philosophy was that the production system must not produce spurious indications since such false indications render warning systems useless. The development team recognized that even infrequent occurrences of false warnings would cause the pilot to ignore audible or visual warning cues and delay taking required action until the indication was verified to be genuine through secondary indications. Experience has shown that pilots are also inclined to disable a warning system that emits frequent or even occasional false warning signals. Experience has also demonstrated that the pilot may inadvertently modify flying habits and techniques to prevent a system prone to false indications from enunciating a spurious warning. Any modification to air vehicle operations due to false warning signals will inherently degrade training and operations and may induce poor flying habits that hamper the completion of the mission or safety of the air vehicle. The development team on the ground proximity warning system chose to eliminate nuisance warnings at the expense of reducing protection since the system would be considered ineffective in preventing ground impact if the pilot spends several seconds assessing the validity of the indication.

C.4.2 Dangerous flight conditions verification.

Verification shall be by analysis, simulation, and flight test. Dangerous flight conditions at which the air vehicle should not be flown shall be identified. As part of envelope expansion, the air vehicle will be flown toward these conditions. The pilot shall evaluate the warnings and indications of approach to dangerous flight conditions. The pilot comments shall indicate that these warnings and indications are clear and unambiguous and that they can recognize the impending dangers in time to take preventive action to avoid the dangerous conditions. Since it is not necessary to actually fly into the dangerous flight conditions, air vehicle normal states and extreme states shall be evaluated in flight. Failure states may be evaluated on the simulator if the failures are considered too dangerous to test in flight. During failure evaluations, the pilot, or the crew member concerned, shall evaluate the failure indications. Crew member comments shall indicate that the failure indication is immediate and easily interpreted. The pilot shall evaluate any special devices incorporated to eliminate dangerous flight conditions. Pilot comments shall indicate that these devices perform their functions as necessary but do not limit performance of required operational maneuvers. Pilot comments shall also indicate that operation of these devices is not hazardous to the air vehicle and, for those conditions at which Level 1 and Level 2 flying qualities are required, that operation of these devices does not create a nuisance in flight. Failure indication for each of these devices shall be verified by inspection.

VERIFICATION RATIONALE (4.2)

The procuring and test activities must assess the degree of danger, and their test pilots must agree on the acceptability of devices, air vehicle characteristics, and flight manual warnings.

VERIFICATION GUIDANCE (4.2)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.2)

FTC-TIH-79-2, FTC-TD-73-2, and USNTPS-FTM-103 contain guidance on flight testing for stall/post-stall and other conditions of concern. Former MIL-F-83691 is an Air Force flight test specification and MIL-D-8708 the corresponding Navy specification.

Testing will be necessary to assure that the limiting or warning is satisfactory in all maneuvers and that functional failure of any such devices is indicated to the pilot. Ultimately, flight testing will be required (see, for example, former MIL-F-83691).

C.3.3 Buffet.

Within the boundaries of the __(1)__, there shall be no objectionable buffet which might detract from the effectiveness of the air vehicle in executing its intended missions.

REQUIREMENT RATIONALE (3.3)

The intent of this requirement is to prevent the occurrence of objectionable levels of buffet in the course of operational flight.

REQUIREMENT GUIDANCE (3.3)

Blank 1. Recommended value is ROSH

"Objectionable" is to be interpreted in the context of operational missions: a distraction, or discomfort so great as to interfere with the operational task. For a combat air vehicle the procuring activity may need to extend the requirement to apply throughout the RORH. The extension would apply for example to an air combat fighter intended to have high-AOA capability and to a trainer for spinning.

REQUIREMENT LESSONS LEARNED (3.3)

In those cases where buffet is a signal to the pilot of approach to a dangerous flight condition (3.2.2) some buffet is desirable; but, there should be no need for that within the ROSH.

C.4.3 Buffet verification.

Verification shall be by flight test during the evaluations of 4.3.13.1.1 and 4.3.13.1.2. Within the __(1)__, vertical acceleration due to buffet shall not exceed __(2)__, and pilot comments shall indicate that the buffet is not so objectionable as to detract from the effectiveness of the air vehicle in executing its intended missions.

VERIFICATION RATIONALE (4.3)

Flight testing at elevated AOAs and load factors, and at lower angles transonically, will reveal any buffeting tendencies. A wind-up turn maneuver while tracking a target can be especially useful in identifying buffet regions.

VERIFICATION GUIDANCE (4.3)

Blank 1. Recommended value is Within the ROSH

Blank 2. Recommended value is Vertical acceleration shall not exceed: "$\pm$ .2 g_z about trim."

VERIFICATION LESSONS LEARNED (4.3)

Wind tunnel tests can give early indication of buffet onset and intensity, but flight testing will be needed to determine the end effect with structural vibrations, noise, etc. included.

AGARD-AR-82 contains a concise discussion of buffet and offers some guidelines on the acceptability of various buffet levels:

To the fighter pilot who knows his aircraft, buffet onset is a valuable source of information in moments of intense activity when he is not able to refer to his flight instruments. Of the many different buffet level criteria to be found ... the following is a summary which smoothes out the variations. The “g” values quoted are maximum excursions about trim:

Onset:	+.035 to .1 g_z	perception depends on workload/normal g
Light:	+.1 to .2 g_z	definitely perceptible
Moderate:	+.2 to .6 g_z	annoying
Severe:	+.6 to 1.0 g_z	intolerable for more than a few seconds

Provided that there are no other effects such as loss of full control or random aircraft motions, light buffet usually had no adverse effect on maneuvering, either coarsely or precisely. The average fighter pilot is so used to flying in this region that he may not even comment on it at the lower amplitudes. He will however feel annoyance and frustration when the buffet characteristics reach the level where his ability to track his target is affected; other effects on his performance may result from the arm-mass feedback to the stick and his ability to see the target on his cockpit controls and instruments. At the intolerable level the motion becomes physically punishing and full control is not possible as a result of the effect of the buffet on the pilot himself.

The significance of buffet in air combat depends upon the task. If flight in buffet gives a performance improvement then pilots will use this region during the tactical phase of combat. Tracking will also take place at high buffet levels, even with guns; but when the low-frequency, high-amplitude “bouncing” buffet occurs then there is no further advantage to be gained from operating in this region.

Judgment is subjective, so marginal or critical cases must be evaluated by a number of pilots.

The test loadings selected for the analysis of F/A-18E/F flying qualities during developmental testing were mission representative loadings that were expected to demonstrate the most degraded flying qualities characteristics induced by loading. The typical mission-representative loadings used in F/A-18 flying qualities flight testing were for the Fighter Escort mission and the Interdiction mission. However, the operational test team selected a loading for test that was representative of an air vehicle that had completed weapons delivery. The operational test loading consisted of a centerline fuel tank with empty wing pylons. The particular loading had not previously been tested by the developmental test team. In preparation for operational testing, the developmental test team evaluated this loading in flight and discovered that the air vehicle had a tendency to buffet at transonic airspeeds in this mission-representative loading. This phenomena had not been encountered in the Fighter Escort or Interdiction loadings. Discovering this critical problem with the air vehicle at a relatively late stage in the air vehicle development potentially compromised the entire program. Although it is not economical to flight test all possible loadings, the test loadings must be selected to ensure all store induced anomalies are discovered since dramatic problems, like those discovered during F/A-18E/F testing, may necessitate a design modification that could require repeating substantial flight testing and significantly affect other air vehicle characteristics.

C.3.4 Release of stores.

For Levels 1 and 2, the intentional release or ejection of any stores shall not result in objectionable flight characteristics or impair tactical effectiveness. The intentional release or ejection of stores shall never result in dangerous or intolerable flight characteristics.

REQUIREMENT RATIONALE (3.4)

This requirement is included to insure that stores release or ejection will not have an adverse effect on flying qualities.

REQUIREMENT GUIDANCE (3.4)

To Be Prepared

REQUIREMENT LESSONS LEARNED (3.4)

Because of the variety of possibilities, this requirement must be left qualitative. All store loadings, internal and external, which are specified in the contract are covered. Also, see 3.4.5 and former MIL-HDBK-244 for additional guidance.

C.4.4 Release of stores verification.

Verification shall be by flight test during stores separation testing. Although **C.3**.4 applies for all flight conditions and store loadings at which normal or emergency release or ejection of the store is permissible, testing of all flight conditions and store loadings is impractical, therefore selected air vehicle normal states shall be tested at selected flight conditions throughout the envelope of permissible stores separation for each state. Pilot comments shall indicate that release or ejection of stores does not result in dangerous or intolerable flight characteristics. Where Levels 1 and 2 are required, pilot comments shall indicate that release or ejection of stores does not result in objectionable flight characteristics or impair tactical effectiveness.

VERIFICATION RATIONALE (4.4)

Evaluation of this criterion shall occur as a natural part of operational flight testing, usually preceded by analysis (e.g., AFFDL-TR-74-130, AFWAL-TR-80-3032, and Computational Fluid

Dynamics (CFD) analysis) and wind tunnel testing. The wind tunnel tests may be guided on-line by trajectory calculations using a combination of currently generated and stored data.

VERIFICATION GUIDANCE (4.4)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.4)

There may be special flight envelopes in which store release or missile firing are not permitted. Generally such envelopes are ultimately cleared by flight testing.

Store motion after release is such a function of the local airflow field that few generalities can be made about the most critical conditions. At the same AOA the aerodynamic forces are greater at higher speed. Dive angle, normal acceleration, store location, and store and ejector configuration and loading are important to consider. The critical conditions will likely be at the boundaries of the release envelopes.

C.3.5 Effects of armament delivery and special equipment.

For Levels 1 and 2, operation of movable parts, such as weapons bay doors, cargo doors, armament pods, refueling devices, and rescue equipment, or firing of weapons, release of bombs, or delivery or pick-up of cargo shall not cause buffet, trim changes, or other characteristics which impair the tactical effectiveness of the air vehicle under any pertinent flight condition.

REQUIREMENT RATIONALE (3.5)

This requirement is included to assure that armament delivery, etc., will not adversely affect flying qualities, impairing mission effectiveness.

REQUIREMENT GUIDANCE (3.5)

To Be Prepared

REQUIREMENT LESSONS LEARNED (3.5)

Because of the variety of possibilities, this requirement must be left qualitative. All armament and equipment for the design missions are covered.

See 3.9.1.1 and 3.9.3 for additional guidance.

C.4.5 Effects of armament delivery and special equipment verification.

Verification shall be by flight test during envelope expansion and stores separation testing. For those conditions for which Level 1 or Level 2 flying qualities are required, pilot comments shall indicate that operation of movable parts, firing of weapons, release of bombs, or delivery or pick-up of cargo, does not cause buffet, trim changes, or other characteristics which impair tactical effectiveness of the air vehicle.

VERIFICATION RATIONALE (4.5)

Operational flight tests should be required, preceded by suitable analyses and wind tunnel tests. Generally the critical conditions should thus be known before flight test.

VERIFICATION GUIDANCE (4.5)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.5)

Each movable part needs to be analyzed for its effect on stability and control.

Gun firing can cause deceleration and, depending on lateral and vertical location, attitude transients. It has also been known to interfere with engine-inlet airflow or pilot vision. Rigidity and dynamics of local structure and items attached to it influence the air vehicle vibration resulting from gun firing.

C.3.6 Failures.

No single failure of any component or system or combination of single independent failures shall result in dangerous or intolerable flying qualities; special failure states are excepted. The crew member concerned shall be given immediate and easily interpreted indications whenever failures occur that require or limit any flight crew action or decision. A realistic time delay of at least __(1)__ between the failure and initiation of pilot corrective action shall be incorporated when determining compliance. This time delay shall include an interval between the occurrence of the failure and the occurrence of a cue such as acceleration, rate, displacement, or sound that will definitely indicate to the pilot that a failure has occurred, plus an additional interval which represents the time required for the pilot to diagnose the situation and initiate corrective action. The air vehicle motions following sudden air vehicle system or component failures shall be such that dangerous conditions can be avoided by the pilot without requiring unusual or abnormal corrective action. Failure-induced transient motions and trim changes either immediately upon failure or upon subsequent transfer to alternate modes shall not cause dangerous or intolerable flying qualities. Configuration changes required or recommended following failure shall not cause dangerous or intolerable flying qualities.

C.3.6.1 Transient following failures.

With controls free, the air vehicle motions due to partial or complete failure of any subsystem of the air vehicle shall not exceed the limits of table C-XIV for at least __(2)__ following the failure.

TABLE C-XIV. Transients following failures.

Required Level After Failure	Flight Phase Category	Transient Limits

C.3.6.2 Trim changes due to failures.

Without retrimming, the change in control force required to maintain constant attitude and sideslip following complete or partial failure of the flight control system shall not exceed the limits of table C-XV for at least __(3)__ following the failure.

TABLE C-XV. Control force limits following failures.

Axis of Response	Maximum Control Force Change
Pitch	
Roll	
Yaw	

REQUIREMENT RATIONALE (3.6)

These provisions involve safety of flight. These requirements are intended to assure that the short term response of the air vehicle to a flight control system failure does not cause loss of control before the pilot can react, and that a large effort to maintain control is not required of the pilot. The flight control system includes any stability and control augmentation as well as manual and automatic control and trim functions. In addition to accounting for flying qualities after a failure, we recognize that the transient between the normal and the failed state could result in further flying qualities degradation. Adequate protection for failure transients must be provided in each axis, in case corrective action is delayed even slightly. The transients due to the failure must be small enough to allow the pilot to regain control; and, having done so, to operate at least adequately to terminate the mission (this is implied by requiring Level 3 or better flying qualities following any single failure). However, there should also be limits on the control forces required to minimize these transient responses. Flight control system failures should not cause abrupt or severe changes in the trim state of the air vehicle. The ability to retain reasonable control is measured in terms of demands on the pilot to maintain trim conditions. Limits must be placed on the maximum force to counter trim changes after a failure of any portion of the primary flight control system. Quantitative limits are needed to avoid pilot workload increases and flight safety problems.

REQUIREMENT GUIDANCE (3.6)

Blank 1. Recommended value: 1 sec

A minimum realistic time delay value of 1 sec is consistent with Paragraph 3.3.9.3 in MIL-F-8785C. For civil operation the Federal Aviation Administration (FAA) is more conservative with hardover failures of autopilot servos, requiring 3 seconds before pilot takeover is assumed. This time delay is to include an interval between the occurrence of the failure and the occurrence of a cue such as acceleration, rate, or sound that will definitely indicate to the pilot that a failure has occurred, plus an additional interval which represents the time required for the pilot to diagnose the situation and initiate corrective action. The length of time should correspond to the pilot's likely readiness to respond, for example longer during cruise than at take-off.

NASA-CR-177331 or NASA-CR-177304 present guidance on determining a realistic time delay that seems as applicable to winged air vehicles as it is to rotorcraft. Table C-XVI and the following paragraph are excerpts.

> Pilot response time is especially critical in defining a reasonable minimum pilot intervention delay time to a failure. The status of the pilot in the overall task of controlling the rotorcraft can be described as active or attended control operation, divided attention control operation (both hands on the controls and hands off), or unattended control operations such as in autopilot mode (both hands on and hands off the control). For example, if the pilot is making a final approach to a landing, he would be considered to be in an attended operation mode of rotorcraft control with his hands on the controls. Should an automatic flight control failure occur, the minimum pilot response time for corrective control input following recognition of the failure would be quite small, approximately half a second. Therefore, for testing the acceptability of failures in this mode of flight it would be unreasonable to require testing (or specification) of a minimum allowable response time any greater than ½ second. However, for cross-country flight at cruise speeds, it is very possible that the pilot will not have his hands on the control if an autopilot is engaged. For failures which have a significant probability of occurrence in this flight mode, the specification of ½ second pilot response time for test purposes would be unreasonable and unsafe. In this standard, therefore, the minimum allowable pilot response time would be adjusted to 2½ seconds following any single failure.

TABLE C-XVI. Example of alternate minimum allowable intervention times for system failures.

Phase of Flight	Rotorcraft Response $t_1 - t_0$*	Pilot Response $t_2 - t_1$**	Minimum Allowable Intervention Delay Time and Method of Test
Attended Operation	Time for rotorcraft to achieve change of rate about any axis of 3 deg/sec or The time to reach a change of "g" in any axis of .2 or For an attention getter to function	½ second	System failures will be injected without warning to the pilot. His ability to recover as rapidly as possible without a dangerous situation developing will be used to assess system failure mode acceptability.
Divided Attention Operation Hands On	Time for rotorcraft to achieve change of rate about any axis of 3 deg/sec or The time to reach a change of "g" in any axis of 0.2 or	1½ seconds (Decision 1 + reaction ½)	The pilot will be warned of the system failure. Demonstration of compliance must show that an intervention delay time equal to 1½ seconds plus ($t_1 - t_2$) can be tolerated.
Divided Attention Operation Hands Off	For an attention getter to function	2½ seconds (Decision 1½ + reaction 1)	As above but intervention delay time 2½ seconds plus ($t_1 - t_0$)
Unattended Operation Hands On	As above but the threshold rates and "g" values are 5 deg/sec and 0.25 respectively	2 ½ seconds (Decision 2 + reaction ½)	As above
Unattended Operation Hands Off		4 seconds (Decision 3 + reaction 1)	As above but intervention delay time 4 seconds plus ($t_1 - t_0$)

*ROTORCRAFT RESPONSE TIME INTERVAL ($t_1 - t_0$). This is the period between the failure occurring and the pilot being alerted to it by a suitable cue. The cue may take the form of an adequate tactical, audio, or visual warning. (The eye cannot be relied upon to distinguish abnormal instrument indications sufficiently early for these to be regarded as an adequate cue.) In the absence of the adequate cues listed above, it can be assumed that a pilot will be alerted when the rotorcraft meets or exceeds the responses listed for unattended operation.

**PILOT RESPONSE TIME INTERVAL ($t_2 - t_1$). The period commences at the time the pilot is alerted to the fact that something abnormal is happening and terminates when the controls are moved to commence the recovery maneuver. The period consists of the recognition time, decision time, and reaction time. As shown above, the recognition and decision times are assumed to increase as the pilot relaxes his level of involvement, i.e., in going from "attended operation" to "unattended operation" and also going from "hands on" to "hands off". The reaction time is longer "hands off" than "hands on" as the pilot has to locate the controls before he can move them.

Recommended values for table C-XIII:

Required Level After Failure	Flight Phase Category	Transient Limits
1 and 2	B and C	No more than ±.5 g incremental normal and lateral acceleration at the pilot's station; No more than ±10°/sec roll rate; Neither stall AOA nor structural limits shall be exceeded
	A	No more than ±.5 g incremental normal and lateral acceleration at the pilot's station; No more than ±10°/sec roll rate; Vertical and lateral excursions no more than ±5 feet; No more than ±2 degrees of bank angle; Neither stall AOA nor structural limits shall be exceeded
3	All	No dangerous attitude or structural limit is reached, and no dangerous alteration of the flightpath results from which recovery is impossible

Blank 2. Recommended value: 2 seconds

Worst-case flight conditions should be identified and tested. High control effectiveness, authority, and gain; low or negative static stability or damping; low weight and inertia will tend to make the transients larger. Generally a dynamic analysis is needed, but constant speed can be assumed for the two-second period of time.

Recommended values for table C-XV:

Axis of Response	Maximum Control Force Change
Pitch	20 lbs*
Roll	10 lbs
Yaw	50 lbs

*While 20 lbs is within the capability of all pilots, a lower value may better accommodate females.

Blank 3. Recommended value: 5 seconds

Any failures specified under 3.3.13.1.3.2 should be evaluated in flight testing at the most critical flight conditions. Other failures and worst-case flight conditions will be found from the Failure Modes and Effects Analyses of 3.3.13.1.3.1. The location of critical points in the flight envelope is highly dependent on the aerodynamic and flight control system configurations.

Some failures may be considered too dangerous to flight test. For those failures and flight conditions judged to be too hazardous to evaluate in flight, demonstration likely will be by simulation. Validated models of the air vehicle and its flight control system will be needed for this, and adequate motion cues should be available to simulate the acceleration environment with one-to-one fidelity for at least two seconds following the failure. Where final demonstration is by simulation, flight-validated aerodynamic data should be used with actual flight hardware and software loaded as necessary to replicate the response in flight.

REQUIREMENT LESSONS LEARNED (3.6)

Air vehicles have been lost from runaway trim. That possibility needs careful consideration for every powered trim system.

The transient motion limits were taken from paragraph 3.5.5.1 of MIL-F-8785C. Although the intent of the requirement is to insure that dangerous flying qualities never result, there may be some benefit to a noticeable transient after a failure, or after transfer to an alternate control mode, in order to alert the pilot to the change. That possibility is left to the designer without explicit direction to minimize transients. This requirement also places quantitative limits on the altitude change, effectively restricting the 2-second average acceleration in addition to the peak value. The 2-second interval is to account for crew distraction and the possible need for time to determine and accomplish corrective action.

The revision to MIL-F-8785C followed the recommendations of Systems Technology Inc. TR-189-1: the authors noted that the allowable transient levels of MIL-F-8785B were consistent with failure probability considerations, but not with flying qualities considerations. Level 2 had a lower probability of occurrence than Level 1 and was permitted to have larger transient responses; however, Level 2 is a poorer handling qualities state and cannot accept the larger responses as readily. It was felt that the values in MIL-F-8785C were representative of transients which could be handled with Level 1 flying qualities. Conversely, the low allowable transients of MIL-F-8785B were conducive to soft failures which could lead to catastrophic situations if undetected by the pilot. This comment applied to the B-58 in particular, and lead General Dynamics/Fort Worth to suggest a minimum allowable transient (according to Systems Technology Inc. TR-189-1). This has not been incorporated into this document, but should be a consideration in the design process.

The control force limits are consistent with the data of AFAMRL-TR-81-39. It seems reasonable to state a time limit during which this requirement applies. Zero to two seconds generally should be a rational range of times for a pilot to react (whether he is set for the failure or taken unawares), and it should be possible to retrim after 5 seconds.

C.4.6 Failures verification.

Verification shall be by analysis during the FMECA and FMET and by evaluation in simulation and flight test. For conditions which are considered too dangerous to test in flight, verification can be shown in a manned simulation. Proof of compliance in these demonstration tasks will consist of pilot comments. Pilot comments shall indicate that no single failure of any component or system results in dangerous or intolerable flying qualities and that transients following sudden failures do not require unusual or abnormal corrective action to avoid dangerous conditions. Crew member comments shall indicate that failure indications are immediate and easily interpreted.

VERIFICATION RATIONALE (4.6)

This requirement limits the severity of failures on controllability until corrective action can be taken, avoiding a possible flight safety problem.

VERIFICATION GUIDANCE (4.6)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.6)

For flight testing, it may be necessary to provide the test air vehicle with special means of introducing failures. Analysis or simulation should precede such flight tests in order to avoid excessively risky combinations of failure and flight condition. Testing of failure modes – in flight or simulation – should always include consideration of demands on the pilot to retrim manually.

C.3.7 Pilot-in-the-loop oscillations.

There shall be no tendency for pilot-in-the-loop oscillations, that is unintentional sustained or uncontrollable oscillations resulting from the efforts of the pilot to control the air vehicle.

REQUIREMENT RATIONALE (3.7)

The purpose of this requirement is to insure that abrupt maneuvers or aggressive tracking behavior will not result in instabilities of the closed-loop pilot-vehicle system. Any such tendency will degrade or even destroy mission effectiveness and likely will be dangerous.

REQUIREMENT GUIDANCE (3.7)

To Be Prepared

REQUIREMENT LESSONS LEARNED (3.7)

Likely causes are equivalent time delay, control system friction, inappropriately-located zeros of air vehicle transfer functions, or nonlinearities such as rate limiting, hysteresis, and abrupt control system gain changes. NORAIR Rpt No. NOR-64-143 discusses a number of possible PIO mechanisms.

This requirement precludes PIO tendencies or general handling qualities deficiencies resulting from inadequate pilot-vehicle closed-loop gain and phase margins. PIO has occurred in the T-38A, A4D, and YF-12 due to abrupt amplitude-dependent changes in air vehicle dynamic response to pilot control inputs. These effects can be of mechanical origin, e.g., bobweights coupled with static friction, or due to saturation of elements within the control system, or due to compensation added to the automatic control system. Other known sources are short-period dynamics (e.g., large $\omega_{sp} T_{\theta_2}$), feel system phasing (e.g., effective bobweight location not far enough forward), and sensitive control force and motion gradients. AFFDL-TR-69-72 and NORAIR Rpt NOR-64-143 can furnish some insight.

A very good summary report on PIOs is given in NOR-64-143. Table C-XVII, from NOR-64-143, lists some known PIO cases and their probable causes for then current (early 1960s) air vehicles. The causes are equally relevant for modern air vehicles and the lessons learned from these cases are valuable in preventing PIOs.

C.4.7 Pilot-in-the-loop oscillations verification.

Verification shall be by analysis, simulation, and flight test in the performance of the tasks of 4.3.13.1.1, 4.3.13.1.2, 4.3.13.1.3.2, and 4.3.13.1.3.3 under various levels of atmospheric disturbances. Final verification shall be by flight test of the following tasks: ___(1)___.

VERIFICATION RATIONALE (4.7)

The need to use high-gain, closed-loop tasks to evaluate handling qualities is fully discussed in the Verification Rationale of 4.3.13.1.1. An additional reason, if any more are needed, is that most of the open-loop design criteria assume a linear system. Pilot evaluation in high-gain, closed-loop tasks is at this time the best evaluation of the effects of nonlinearities. This is particularly important in the evaluation of PIO tendencies because nonlinearities, such as rate limiting, hysteresis, abrupt gain changes, and aerodynamic nonlinearities are some of the common causes of PIO.

VERIFICATION GUIDANCE (4.7)

Blank 1. Based on the following discussions and the number of tasks selected, complete by listing each task.

PIOs are associated with abrupt maneuvers and precise tracking as in air-to-air gunnery, formation flying, flare, and touchdown. Tight, aggressive pilot control action will tend to bring on any PIO tendency. High sensitivity to control inputs is often a factor. Some pilots are better at exposing PIO tendencies than others, depending upon piloting technique.

Ground-based simulation may or may not show up any PIO tendencies. Flight evaluation in variable-stability air vehicles is a valuable tool. Final determination will come from flight test of the actual vehicle.

The recommended tasks to demonstrate compliance with this requirement are the tasks described in Verification Guidance of 4.3.13.1.1 using the HQDT technique. AFFTC makes a distinction between HQDT and "operational" closed-loop evaluation tasks. The key element of the HQDT technique is that the pilot must attempt to totally eliminate any error in the performance of the task; he adopts the most aggressive control strategy that he can. Adequate and desired performance objectives are not defined and Cooper-Harper ratings are not recommended. The reason for this is that, in the "operational" tasks, definition of adequate and desired performance encourages the pilot to adopt a control strategy which best meets these performance objectives. In the case of a PIO-prone air vehicle, attempting to totally eliminate any deviation may induce oscillations which reduce task performance, but by accepting small errors (reducing pilot gain) the pilot may be able to avoid these oscillations and still meet the performance objectives (which, by their definition, allow such a tactic). The HQDT technique does not allow the pilot to do this, thus exposing any possible handling qualities deficiencies. HQDT could be considered a "stress test" of handling qualities. For this reason, the HQDT technique is considered the best test of PIO tendencies.

TABLE C-XVII Classification of some known PIO cases (from NOR-64-143).

Examples shown as: SPECIES (Air vehicle); Critical Subsystem*; Critical Flight Condition**: Remarks

CLASS	TYPE: I. LINEAR	TYPE: II. SERIES NONLINEAR ELEMENTS	TYPE: III. SUBSIDIARY FEEDBACK NONLINEAR ELEMENTS
PITCH	IMPROMPER SIMULATION; D, V; a: Abnormally high value of $1/T_{\theta_2}$ and low $(\zeta\omega)_{sp}$ led to zero ζ_{sp} when regulating large disturbances. GCA-INDUCED PHUGOID (C-97); D; c, b: Lag from radar-detected error to voice command led to unstable closed-loop phugoid mode. ARM ON STICK (A4D-1, T-38A); F; a: Arm mass increases feel system inertia, leads via B feedback to unstable coupling with short-period dynamics if pilot merely hangs loosely onto stick after a large input.	PORPOISING (SB2C-1); F; c: Hysteresis in stick versus elevator deflection resulted in low-frequency speed and climb oscillations. J. C. MANEUVER (F-86D, F-100C); F, S; a: Valve friction plus compliant cabling resulted in large oscillations at short period. PITCH-UP (XF-104, F-101B, F-102A); V; c: Unstable kink in $M(\alpha)$ curve led to moderate-period oscillations of varying amplitudes (depending on extent and nature of the kink) during maneuvers near the critical angle-of-attack. LANDING PIO (X-15); S; b: Closed loop around elevator rate limiting caused moderate oscillations at short-period.	BOBWEIGHT BREAKOUT (A4D-1, T-38A): F, B; a: At high-g maneuvers the bobweight overcomes system friction and reduces apparent damping of the air vehicle in response to force inputs, resulting in large oscillations at short-period. LOSS OF PITCH DAMPER
LATERAL-DIRECTIONAL	ω_f/ω_d EFFECT (X-15, NT-33A, F-101B, F-106A, KC-135A, B-58); V; c: Zeros of roll/aileron transfer function are higher than Dutch roll frequency, $\lvert \omega_f/\omega_d \rvert > 1.0$, leading to closed-loop instability at low ζ_d conditions. BORESIGHT OSCILLATIONS (F-5A); D, V; c: Spiral roll mode driven unstable if roll information is degraded during gunnery.		LOSS OF YAW DAMPER
YAW	FUEL SLOSH SNAKING (KC-135A, T-37A); V; c: Fuel slosh mode couples with Dutch roll mode when rudder used to stop yaw oscillation.	TRANSONIC SNAKING (A3D); V, F; a,c: Separation over rudder causes control reversal for small deflections, leading to limit cycle if rudder used to damp yaw oscillations.	
ROLL	NONE KNOWN	PILOT-INDUCED CHATTER (F-104B); A; c: Small limit cycle due to damper aggravated whenever pilot attempted to control it.	

* Critical Subsystems:
D = Display
F = Feel system (except B)
B = Bobweight
S = Power servo actuator
V = Vehicle (airframe)
A = Augmentor (damper)

** Critical Flight Conditions:
a = Low altitude, near-sonic Mach
b = Landing approach and take-off
c = Cruise

HQDT is not exclusively a PIO evaluation technique. It is a general handling qualities evaluation technique. It is discussed in more detail here in the PIO requirement because it is a better PIO evaluation technique than the "operational" technique. On the other hand, the "operational" technique uses performance objectives more representative of operational use, and the C-H ratings provide a quantitative measure of flying qualities which can be related to the required Levels. Therefore, use of both techniques is recommended in the flight test evaluation, as well as parameter identification techniques and capture tasks. As mentioned in the Verification Rationale of 4.3.13.1.1, the recommended parts of the handling qualities evaluation are: 1) steps, doublets, and frequency sweeps for parameter identification and comparison to open-loop requirements, 2) capture tasks for pilot familiarization with air vehicle dynamic response and evaluation of gross acquisition, 3) HQDT for initial handling qualities and PIO evaluation (HQDT may also provide good inputs for frequency-domain analysis), and 4) "operational" tasks for handling qualities evaluation with C-H ratings.

The PIO tendency classification scale shown in figure C-3 has been developed specifically for evaluation of PIO tendencies. It can be used with either the HQDT or the "operational" techniques. Comparing the PIO rating descriptions with descriptions of Levels of flying qualities, a rough approximation would be: PIO ratings of 1 or 2 would be Level 1, PIO ratings of 3 or 4 would be Level 2, and a PIO rating of 5 would be Level 3. A PIO rating of 6 would be extremely dangerous.

Tom Twisdale provides some guidance on possible HQDT tasks:

> Probably any test maneuver that allows the evaluation pilot to aggressively and assiduously track a precision aim point is a suitable HQDT test maneuver. In HQDT testing, the test maneuver is not nearly as important as the piloting technique. It is the piloting technique that increases the evaluation pilot's bandwidth and makes possible a good handling qualities evaluation. For this reason there is no exclusive catalog of HQDT maneuvers. The ones discussed below have worked well, but others, perhaps better suited to a particular airplane, may be invented as the need arises.

Air-to-Air HQDT

> Air-to-air HQDT involves tracking a precision aim point on a target airplane while using a fixed, or non-computing gunsight. There are three main variations of air-to-air HQDT: constant load factor HQDT at a constant range of about 1500 feet; wind-up turn HQDT at a constant range of about 1500 feet; and HQDT while closing on the target.

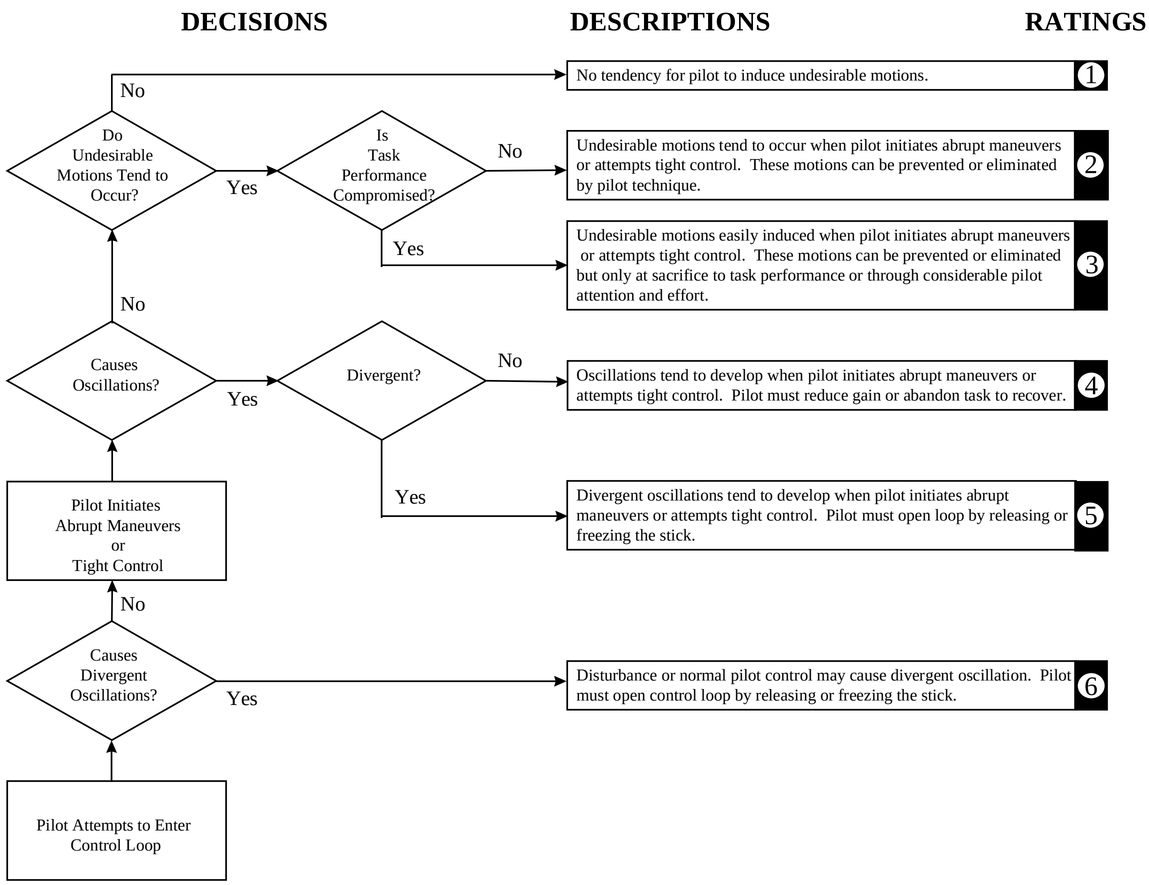

FIGURE C-3. PIO tendency classification.

The purpose of a constant load factor air-to-air HQDT maneuver is to evaluate handling qualities at a specific angle of attack. The maneuver begins with the test airplane positioned 1500 feet behind and offset above, or below, or to the inside of the target. The offset position is helpful in avoiding jet-wake encounters. At the evaluation pilot's signal the target pilot rolls smoothly into a turn and slowly increases load factor until the test load factor is attained. A g onset rate of two seconds or so per g is satisfactory. When the test load factor has been attained the target pilot calls "on condition" and maintains the turn and the test conditions for the specified period of time, which will depend on the test and analysis objectives. During the load factor build-up the evaluation pilot turns on the airborne instrumentation system and positions the target airplane 50 mils or so from the pipper or aiming index at a clock position of 1:30, 4:30. 7:30, or 10:30. After the target pilot calls "on condition" the evaluation pilot calls "tracking" and drives the pipper toward the precision aim point to initiate the evaluation. The evaluation pilot continues to track while using the HQDT piloting technique, until the target pilot or other aircrew or the control room calls "time". However the maneuver is not concluded until the evaluation pilot calls "end tracking". At that time the target pilot rolls out of the turn.

The constant load factor air-to-air HQDT maneuver may be a constant turn to the left or right, or turn reversals may be included. When reversals are included they should be performed at constant load factor. The evaluation pilot continues to track the precision aim point throughout the reversal, always using the HQDT piloting technique.

The evaluation pilot should maintain a 1500 foot separation from the target airplane. Variations of a few hundred feet either way are permissible, but range to the target should not be allowed to exceed 2000 feet. Range may be determined stadiometrically with adequate accuracy.

The purpose of a wind-up turn air-to-air HQDT maneuver is to quickly explore handling qualities across a range of angle of attack. The maneuver gets under way when the target pilot establishes the test conditions and calls "on condition". The evaluation pilot positions the test airplane 1500 feet behind and offset above, or below, or to the inside of the target. The offset position is helpful in avoiding jet-wake encounters. The evaluation pilot turns on the airborne instrumentation system and positions the target airplane 50 mils or so from the pipper or aiming index at a clock position of 1:30, 4:30, 7:30, or 10:30. The evaluation pilot then signals the target pilot to begin the maneuver. The target pilot rolls smoothly into a turn and slowly increases load factor at a g onset rate of five or six seconds per g. As the target airplane begins rolling into the wind-up turn, the evaluation pilot calls "tracking" and drives the pipper toward the precision aim point to initiate the evaluation. The evaluation pilot continues to track while using the HQDT technique, until the target pilot attains the target load factor and calls "target g". The target load factor is maintained until the evaluation pilot calls "end tracking". At that time the target pilot may unload and roll out of the turn.

The evaluation pilot should maintain a 1500 foot separation from the target airplane. Variations of a few hundred feet either way are permissible, but range to the target should not be allowed to exceed 2000 feet. Range may be determined stadiometrically with adequate accuracy.

In HQDT with closure, the evaluation pilot slowly closes on the target airplane while tracking. The purpose of the closing HQDT maneuver is to help the evaluation pilot distinguish attitude dynamics from normal and lateral acceleration dynamics. Attitude dynamics are evident at any tracking range, but translation caused by normal and lateral acceleration become more noticeable as the evaluation pilot closes on the target.

In a closing HQDT maneuver the target airplane may either fly straight and level, maneuver gently in pitch and roll, or perform a constant load factor turn. Gently maneuvering or a constant load factor turn is often preferred because it helps to increase the evaluation pilot's bandwidth. In all other respects the closing maneuver is similar to a constant load factor or wind-up tracking turn.

The closing HQDT maneuver can begin once the target pilot has established the test conditions and calls "on condition". The evaluation pilot positions the test airplane 1500 feet behind and above, below, or to the inside of the target; turns on the airborne instrumentation system; and positions the target airplane 50 mils or so from the pipper or aiming index at a clock position of 1:30, 4:30, 7:30, or 10:30. The evaluation pilot then signals the target pilot to begin the maneuver. The target pilot flies straight and level; or begins to maneuver gently and randomly in pitch and roll; or performs a constant load factor turn. The evaluation pilot calls "tracking" and drives the pipper toward the precision aim point to initiate the evaluation. The evaluation pilot continues to track, using the HQDT technique, while slowly closing on the target airplane. The rate of closure will depend on the desired tracking time (which will depend on the test and analysis objectives). The evaluation pilot may find it easier to control the rate of closure if the control room or the target pilot or other aircrew announce the elapsed time in five second increments. At the end of the specified tracking time, the target pilot or other aircrew or the control room calls "time". However the maneuver is not concluded until the evaluation pilot calls "end tracking".

Power Approach HQDT

Power approach HQDT is air-to-air HQDT performed with the test airplane configured for power approach. This maneuver is designed to evaluate approach and landing handling qualities at a safe altitude (10,000 to 15,000 feet), rather than a few feet above the ground during a real landing. Power approach HQDT may be flown with or without closure, however closure is a desirable feature because it helps the evaluation pilot distinguish between attitude and translation dynamics.

The target airplane may either fly straight and level or maneuver gently in pitch and roll. Maneuvering gently is often preferred because it helps to increase the evaluation pilot's bandwidth. In all other respects the power approach HQDT maneuver is similar to a closing HQDT maneuver.

Closure during the maneuver is useful for distinguishing attitude dynamics from normal and lateral acceleration dynamics. Attitude dynamics are evident at any tracking range, but translation caused by normal and lateral acceleration become more noticeable as the evaluation pilot closes on the target.

Jet-wake encounters are a frequent source of difficulty during power approach HQDT testing. Simple geometry, together with a maneuvering target airplane, make jet-wake encounters difficult to avoid. The slow speeds introduce the risk that a jet-wake encounter will precipitate a stall or departure, although this has never occurred. There are two solutions to the problem of jet-wake encounters. One is to use a small propeller-driven airplane as a target. Excellent candidates are the T-34C or Beechcraft Bonanza, or similar airplanes. These airplanes can easily match the slowest speeds of most military airplanes, and they produce very little propwash. The second solution is to use a target that is programmed into a flight test head-up display, similar to the head-up display used on the Calspan NT-33.

Air-to-Ground HQDT

Air-to-ground HQDT involves tracking a precision aim point on the ground with a fixed, or non-computing gunsight. Shallow or steep dive angles may be used. Shallow dive angles approximate strafing attack profiles and steeper angles approximate ballistic weapons delivery profiles.

The evaluation pilot trims the airplane at the specified dive entry altitude and airspeed, turns on the airborne instrumentation system, calls "on condition", and rolls or pitches to the specified dive angle. When the outer ring of the gunsight reticle crosses the precision aim point, the evaluation pilot calls "tracking" and commences to track the precision aim point using the HQDT piloting technique. The evaluation pilot continues to track until the recovery altitude is reached, then calls "end tracking" and recovers from the dive.

A useful variation, on the basic maneuver is to track two or more precision aim points, instead of one. For example, precision aim points may be positioned at each apex of an imaginary isosceles triangle laid out on the ground. This triangle has a base of 100 feet and a height of 375 feet (for 15 degree dive angles) or a height of 100 feet (for 45 degree dive angles). During the maneuver the evaluation pilot randomly switches from one precision aim point to another, perhaps at a signal from the control room.

Boom Tracking HQDT

In boom tracking, the evaluation pilot tracks the nozzle on an aerial refueling boom. This maneuver is designed to explore aerial refueling handling qualities without the risk of close proximity to a tanker and a refueling boom.

The tanker airplane establishes the test conditions of Mach number (or airspeed) and altitude and maintains them during the test maneuver. The boom operator positions the refueling boom at zero degrees of azimuth and a midrange elevation angle. When the test conditions have been established the tanker pilot or the boom operator call "on condition". The evaluation pilot moves the test airplane into position a short distance behind the nozzle (20 to 50 feet) and positions the nozzle about 50 mils from the pipper or aiming index at a clock position of 1:30, 4:30, 7:30, or 10:30. To begin the maneuver, the evaluation pilot turns on the airborne instrumentation system, calls "tracking", and drives the pipper toward the nozzle. The evaluation pilot continues to track the nozzle, using the HQDT piloting technique, while the boom operator randomly maneuvers the refueling boom in azimuth and elevation. The boom motion should be a combination of gently and abrupt changes in rate and position. After the specified period of tracking time (which will depend on the test and analysis objectives) has elapsed, the control room or another crew member calls "time". The maneuver is not concluded, however, until the evaluation pilot call "end tracking".

Formation HQDT

In formation HQDT, the evaluation pilot attempts to maintain a precisely defined position relative to the lead airplane during a series of gentle maneuvers. Properly done, formation HQDT can highlight for the evaluation pilot the vertical and lateral translation dynamics of the test airplane. This maneuver is also useful for evaluating the throttle response of the airplane. Care must be taken not to force the evaluation pilot to fly too close to the lead airplane. Close proximity can increase bandwidth, but too close proximity can reduce it. As the separation between airplanes narrows, good and prudent pilots will reduce their bandwidth to reduce the risk of collision.

VERIFICATION LESSONS LEARNED (4.7)

The existence of a PIO tendency is difficult to assess. Attention to flying qualities per se during flight control design will take care of many potential problems. PIOs may occur early in the air vehicle life as on the YF-16 high-speed taxi test that became airborne before its first scheduled flight, or later in service, as with the T-38 as more pilots flew it. If PIO is not found readily, it should be sought during the flight test program. High-stress tasks such as approach and landing with a lateral offset, air-to-air tracking, air-to-ground tracking, or terrain following may reveal PIO proneness.

Depending upon the cause, ground-based simulation may or may not prove a useful investigation technique – often it does not. PIOs observed in flight are often not obtained in ground-based simulators, even simulators with some motion. In a number of cases, optimization of p/F_{as} in a fixed-base simulator has resulted in gross oversensitivity in actual flight.

C.3.8 Residual oscillations.

Any sustained air vehicle residual oscillations in calm air shall not interfere with the pilot's ability to perform all flight phase tasks required in service use of the air vehicle. For Levels 1 and 2, with pitch control fixed and with it free, any sustained residual oscillations in calm air shall not exceed __(1)__ in normal acceleration at the pilot station for any flight phase.

REQUIREMENT RATIONALE (3.8)

The requirement prohibits limit cycles in the control system or structural oscillations that might compromise tactical effectiveness, cause pilot discomfort, etc.

REQUIREMENT GUIDANCE (3.8)

Blank 1. The recommended value is $\pm.02$ g. Given the proper data, this threshold could be made a function of frequency in order to correspond more closely with human perception.

REQUIREMENT LESSONS LEARNED (3.8)

Former MIL-STD-1797 decreased the allowable normal acceleration oscillations to ±0.02 g from the ±0.05 g of MIL-F-8785C. This is based on flight test experience with the B-1 (AFFTC-TR-79-2), which encountered limit cycle oscillations during aerial refueling, subsonic and supersonic cruise. A primary contributor was identified to be mechanical hysteresis in the pitch system. According to AFFTC-TR-79-2, "Flying qualities were initially undesirable due to this limit cycle". Normal acceleration transients were about 0.05 to 0.12 g, as figure C-4 shows. The limit cycle was eliminated by installation of a mechanical shaker (dither) vibrating at 20 Hz.

Residual oscillations are limit cycles resulting from nonlinearities such as friction and poor resolution. Negative static stability will contribute and low damping may augment the amplitude. Thus high speed, high dynamic pressure, or high altitude may be critical. Residual oscillations are most bothersome in precision tasks.

Likely causes are flight control system nonlinearities such as valve friction or, especially in unpowered flight control systems, control system friction, or hinge-moment nonlinearities. The X-29A, an unstable basic air vehicle, exhibited very noticeable control-surface activity during ground roll. This was a result of a compromise which kept the stability and control augmentation active on the ground in order to assure flight safety in the event of bouncing or early lift-off.

C.4.8 Residual oscillations verification.

Verification shall be by analysis and by simulation or flight test in the performance of the tasks of 4.3.13.1.1, 4.3.13.1.2, 4.3.13.1.3.2, and 4.3.13.1.3.3 in calm air. These tasks will be flown by test pilots at specific flight conditions throughout the ROSH and ROTH. The specific flight conditions to be evaluated shall be the most common operating conditions, any operating conditions critical to the mission of the air vehicle, and any conditions determined by analysis or simulation to be worse than the Level of flying qualities required by table C-I. Proof of compliance in these demonstration tasks will consist of time histories of normal acceleration, pilot comments, and C-H ratings. The comments and ratings shall indicate that the flying qualities are no worse than the required Level of flying qualities for each combination of air vehicle state and flight phase.

VERIFICATION RATIONALE (4.8)

In order to insure that the air vehicle has achieved the required Levels of flying qualities, the air vehicle must be evaluated by pilots in high-gain, closed-loop tasks. (In the context of 3.3.13, high-gain task means a wide-bandwidth task, and closed-loop means pilot-in-the-loop.) For the most part, these tasks must be performed in actual flight. However, for conditions which are considered too dangerous to attempt in actual flight (e.g., certain flight conditions outside the ROTH, flight in Extraordinary atmospheric disturbances, flight with certain failure states and special failure states, etc.), the closed-loop evaluation task can be performed in a simulator..

VERIFICATION GUIDANCE (4.8)

To Be Prepared

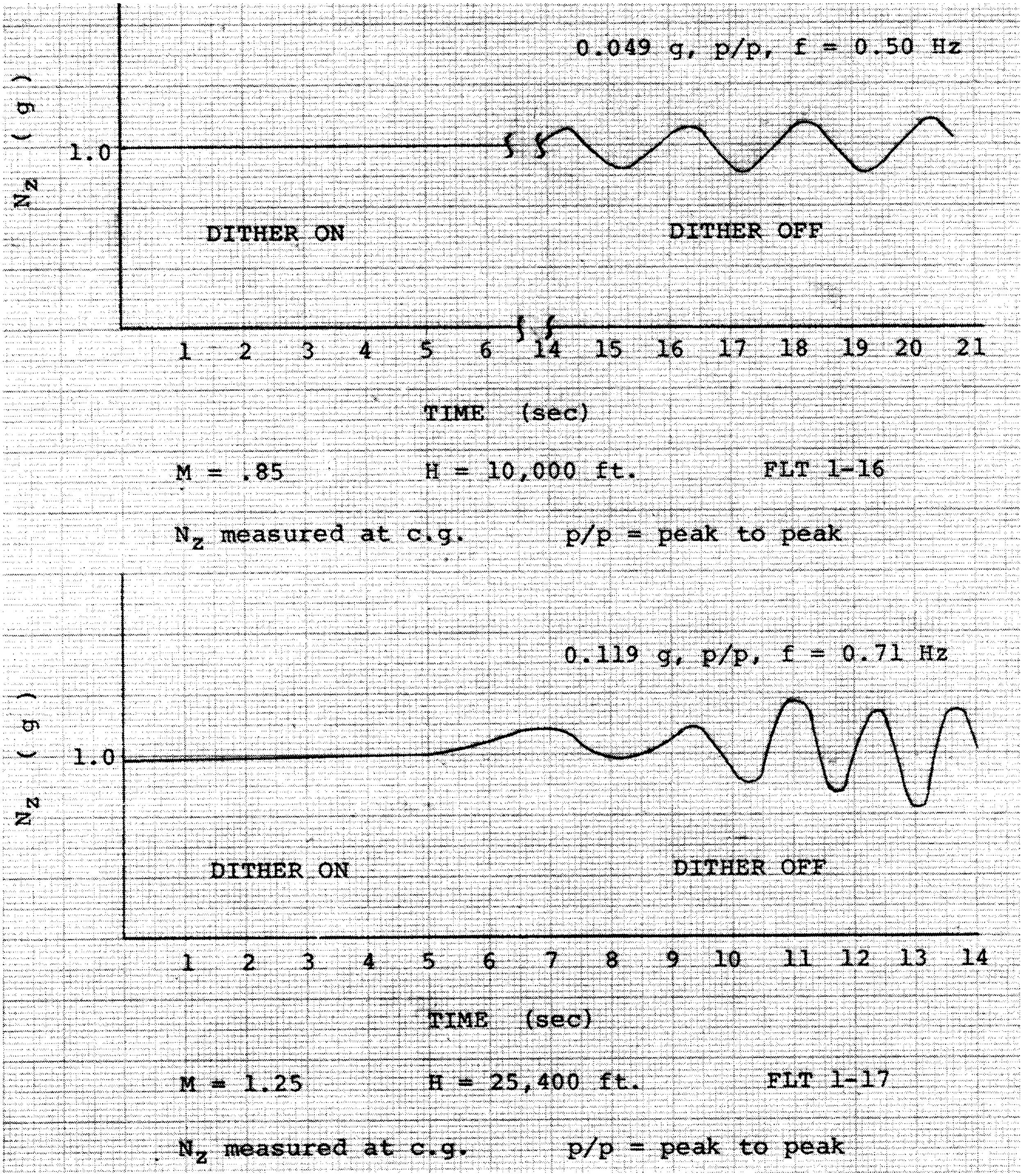

FIGURE C-4. Effect of dither on B-1 limit cycle oscillations (from AFFTC-TR-79-2).

VERIFICATION LESSONS LEARNED (4.8)

Limit cycle amplitude depends on characteristics of the actual hardware and software, and so may be different in simulations than in actual flight. Measurements of normal acceleration at the pilot's station should be made in the course of test flight.

Any residual oscillations should become manifest during expansion of the flight envelope, if they have not already been discovered during ground simulations with flight hardware. Flight or ground-roll conditions with high stability-augmentation gains may be critical.

C.3.9 Transfer to alternate control modes.

The transient motions and trim changes resulting from any mode changes of the flight control system shall be such that dangerous flying qualities never result. The mode changes shall include intentional mode switches by the pilot, as well as any mode switches caused by the flight control system automatically, with or without the pilot's conscious intent. For air vehicle normal states, with controls free, the motion transients resulting from intentional mode changes shall not exceed the limits of table C-XVIII for at least __(1)__ following the mode change. Without retrimming, the changes in control forces required to maintain attitude and sideslip shall not exceed the limits of table C-XIX for at least __(2)__ following an intentional mode change.

TABLE C-XVIII. Transient response limits to configuration or control mode change.

Axis of Response	Flight Envelope	Transient Limits
Pitch		
Roll		
Yaw		

TABLE C-XIX. Control force limits for configuration or control mode change.

Axis of Response	Maximum Control Force Change
Pitch	
Roll	
Yaw	

REQUIREMENT RATIONALE (3.9)

Transients due to mode switching are distracting, and if the transients are too large, pilots will object. Any unnecessary distractions and added workload can interfere with a pilot's mission performance. Mode switching of the flight control system should never result in unusual or unreasonable demands on the pilot to retain control. Transients due to mode switching must not be excessive or cause excessive distraction.

REQUIREMENT GUIDANCE (3.9)

Recommended values for table C-XVIII:

Axis of Response	Flight Envelope	Transient Limits
Pitch	ROSH and ROTH	No more than ±.05 g normal acceleration at the pilot's station
Roll	ROSH	No more than ±3 deg/sec roll
	ROTH	No more than ±5 deg/sec roll
Yaw	ROSH and ROTH	No more than ±5 degrees sideslip, but never to exceed the structural limit

Blank 1. Recommended value: 2 seconds

Recommended values for table C-XIX:

Axis of Response	Maximum Control Force Change
Pitch	20 lbs
Roll	10 lbs
Yaw	50 lbs

Blank 2. Recommended value: 5 seconds

REQUIREMENT LESSONS LEARNED (3.9)

This requirement is intended to apply both to pilot-initiated changes and to automatic changes initiated by selection of weapons, flap setting, etc. Since this requirement deals with intentional modification of the flight control system, it is implied that no failures have occurred, except where operating procedures call for the crew to switch modes upon experiencing a particular failure. Failures are covered explicitly by 3.6. Proper application of this requirement may be performed by careful design of the air vehicle augmentation systems. Mode switching should assure that the new mode chosen does not have any large transients in initialization.

Trim transients following intentional pilot actions should obviously be small enough not to produce significant distractions. Do not overlook such automatic changes as a switch to a different control mode when the pilot selects a particular weapon.

Since the intent of a flight control system is to improve the air vehicle response characteristics – whether measured by improved flying qualities or by increased mission effectiveness – any system which can be chosen by the pilot should not cause objectionable transient motions. There has been some speculation as to whether some small transient motion is or is not desirable. The argument for an intentional transient is that inadvertent pilot switching of autopilot modes is less likely if accompanied by a noticeable transient motion.

For pitch transients following mode changes, MIL-F-8785B allowed 0.05 g normal acceleration. This was increased to 0.10 g in MIL-F-8785C, in order to allow if not encourage designers to provide some noticeable transient (see AFWAL-TR-81-3109). In AFWAL-TR-81-3109 an accident was cited wherein the pilot inadvertently bumped off the altitude hold mode (which automatically disengaged when a small force was applied to the control column). The flight recorder showed a 0.04 g transient which was unnoticed by the crew, who were deeply involved in trying to lower a malfunctioning landing gear. However, it is our contention that the undesirable features of transient motions due to mode switching are significant. Furthermore, a distracted crew would probably not notice a transient considerably larger than 0.04 g, especially if there were any turbulence at all. Therefore, we are recommending that the maximum allowable transient of 0.05 g used in MIL-F-8785B be utilized. As in MIL-F-8785B and MIL-F-8785C, two seconds is deemed a reasonable time to allow for the pilot to resume control.

C.4.9 Transfer to alternate control modes verification.

Verification shall be by analysis and by simulation or flight test in the performance of the tasks of 4.3.13.1.1, 4.3.13.1.2, 4.3.13.1.3.2, and 4.3.13.1.3.3. These tasks will be flown by test pilots at specific flight conditions throughout the ROSH and ROTH. The specific flight conditions to be evaluated shall be the most common operating conditions, any operating conditions critical to the mission of the air vehicle, and those flight conditions where transients due to mode change are predicted to be at their greatest. The mode changes to be evaluated shall include intentional mode switches by the pilot, as well as any mode switches caused by the flight control system automatically, with or without the pilot's conscious intent. Proof of compliance in these demonstration tasks will consist of time histories of air vehicle response and pilot inputs, pilot comments, and C-H ratings. The comments and ratings shall indicate that the flying qualities are no worse than the required Level of flying qualities for each combination of air vehicle state and flight phase.

VERIFICATION RATIONALE (4.9)

Trim transients following intentional pilot actions with the flight control system should obviously be small.

VERIFICATION GUIDANCE (4.9)

This flying qualities requirement pertaining directly to the flight control system applies to all axes of control and response. Demonstration will involve mode switching at representative altitudes throughout the ROSH and ROTH, focusing on those areas of airspeed, altitude, and task that would produce the largest transients between the two modes involved. Configuration changes and control mode changes are to be made by normal means.

Compliance should be evaluated at likely conditions for mode switching and at the most critical flight conditions. Critical conditions will usually be at the corners of the expected ROSHs and ROTHs (e.g., a stability augmentation system (SAS) for power approach should be switched at the highest and lowest expected airspeeds at low altitudes). The critical flight conditions are highly dependent on the aerodynamic and flight control system configurations. Some factors which determine critical conditions are given in the discussion of 3.6. Limited analytical and ground-based simulation may be used to supplement actual flight testing, especially in the early stages of development, but flight testing is ultimately required with production hardware and software.

VERIFICATION LESSONS LEARNED (4.9)

To Be Prepared

C.3.10 Augmentation systems.

Operation of stability augmentation and control augmentation systems and devices, including any performance degradation due to saturation, shall not introduce any objectionable flight or ground handling characteristics. Any performance degradation of stability and control augmentation systems due to saturation of components, rate limiting, or surface deflections, shall only be momentary, and shall not introduce any objectionable flight or ground handling characteristics.

REQUIREMENT RATIONALE (3.10)

In certain flight conditions, turbulence intensities, and failure states, performance of augmentation systems can actually degrade the flying qualities. The purpose of this requirement is to insure that this effect is analyzed and minimized. Compliance with this paragraph is especially important to vehicles employing relaxed static stability.

REQUIREMENT GUIDANCE (3.10)

These requirements particularly apply for all normal states and failure states in the atmospheric disturbances of 6.4.6 and during maneuvering flight at the AOA, sideslip, and load factor limits of the RORH. They also apply to post-stall gyrations, spins, and recoveries with all systems, such as the hydraulic and electrical systems, operating in the state that may result from the gyrations encountered.

REQUIREMENT LESSONS LEARNED (3.10)

Atmospheric disturbances in the form of gusts should not prevent any maneuvering in the ROSH. This means that no limitations should be imposed due solely to control travel. Since ability to counter gusts includes surface rate characteristics, these too are mentioned explicitly. While specific disturbances are listed, the evaluation remains somewhat qualitative. The control required for attitude regulation is in addition to that required for trim and maneuvering.

Auxiliary hydraulic devices may use up significant portions of the available hydraulic power during critical phases of the mission. For example, actuation of landing gear, flaps, slats, etc., during the landing approach, when the engines are operating at relatively low power settings, could drain enough hydraulic power to make it difficult for the pilot to make a safe approach, especially in turbulence. In other flight conditions with less auxiliary demand or higher engine thrust, that same hydraulic system might be more adequate. Also, at high dynamic pressure high hinge moments may limit control surface rate and deflection.

In precision control tasks, such as landing approach and formation flying, it has been observed that the pilot sometimes resorts to elevator stick pumping to achieve better precision (see AFFDL-TR-65-198, AFFDL-TR-66-2, and Boeing Report D6-10732 T/N). This technique is likely to be used when the short-period frequency is low or if the phugoid is unstable, but has been observed in other conditions also. Some important maneuvers, such as correcting an offset on final approach, call for simultaneous, coordinated use of several controls.

C.4.10 Augmentation systems verification.

Verification shall be by simulation or flight test in the performance of the tasks of 4.3.13.1.1 and 4.3.13.1.2 under various levels of atmospheric disturbances. These tasks will be flown by test pilots at specific flight conditions throughout the ROSH and ROTH. The specific flight conditions to be evaluated shall be the most common operating conditions, any operating conditions critical to the mission of the air vehicle, and any conditions determined by analysis or simulation to be worse than the Level of flying qualities required by table C-I. For conditions which are considered too dangerous to test in flight, verification can be shown in a manned simulation. Proof of compliance in these demonstration tasks will consist of pilot comments and C-H ratings. The comments and ratings shall indicate that the flying qualities are no worse than the required Level of flying qualities for each combination of air vehicle state, flight phase, and level of atmospheric disturbance.

VERIFICATION RATIONALE (4.10)

See C-4.8 Verification Rationale.

VERIFICATION GUIDANCE (4.10)

This group of flying qualities requirements pertaining directly to the flight control system applies to all axes of control and response. These generally qualitative requirements result from experience. Verification normally will be a part of flight control system design and testing, and of flight envelope expansion.

VERIFICATION LESSONS LEARNED (4.10)

The required operational maneuvers are commensurate with the particular Level of flying qualities under consideration. The maneuvers required in Level 3 operation, for example, will normally be less precise and more gradual than for Level 1 and 2 operation. In some cases this may result in lower demands on control authority and rates for Level 3 operation. Note, however, that when the handling qualities of the air vehicle are near the Level 3 limits, increased control authority may occur, even though the maneuvers are more gradual.

The demands of various performance requirements and the rapid advancement of control system technology have resulted in the application of relaxed static stability in both the pitch and yaw axes. These systems provide excellent flying qualities until the limits of surface deflection or rate are reached. In this case, the degradation in flying qualities is rapid and can result in loss of control due to pilot-induced oscillations or divergence. It has been found, however, that momentarily reaching the rate or deflection limit does not always result in loss of control; the time interval that a surface can remain on its rate or deflection limit depends on the dynamic pressure, the level of instability of the vehicle, and other factors. A thorough analysis of the capability of the augmentation system should be performed over the RORH and should include variations in predicted aerodynamic terms, e.g., position and system tolerance. During flight at high AOA, operation of augmentation systems has caused departure, either because the aerodynamic characteristics of the surface have changed or the surface has reached its limit. During departures or spins, engines may flameout or have to be throttled back or shut down such that limited hydraulic or electric power is available to control the gyrations, recover to controlled flight, and restart the engine(s). The analysis of flying qualities should take into account these degraded system capabilities.

Evaluation pilots should be alert for potential operational problems in exploring the safe limits of the flight envelope. Critical conditions will usually be at the corners of the expected envelopes. Limited analytical and ground-based simulation may be used to supplement actual flight testing, especially in early stages of development; but flight testing is ultimately required. The conditions examined should be in the range of those encountered operationally.

For requirements involving flight in turbulence, compliance may be shown principally through analysis of gust response characteristics using either an analytical model or a piloted simulation involving the gust models of 6.4.6 and a flight-validated model of the air vehicle. Such analyses must include not only the normal operational maneuvers involving pitch, roll, and yaw controls; but also the critical maneuvers (especially for hydraulic actuation systems) which may limit the responsiveness of the control surfaces. These might include extension of landing gear and high-lift devices on landing approaches, etc. Some evaluation should be conducted by flying in real turbulence.

Common sense is required in the application of this requirement. The specific intensities of atmospheric disturbance to be applied are not specified, however 6.4.6 contains turbulence up to the thunderstorm level. Although operational maneuvering is not normally required in thunderstorm turbulence, it would seem reasonable to require operational maneuvering in turbulence intensities up to Uncommon. For turbulence intensities greater than Uncommon it seems reasonable to require sufficient maneuver capability for loose attitude control.

C.3.11 Direct force controllers.

Direct force controllers (such as in direct lift or lateral translation modes) which are separate from the attitude controllers shall have a direction of operation consistent with the sense of the air vehicle motion produced, be conveniently and accessibly located, comfortable to use, and compatible with pilot force and motion capabilities.

C.3.11.1 Engagement of direct force controller modes.

Functions shall be provided in the control system that would only allow these modes to be engaged within their design flight regime or maneuvers.

C.3.11.2 Use of direct force controllers.

When used either by themselves or in combination with other controllers, flight safety and mission effectiveness shall not be degraded. These systems shall not defeat limiters that are necessary for stable and controlled flight, or for structural considerations.

REQUIREMENT RATIONALE (3.11 through 3.11.2)

This group of flying qualities requirements pertains to direct force control modes which are actuated by cockpit control manipulators that are separate and distinct from the normal cockpit controls (i.e. centerstick, sidestick, or wheel, rudder pedals, and throttle quadrant), as opposed to direct force control modes which are blended or integrated to modify the responses to the conventional cockpit control manipulators. This group of requirements applies to all axes of control and response. These requirements are written to insure that operation of the controllers is simple and straightforward. When implementing these controllers, it must be assumed that the pilot may elect to engage the device in the middle of a maneuver, or in conjunction with another mode.

REQUIREMENT GUIDANCE (3.11 through 3.11.2)

To Be Prepared

REQUIREMENT LESSONS LEARNED (3.11 through 3.11.2)

If loss of control or structural damage could occur, an inhibiter should be incorporated in the system such that it cannot be engaged, or if it is already engaged, that other modes with which it is not compatible cannot be engaged. Furthermore, operation of these devices should not be capable of defeating AOA limiters, sideslip limiters, or load factor limiters that are built into the basic flight control system to provide stable and controlled flight.

C.4.11 Direct force controllers verification.

Verification shall be by simulation or flight test in the performance of the tasks of 4.3.13.1.1 and 4.3.13.1.2. These tasks will be flown by test pilots at specific flight conditions throughout the __(1)__, except that these controllers need not be evaluated in flight regimes in which they cannot be engaged. The specific flight conditions to be evaluated shall be the most common operating conditions, any operating conditions critical to the mission of the air vehicle, and any conditions determined by analysis or simulation to be worse than the Level of flying qualities required by table C-I. For conditions which are considered too dangerous to test in flight, verification can be shown in a manned simulation. Proof of compliance in these demonstration tasks will consist of pilot comments and C-H ratings. The comments and ratings shall indicate that the flying qualities are no worse than the required Level of flying qualities for each combination of air vehicle state, flight phase, and level of atmospheric disturbance.

VERIFICATION RATIONALE (4.11)

See C-4.8 Verification Rationale.

VERIFICATION GUIDANCE (4.11)

Blank 1. Recommended value: ROSH and ROTH

If the air vehicle has any direct force controllers, the set of evaluation tasks for 4.3.13.1.1 and 4.3.13.1.2 should include some tasks which utilize these controllers.

VERIFICATION LESSONS LEARNED (4.11)

According to AFWAL-TR-81-3027:

> The “separate” manipulators can be used as trimming devices or for continuous tracking. In the first case the control is used only intermittently, to establish a new trim condition or operating point. It operates like a trim button; changes are “beeped in”. In the second case the auxiliary manipulator is used continuously, as in tracking a target. Presumably the conventional controls are used to establish the operating point.
>
> If the system design is such that both conventional and auxiliary manipulators are used continuously, then it violates a pilot-centered requirement for frequency separation of controls. A pilot cannot easily coordinate more than two control axes continuously, simultaneously, and in the same frequency range of operation. He must time share his attention between the multiple controls.

> Even when conventional controls are used to establish an operating point, i.e., as “trim” controls, use of the auxiliary manipulators implies additional pilot workload relative to using the conventional controls alone. The increased workload is presumably traded for significant performance advantages obtainable only by using the auxiliary controllers. This implies careful tailoring of the response characteristics when using the separated manipulator to achieve flying task performance that is significantly better than that obtainable with conventional control responses.

Recommended tasks for the evaluation of flying qualities for direct force modes include open-loop tasks, air-to-air tracking, air-to-ground tracking, dive bombing, and approach and landing. Examples of tasks using direct force controls in both the trimming and continuous tracking roles are given below.

Open-loop tasks

Open-loop tasks with direct force control modes include step, ramp, pulse, and doublet inputs with the associated controllers, attitude captures, vertical and lateral displacements, and wind-up turns and pullups. Examples of the use of open-loop tasks to evaluate direct force control modes are included in AFFTC-TR-77-23, AFFDL-TR-78-9, AFFTC-TR-83-45, AFFTC-TR-83-46, and AFWAL-TR-84-3008.

Air-to-air tracking

Air-to-air tracking has been found suitable for testing such direct force control modes as direct lift, pitch pointing, wings-level turn (direct side force), lateral translation, and yaw pointing. Examples of the use of these modes in air-to-air tracking evaluation tasks can be found in AFFTC-TR-77-23, AFFDL-TR-78-9, AFWAL-TR-81-3027, AFFTC-TR-83-45, AFWAL-TR-84-3008, and AFWAL-TR-84-3060.

Air-to-ground tracking

Air-to-ground tracking has been found suitable for testing such direct force control modes as direct lift, pitch pointing, wings-level turn, lateral translation, and yaw pointing. Examples of the use of these modes in air-to-ground tracking evaluation tasks can be found in AFFDL-TR-71-106, AFFDL-TR-72-120, AFFTC-TR-77-23, AFFDL-TR-78-9, AFFTC-TR-83-45, AFWAL-TR-84-3008, and AFWAL-TR-84-3060.

Simulated bombing

Simulated bombing has been found suitable for testing such direct force control modes as direct lift, vertical translation, wings-level turn, lateral translation. Examples of the use of these modes in simulated bombing evaluation tasks can be found in AFFDL-TR-71-106, AFFDL-TR-72-120, AFFDL-TR-76-78, AFFTC-TR-77-23, AFFDL-TR-78-9, AFFTC-TR-83-45, AFWAL-TR-84-3008, and AFWAL-TR-84-3060.

Approach and landing

Approach and landing has been found suitable for testing such direct force control modes as vertical translation, wings-level turn, lateral translation, and yaw pointing.

Examples of the use of these modes in approach and landing evaluation tasks can be found in AFFDL-TR-73-2, AFFTC-TR-77-23, AFFDL-TR-78-9, and AFWAL-TR-84-3060.

Formation flying

Formation flying has been found suitable for testing such direct force control modes as direct lift, vertical translation, wings-level turn, and lateral translation. Examples of the use of these modes in formation flying evaluation tasks can be found in AFFTC-TR-77-23, AFFDL-TR-78-9, AFFTC-TR-83-45, and AFWAL-TR-84-3008.

Aerial refueling

Aerial refueling has been found suitable for testing such direct force control modes as direct lift, vertical translation, wings-level turn, and lateral translation. Examples of the use of these modes in aerial refueling evaluation tasks can be found in AFFTC-TR-83-45 and AFWAL-TR-84-3008.

C.3.12 Trim system requirements.

The trim system shall meet the requirement of 3.12.1 through 3.12.8.

C.3.12.1 Trim system capability.

In straight flight, throughout the ROSH, the trim system shall be capable of reducing the steady-state control forces to the values given in table C-XX.

TABLE C-XX. Untrimmed steady-state cockpit control forces.

Level	Pitch	Roll	Yaw
1			
2			
3			

C.3.12.2 Trim system restrictions.

Trim systems shall not defeat other features incorporated in the flight control system that prevent or suppress departure from controlled flight or exceedance of structural limits, or that provide force cues which warn of approach to flight limits.

C.3.12.3 Trim system irreversibility.

All trimming devices shall maintain a given setting indefinitely unless changed by the pilot, or by a special automatic interconnect (such as to the landing flaps), or by the operation of an augmentation device.

C.3.12.3.1 Automatic interconnects or augmentation devices.

If an automatic interconnect or augmentation device is used in conjunction with a trim device, the trim device shall return to its initial trim position on removal of each interconnect or augmentation command.

C.3.12.4 Rate of trim operation.

Trim devices shall operate rapidly enough to enable the pilot to maintain low control forces under changing conditions normally encountered in service, yet not so rapidly as to cause oversensitivity or trim precision difficulties under any conditions, including:

a. Level-flight accelerations at maximum augmented thrust from 250 knots or $V_{R/C}$, whichever is less, to V_{max} at any altitude when the air vehicle is trimmed for level flight prior to initiation of the maneuver;

b. Dives required in normal service operation; or

c. __(1)__

C.3.12.5 Stalling of trim systems.

Stalling of a trim system due to aerodynamic loads during maneuvers shall not result in an unsafe condition.

C.3.12.5.1 Operation during dive recoveries.

The entire trim system shall be capable of operating during dive recoveries from dives to all attainable speeds throughout the RORH, at any attainable, permissible load factor, at any possible position of the trimming device.

C.3.12.6 Transients and trim changes due to operation of control devices.

The transients and steady-state trim changes for normal operation of control devices (such as throttle, thrust reversers, flaps, slats, speed brakes, deceleration devices, dive recovery devices, wing sweep, and landing gear) shall not impose excessive control forces to maintain the desired heading, altitude, attitude, rate of climb, speed, or load factor without use of the trimmer control.

C.3.12.6.1 Transients and trim changes due to in-flight configuration changes.

The transients and steady-state trim changes due to in-flight configuration changes and combinations of changes made under service conditions (including the effects of asymmetric operations such as unequal operation of landing gear, speed brakes, slats, or flaps) shall not impose excessive control forces to maintain the desired heading, altitude, attitude, rate of climb, speed, or load factor without use of the trimmer control.

C.3.12.6.2 Buffeting or oscillation due to operation of control devices.

In no case shall there be any objectionable buffeting or oscillation caused by such devices.

C.3.12.7 Trim for asymmetric thrust.

For all multi-engine air vehicles, for Level 1 it shall be possible to trim the cockpit-control forces to zero in straight, level-flight with up to two engines inoperative following asymmetric loss of thrust from the most critical propulsive factors at speeds from the maximum-range speed for the engine(s)-out configuration to the speed obtainable with normal rated thrust on the functioning engine(s).

C.3.12.8 Automatic trim systems.

Automatic trimming devices shall not degrade or inhibit the action of response limiters.

REQUIREMENT RATIONALE (3.12 through 3.12.8)

Establishing, maintaining, and changing the trim or operating point are basic factors in piloting. To ease pilot workload, it is necessary to specify the ability of the trim system to reduce control forces in operational flight and in the event of trim system failures or flight control failures affecting other control surfaces. These paragraphs are included to insure adequate trim system operation.

Some air vehicles have features in the flight control system that are incorporated to prevent g overstress or departure, or provide force cues that air vehicle limits are being reached. The use or misuse of the trim system should not degrade the protection afforded by these features.

REQUIREMENT GUIDANCE (3.12 through 3.12.8)

Recommended values for table C-XX:

Level	Pitch	Roll	Yaw
1	0	0	0
2	0	0	0
3	10	5	20

Blank 1. Recommended value for blank 1 in 3.12.4, for combat air vehicles add:

c. "Ground attack maneuvers required in normal service operation."

REQUIREMENT LESSONS LEARNED (3.12 through 3.12.8)

The purpose of a trim system is to reduce steady-state forces on cockpit controls, preferably to zero. Transient forces are similarly limited by 3.6. The ROSHs cover the design missions and also delineate the minimum requirement. It would be desirable, however, to have trim capability throughout the larger ROTH and perhaps even to the maximum permissible speed. Straight flight includes climbs and dives.

In normal operations, this requirement is very straightforward. If a trim system is provided, it must be effective. However, the more quick or powerful a trim system, the more catastrophic a trim failure can be. The difficulty in designing a trim system will be in assuring that extreme failures (trim hardover, sticking, etc.) are capable of being overcome by the pilot. Hence override or alternate trim mechanisms (e.g., dual trim systems) can be of prime importance.

Operational experience with early electrical trim systems running away included crashes not only due to loss or inadequacy of control, but also due to excessive pilot fatigue from having to hold high forces for an extended time until a landing could be made.

Load factor or AOA limiting systems are often provided for relaxed static stability application. In some of these systems, however, trim system inputs are made downstream of the output from the primary system control laws. The result is that load factor or AOA limiting systems can be defeated by use of trim. In some cases, it has been found that autopilot inputs through the trim system can also defeat these AOA limiting systems. A similar problem may exist in yaw for air vehicles with sideslip limiters.

The irreversibility requirement allows trim scheduling or interconnection with other control devices (e.g., flaps), but it specifically disallows float or drift.

It may be difficult to find a trim rate which will be good for all loadings in all mission phases. Slow trim rates will not keep up with rapidly changing flight conditions, and so will fatigue the pilot. Too rapid trim rates give oversensitivity, make trim difficult, and accentuate the effect of any runaway trim.

While the requirement on stalling of trim systems applies generally, the problem has been encountered with pitch trim by adjusting incidence of the horizontal tail. First, some of the available elevator capability goes to oppose the mistrimmed stabilizer and less is left to counter any adverse gust-induced pitching motions. Second, elevator forces will be increased and may complicate recovery from a high-speed dive. Third, and perhaps most significant, whenever the elevator opposes the stabilizer, the aerodynamic hinge moment on the stabilizer may reach a level that is impossible for the trim actuator to overcome. See, for example, AIAA 64-353.

If, for example, nose-down trim is used to counter the air vehicle's pitch-up response to a vertical downdraft, the air vehicle will pitch down more sharply when the draft reverses in direction. Elevator will be used to counter the pitch-down motion, and the resulting aerodynamic load may be sufficient to stall the stabilizer actuator when nose-up retrim is attempted. As speed increases, the adverse effects increase, and the elevator may have insufficient effectiveness to counter the nose-down forces of the draft and the mistrimmed stabilizer. It is obvious that tuck effects may also complicate the picture, and it is significant that tuck effects can not be countered by a Mach trim system that is unable to move the stabilizer.

A Boeing 720B airliner encountered stalling of the pitch trim actuator during a turbulence upset over O'Neill, Nebraska, on 12 July 1993 (NASA CR-2677). The air vehicle was passing through 39,000 ft in a climb to 41,000 ft in IMC when severe turbulence was encountered. A large downdraft was penetrated and the air vehicle pitch attitude increased to +60 degrees. This occurred despite application of full forward stick. The gust was reversed to a large updraft, putting the air vehicle into a severe dive with an estimated flightpath angle of about -35 degrees. The pitch trim control was reported by the crew to be frozen in the dive. Recovery was made with power (pullout at 14,000 ft) and pitch trim control was restored.

Two other turbulence upsets occurred with commercial jet transports (another Boeing 720B and a DC-8), in which the wreckage of both air vehicles showed the trim actuator in the full nose-down position. The frequency of such turbulence upset accidents has been reduced drastically in recent years by pilot training to fly loose attitude control and to essentially ignore large airspeed excursions in severe turbulence. However, the possibility of entering a dive with full nose-down mistrim should be considered in the design process.

KC-135, B-57, and other air vehicles have been lost due to runaway trim, so that now elaborate precautions are commonly taken to preclude dangerous trim runaway, trim and control use of the same surface, or trimming by adjusting the null position of the feel spring through a limited range. Civil airworthiness regulations have long required ability to continue flight and land safely with maximum adverse trim.

Autotrim can be insidious. Several B-58s are thought to have been lost because the pitch autotrim would allow approach to stall AOA with no indication whatsoever to the pilot until very close to stall. Attitude hold stabilization has a similar effect with the pilot's hand lightly on the control. Pitch autotrim does not promote holding airspeed, and a number of trim and autostabilization mechanizations need the addition of some form of stall and overspeed limiters.

External stores can affect both stability and the zero-lift pitching moment as well as the air vehicle loading.

C.4.12 Trim system requirements verification.

Verification shall be by demonstration in setting up on conditions for various tests throughout the flight test program. Flight conditions shall explore the boundaries of trim authority. Inducing failures at these conditions may be impractical or judged too dangerous for flight. For conditions which are considered too dangerous to test in flight, verification can be shown by intentionally mistrimming the air vehicle and recovering from the mistrim, or by manned simulation. Proof of compliance will consist of flight data records and pilot comments. Flight data records shall be used to verify compliance with 3.12.1, 3.12.2, 3.12.3, 3.12.3.1, 3.12.5, 3.12.5.1, 3.12.7, and 3.12.8. Pilot comments shall be used to verify compliance with 3.12.4, 3.12.5, 3.12.5.1, 3.12.6, 3.12.6.1, and 3.12.6.2. For verification of 3.12.2 and 3.12.8, deliberate attempts shall be made to defeat limiters and departure prevention systems. For verification of 3.12.5 and 3.12.5.1, deliberate attempts shall be made to stall the trim system.

VERIFICATION RATIONALE (4.12)

Trim capability must eventually be shown through flight testing at conditions covering the range of operational flight.

VERIFICATION GUIDANCE (4.12)

Most flight verification will be accomplished during the normal course of the flight test program (all flight tests, not just flying qualities).

Flight conditions should be chosen to explore the boundaries of trim authority, e.g., low altitude and high speed (high dynamic pressure), and high altitude and low speed (low dynamic pressure) at most forward and most aft c.g. Inducing failures at these conditions may be impractical or judged too dangerous for flight. In this case, compliance with the failure requirements may be demonstrated by intentionally mistrimming the air vehicle and recovering from the mistrim, or by simulation. Conditions which are the most critical will depend on the control feel.

The failures to be considered in applying Level 2 and Level 3 requirements should include trim sticking and runaway in either direction. It is permissible to meet Level 2 and 3 requirements by providing the pilot with alternate trim mechanisms or override capability.

VERIFICATION LESSONS LEARNED (4.12)

Flight test crews should monitor trim system characteristics throughout the program to note any discrepancies. Of special interest are extreme loadings and corners of the flight envelope, including sustained maneuvers at $n \neq 1$, e.g., dives and dive recoveries, pullups, wind-up turns, with the cockpit trim setting fixed throughout – and for trim rate, rapid speed changes, and configuration and thrust changes. Check at the highest trim system loadings, which may be the critical test of irreversibility.

It is clear that full nose-down mistrim should be accounted for in the dives. For example, a Boeing 720 with full nose-down trim at the dive entry will encounter stalling of the pitch trim drive in the dive if the pilot is manually attempting to pull out. Judgement will have to be applied to decide if the mission requirements and failure considerations such as runaway trim or trim actuation power failure should allow this type of abuse. FAA Advisory Circular 25.253-1A gives guidance on design upset maneuvers for civil transport air vehicles.

C.3.13 High angle of attack requirements.

Air vehicle flying qualities at high angles of attack shall meet the requirements of 3.13.1 through 3.13.6.4.

REQUIREMENT RATIONALE (3.13)

3.13.1 through 3.13.6.4 concern stall warning, stalls, departures from controlled flight, post-stall gyrations, spins, recoveries, and related characteristics. They apply at speeds and AOAs which in general are outside the ROTH. They are intended to assure safety and the absence of mission limitations due to high-AOA flight characteristics.

REQUIREMENT GUIDANCE (3.13)

Note that the requirements apply as well to asymmetric loadings called out in the contract or experienced in normal operation.

REQUIREMENT LESSONS LEARNED (3.13)

A large number of air vehicle incidents have been attributed to loss of control at high AOA. It is conjectured that many losses in Vietnam combat with no evidence to determine a cause might well have been due to loss of control at high AOA. Whereas previous requirements have concentrated on demonstration of acceptable stall and spin characteristics, these requirements emphasize prevention of loss of control (departure) as well. These requirements define flight demonstration maneuvers and control abuse appropriate to each air vehicle Class and mission. The requirements in this regime of nonlinearities remain largely qualitative.

The stall and spin requirements that follow are related by their application at high AOA outside the ROTH. Therefore, this requirement is retained to serve as an overview of characteristics and problems with high-AOA flight. The discussions presented in Verification Lessons Learned summarize recent insights and information on high-AOA flight, applicable in general to any of the stall/spin requirements. Based upon the requirements of this paragraph, high AOA is considered to be at and above the AOA for stall warning (3.13.2.5), generally outside the ROTH in which the bulk of the other flying qualities requirements apply. Thus the AOA value which is considered high will vary with the situation: air vehicle, configuration, and Mach number.

Future advanced fighter air vehicles may have the capability to fly/maneuver in the post-stall region. This capability will exist through the use of improved high-AOA aerodynamics, digital flight control systems, and thrust-vectored control. Manned simulation studies indicate tactical utility and increased combat effectiveness available via high-AOA maneuvering. Consequently, continued flying qualities research is needed to establish stability and control requirements for flight operations in this region. Suggested areas to address are

- Definition of the post-stall region
- Control power requirements to provide deep-stall recovery capability
- Control power requirements to prevent departures from controlled flight
- Engine operating requirements and means to fulfill them
- Post-stall warning and pilot cues
- Multi-axis, nonlinear dynamics at high-AOA, with good representation of the aerodynamics
- Roll, pitch, and yaw rate capability (where rolling about the flightpath is mostly body-axis yawing)
- Agility
- Deceleration/acceleration capability (nobody wants to stay long in a state of very low energy)
- Maximum allowable/usable sideslip and yaw rate at high AOA
- Design criteria for departure resistance
- Falling leaf prevention
- Aerodynamic means to improve departure/post-stall characteristics, compatible with high-performance, low-observable, etc.
- Thrust-vectoring control power requirements for high-AOA stabilization and control
- Cockpit display and field of view requirements at high AOA.

These needs are listed to indicate the considerations necessary if an air vehicle is to be designed for effective post-stall flight. Data are lacking for more quantitative recommendations.

C.4.13 High angle of attack requirements verification.

Verification shall be by demonstration in analysis, simulation, and flight test. The air vehicle shall demonstrate compliance with the requirements of 3.13.1 through 3.13.6.4 by flight test according to table C-XVIV. Reasonable delayed recovery attempts after a stall or departure, and exaggerated misapplication of controls following a stall or departure, to simulate possible incorrect pilot responses shall be investigated under the least conservative circumstances to ascertain the degree of spin susceptibility/resistance for operational users. When spins result as a natural consequence of testing through departures from controlled flight or as a result of deliberate spin attempts, a satisfactory spin recovery technique shall be demonstrated. The use of prolonged pro-spin control to sustain a developed spinning condition is __(1)__.

TABLE C-XVIV. Flight demonstration maneuvers for air vehicles.

Test Phase	Flight Phase Category	Control Application	Maneuver Requirements

VERIFICATION RATIONALE (4.13)

A high-AOA flight test program (a) is necessary to bring out under controlled conditions any idiosyncrasies of the air vehicle that might be encountered later in service use, and (b) needs careful preparation, including prior analysis and model testing, provision of emergency recovery means, propulsion system modification such as continuous ignition, backup hydraulic power, etc.

VERIFICATION GUIDANCE (4.13)

Blank 1.

a. For Class II and III air vehicles the following would be applicable:

The use of prolonged pro-spin control to sustain a developed spinning condition is <u>not required</u>.

b. For most Class I and Class IV air vehicles the following would be applicable: The use of prolonged pro-spin control to sustain a developed spinning condition is <u>required for no more than 3 turns</u>.

c. For trainer-type air vehicles to be cleared for intentional spins, and for Class I and Class IV air vehicles in which sufficient departures and developed spins do not result during Test Phases A, B, and C, the following would be applicable:

The use of prolonged pro-spin control to sustain a developed spinning condition is required for 15 sec or until three turns of the fully developed spin has been encountered, whichever occurs first.

Recommended values for table C-XVIV (see following pages):

For Class I air vehicles which do not employ AOA limiting devices:

Test Phase	Control Application	Flight Phase Category	Maneuver Requirements
A Stalls	Pitch control applied to achieve the specified AOA rate. Roll, yaw, and decoupled[1] control inputs as normally required for the maneuver task. Recovery initiated after the pilot has a clear indication of: a) a definite g break, or b) a rapid, uncommanded angular motion, or c) the aft stick stop has been reached and AOA is not increasing, or d) sustained intolerable buffet. For those air vehicles where clear indications of stall are not evident and where the minimum permissible speed is other than the stall speed, recovery may be initiated somewhat beyond the arbitrary limit(s).	A and B	Entry conditions[2]: 1) One-g stall with smooth AOA rate[3] 2) Accelerated[4] stall with smooth AOA rate 3) One-g stall with abrupt AOA rate[5] of at least 4 deg/sec 4) Accelerated stall with abrupt AOA rate of at least 4 deg/sec 5) Tactical[6]
		C	Entry conditions: 1) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate
B Stalls with aggravated control inputs	Pitch control applied to achieve the specified AOA rate. Roll, yaw, and decoupled control inputs as normally required for the maneuver task. When conditions a), b), c), or d) from above have been attained, controls briefly misapplied[7], intentionally or in response to unscheduled air vehicle motions, before recovery is initiated.	A and B	Entry conditions: 1) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate 3) One-g stall with abrupt AOA rate of at least 4 deg/sec 4) Accelerated stall with abrupt AOA rate of at least 4 deg/sec 5) Tactical
		C	Entry conditions: 1) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate
C Stalls with aggravated and sustained control inputs[8]	Pitch control applied to achieve the specified AOA rate. Roll, yaw, and decoupled control inputs as normally required for the maneuver task. When conditions a), b), c), or d) from above have been attained, controls are misapplied[7,9], intentionally or in response to unscheduled air vehicle motions, and held for three seconds[9,10] before recovery attempt is initiated.	A and B	Entry conditions: 1) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate 3) One-g stall with abrupt AOA rate of at least 4 deg/sec 4) Accelerated stall with abrupt AOA rate of at least 4 deg/sec 5) Tactical
D Post-Stall Gyration, Spin and Deep Stall Attempts[8] (This phase required only for training air vehicles which may be intentionally spun and for air vehicles in which sufficient departures and developed spins did not result during Test Phases A, B, and C to define characteristics of each possible out-of-control mode)	Pitch control applied to achieve the specified AOA rate. Roll, yaw, and decoupled control inputs as normally required for the maneuver task. When conditions a), b), c), or d) from above have been attained, controls applied in the most critical[11] manner to attain each possible mode of post-stall motion, and held for various lengths of time up to 15 seconds or three fully developed spin turns, whichever occurs first, before the recovery attempt is initiated.[9,12]	A and B	Entry conditions: 1) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate 3) One-g stall with abrupt AOA rate of at least 4 deg/sec 4) Accelerated stall with abrupt AOA rate of at least 4 deg/sec 5) Tactical

For Class II air vehicles which do not employ AOA limiting devices:

Test Phase	Control Application	Flight Phase Category	Maneuver Requirements
A Stalls	Pitch control applied to achieve the specified AOA rate. Roll, yaw, and decoupled[1] control inputs as normally required for the maneuver task. Recovery initiated after the pilot has a clear indication of: a) a definite g break, or b) a rapid, uncommanded angular motion, or c) the aft stick stop has been reached and AOA is not increasing, or d) sustained intolerable buffet. For those air vehicles where clear indications of stall are not evident and where the minimum permissible speed is other than the stall speed, recovery may be initiated somewhat beyond the arbitrary limit(s).	A and B	Entry conditions[2]: 1) One-g stall with smooth AOA rate[3] 2) Accelerated[4] stall with smooth AOA rate 3) One-g stall with abrupt AOA rate[5] of at least 2 deg/sec 4) Accelerated stall with abrupt AOA rate of at least 2 deg/sec 5) Tactical[6]
		C	Entry conditions: 1) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate
B Stalls with aggravated control inputs	Pitch control applied to achieve the specified AOA rate. Roll, yaw, and decoupled control inputs as normally required for the maneuver task. When conditions a), b), c), or d) from above have been attained, controls briefly misapplied[7], intentionally or in response to unscheduled air vehicle motions, before recovery is initiated.	A and B	Entry conditions: 1) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate 3) One-g stall with abrupt AOA rate of at least 2 deg/sec
		C	Entry conditions: 1) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate
C Stalls with aggravated and sustained control inputs[8]	Pitch control applied to achieve the specified AOA rate. Roll, yaw, and decoupled control inputs as normally required for the maneuver task. When conditions a), b), c), or d) from above have been attained, controls are misapplied[7,9], intentionally or in response to unscheduled air vehicle motions, and held for three seconds[9,10] before recovery attempt is initiated.	A and B	Entry conditions: 1) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate 3) One-g stall with abrupt AOA rate of at least 2 deg/sec

For Class III air vehicles which do not employ AOA limiting devices:

Test Phase	Control Application	Flight Phase Category	Maneuver Requirements
A Stalls	Pitch control applied to achieve the specified AOA rate. Roll, yaw, and decoupled[1] control inputs as normally required for the maneuver task. Recovery initiated after the pilot has a clear indication of: a) a definite g break, or b) a rapid, uncommanded angular motion, or c) the aft stick stop has been reached and AOA is not increasing, or d) sustained intolerable buffet. For those air vehicles where clear indications of stall are not evident and where the minimum permissible speed is other than the stall speed, recovery may be initiated somewhat beyond the arbitrary limit(s).	A and B	Entry conditions[2]: 1) One-g stall with smooth AOA rate[3] 2) Accelerated[4] stall with smooth AOA rate 3) One-g stall with abrupt AOA rate[5] of at least 1 deg/sec 4) Accelerated stall with abrupt AOA rate of at least 1 deg/sec 5) Tactical[6]
		C	Entry conditions: 1) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate
B Stalls with aggravated control inputs	Pitch control applied to achieve the specified AOA rate. Roll, yaw, and decoupled control inputs as normally required for the maneuver task. When conditions a), b), c), or d) from above have been attained, controls briefly misapplied[7], intentionally or in response to unscheduled air vehicle motions, before recovery is initiated.	A and B	Entry conditions: 1) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate 3) One-g stall with abrupt AOA rate of at least 1 deg/sec
		C	Entry conditions: 1) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate

For Class IV air vehicles which do not employ AOA limiting devices:

Test Phase	Control Application	Flight Phase Category	Maneuver Requirements
A Stalls	Pitch control applied to achieve the specified AOA rate. Roll, yaw, and decoupled[1] control inputs as normally required for the maneuver task. Recovery initiated after the pilot has a clear indication of: a) a definite g break, or b) a rapid, uncommanded angular motion, or c) the aft stick stop has been reached and AOA is not increasing, or d) sustained intolerable buffet. For those air vehicles where clear indications of stall are not evident and where the minimum permissible speed is other than the stall speed, recovery may be initiated somewhat beyond the arbitrary limit(s).	A and B	Entry conditions[2]: 1) One-g stall with smooth AOA rate[3] 2) Accelerated[4] stall with smooth AOA rate 3) One-g stall with abrupt AOA rate[5] of at least 8 deg/sec 4) Accelerated stall with abrupt AOA rate of at least 8 deg/sec 5) Tactical[6]
		C	Entry conditions: 1) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate
B Stalls with aggravated control inputs	Pitch control applied to achieve the specified AOA rate. Roll, yaw, and decoupled control inputs as normally required for the maneuver task. When conditions a), b), c), or d) from above have been attained, controls briefly misapplied[7], intentionally or in response to unscheduled air vehicle motions, before recovery is initiated.	A and B	Entry conditions: 1) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate 3) One-g stall with abrupt AOA rate of at least 8 deg/sec 4) Accelerated stall with abrupt AOA rate of at least 8 deg/sec 5) Tactical
		C	Entry conditions: 1) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate
C Stalls with aggravated and sustained control inputs[8]	Pitch control applied to achieve the specified AOA rate. Roll, yaw, and decoupled control inputs as normally required for the maneuver task. When conditions a), b), c), or d) from above have been attained, controls are misapplied[7,9], intentionally or in response to unscheduled air vehicle motions, and held for three seconds[9,10] before recovery attempt is initiated.	A and B	Entry conditions: 1) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate 3) One-g stall with abrupt AOA rate of at least 8 deg/sec 4) Accelerated stall with abrupt AOA rate of at least 8 deg/sec 5) Tactical
D Post-Stall Gyration, Spin and Deep Stall Attempts[8] (This phase required only for training air vehicles which may be intentionally spun and for air vehicles in which sufficient departures and developed spins did not result during Test Phases A, B, and C to define characteristics of each possible out-of-control mode)	Pitch control applied to achieve the specified AOA rate. Roll, yaw, and decoupled control inputs as normally required for the maneuver task. When conditions a), b), c), or d) from above have been attained, controls applied in the most critical[11] manner to attain each possible mode of post-stall motion, and held for various lengths of time up to 15 seconds or three fully developed spin turns, whichever occurs first, before the recovery attempt is initiated.[9,12]	A and B	Entry conditions: 1) One-g stall with smooth AOA rate 2) Accelerated stall with smooth AOA rate 3) One-g stall with abrupt AOA rate of at least 8 deg/sec 4) Accelerated stall with abrupt AOA rate of at least 8 deg/sec 5) Tactical

For Class I and Class IV air vehicles which employ AOA limiting devices:

Test Phase	Control Application	Flight Phase Category	Maneuver Requirements[2]
A	Longitudinal maneuvers to the limiter AOA ranging from 1-g decelerations to maximum-g decelerations and wind-up turns and pushover-pullups to the limiter AOA over the airspeed range between the minimum sustainable speed and maximum level flight speed. Recovery attempts should be initiated immediately after departure occurs.	A, B, and C	1-g decelerations to the limiter AOA will be performed using a slow control rate which will produce a speed deceleration of approximately 1 knot per second AOA rate during accelerated maneuvers and pushover-pullups to the limiter AOA will be increased in a build-up fashion until the maximum attainable AOA rate or the maximum suitable AOA rate (if considered less than maximum attainable) is demonstrated.
B	Combinations of pitch, roll, yaw, and decoupled[1] controls applied while the air vehicle is at or near limiter AOA outside the airspeed range between minimum sustainable speed and maximum level flight speed. These maneuvers include roll and sideslips at limiter AOA. Recovery attempts should be initiated immediately after departure occurs.	A, B, and C	The control inputs shall consist of applying controls in the most critical directions, combinations, and rates of application. AOA rate during accelerated maneuvers and pushover-pullups to the limiter AOA will be increased in a build-up fashion until the maximum attainable AOA rate or the maximum suitable AOA rate (if considered less than maximum attainable) is demonstrated. Controls should be applied below limiter AOA if predictions indicate the possibility of inducing a departure. This includes combinations of roll, yaw, and decoupled control inputs below limiter AOA while AOA is increasing both at smooth and abrupt rates. The air vehicle will not be required to roll in excess of 360 degrees.
C	Combinations of pitch, roll, yaw, and decoupled controls applied while the air vehicle is at or near limiter AOA outside the airspeed range between minimum sustainable speed and maximum level flight speed. These maneuvers include high pitch attitude, low airspeed recoveries and high-speed dive pullouts. Recovery attempts should be initiated immediately after departure occurs.[8]	A and B	The control inputs shall consist of applying controls in the most critical directions, combinations, and rates of application. AOA rate during accelerated maneuvers and pushover-pullups to the limiter AOA will be increased in a build-up fashion until the maximum attainable AOA rate or the maximum suitable AOA rate (if considered less than maximum attainable) is demonstrated. Controls should be applied below limiter AOA if predictions indicate the possibility of inducing a departure. This includes combinations of roll, yaw, and decoupled control inputs below limiter AOA while AOA is increasing both at smooth and abrupt rates. The air vehicle will not be required to roll in excess of 360 degrees.
D	Combinations of pitch, roll, yaw, and decoupled controls of a gross and abnormal nature not likely to occur during operational use of the air vehicle.[8,11,12] This includes deliberate out-of-control events held for various lengths of time up to 15 seconds or three spin turns, whichever is longer, to demonstrate out-of-control recovery.	A and B	The control inputs shall consist of applying controls in the most critical directions, combinations, and rates of application.

For Class II air vehicles which employ AOA limiting devices:

Test Phase	Control Application	Flight Phase Category	Maneuver Requirements[2]
A	Longitudinal maneuvers to the limiter AOA ranging from 1-g decelerations to maximum-g decelerations and wind-up turns and pushover-pullups to the limiter AOA over the airspeed range between the minimum sustainable speed and maximum level flight speed. Recovery attempts should be initiated immediately after departure occurs.	A, B, and C	1-g decelerations to the limiter AOA will be performed using a slow control rate which will produce a speed deceleration of approximately 1 knot per second AOA rate during accelerated maneuvers and pushover-pullups to the limiter AOA will be increased in a build-up fashion until the maximum attainable AOA rate or the maximum suitable AOA rate (if considered less than maximum attainable) is demonstrated.
B	Combinations of pitch, roll, yaw, and decoupled[1] controls applied while the air vehicle is at or near limiter AOA outside the airspeed range between minimum sustainable speed and maximum level flight speed. These maneuvers include roll and sideslips at limiter AOA. Recovery attempts should be initiated immediately after departure occurs.	A, B, and C	The control inputs shall consist of applying controls in the most critical directions, combinations, and rates of application. AOA rate during accelerated maneuvers and pushover-pullups to the limiter AOA will be increased in a build-up fashion until the maximum attainable AOA rate or the maximum suitable AOA rate (if considered less than maximum attainable) is demonstrated. Controls should be applied below limiter AOA if predictions indicate the possibility of inducing a departure. This includes combinations of roll, yaw, and decoupled control inputs below limiter AOA while AOA is increasing both at smooth and abrupt rates. The air vehicle will not be required to roll in excess of 120 degrees.
C	Combinations of pitch, roll, yaw, and decoupled controls applied while the air vehicle is at or near limiter AOA outside the airspeed range between minimum sustainable speed and maximum level flight speed. These maneuvers include high pitch attitude, low airspeed recoveries and high-speed dive pullouts. Recovery attempts should be initiated immediately after departure occurs.[8]	A and B	The control inputs shall consist of applying controls in the most critical directions, combinations, and rates of application. AOA rate during accelerated maneuvers and pushover-pullups to the limiter AOA will be increased in a build-up fashion until the maximum attainable AOA rate or the maximum suitable AOA rate (if considered less than maximum attainable) is demonstrated. Controls should be applied below limiter AOA if predictions indicate the possibility of inducing a departure. This includes combinations of roll, yaw, and decoupled control inputs below limiter AOA while AOA is increasing both at smooth and abrupt rates. The air vehicle will not be required to roll in excess of 120 degrees.

For Class III air vehicles which employ AOA limiting devices:

Test Phase	Control Application	Flight Phase Category	Maneuver Requirements[2]
A	Longitudinal maneuvers to the limiter AOA ranging from 1-g decelerations to maximum-g decelerations and wind-up turns and pushover-pullups to the limiter AOA over the airspeed range between the minimum sustainable speed and maximum level flight speed. Recovery attempts should be initiated immediately after departure occurs.	A, B, and C	1-g decelerations to the limiter AOA will be performed using a slow control rate which will produce a speed deceleration of approximately 1 knot per second AOA rate during accelerated maneuvers and pushover-pullups to the limiter AOA will be increased in a build-up fashion until the maximum attainable AOA rate or the maximum suitable AOA rate (if considered less than maximum attainable) is demonstrated.
B	Combinations of pitch, roll, yaw, and decoupled[1] controls applied while the air vehicle is at or near limiter AOA outside the airspeed range between minimum sustainable speed and maximum level flight speed. These maneuvers include roll and sideslips at limiter AOA. Recovery attempts should be initiated immediately after departure occurs.	A, B, and C	The control inputs shall consist of applying controls in the most critical directions, combinations, and rates of application. AOA rate during accelerated maneuvers and pushover-pullups to the limiter AOA will be increased in a build-up fashion until the maximum attainable AOA rate or the maximum suitable AOA rate (if considered less than maximum attainable) is demonstrated. Controls should be applied below limiter AOA if predictions indicate the possibility of inducing a departure. This includes combinations of roll, yaw, and decoupled control inputs below limiter AOA while AOA is increasing both at smooth and abrupt rates. The air vehicle will not be required to roll in excess of 120 degrees.

[1] Decoupled controls are defined as unconventional controls such as direct normal force, direct side force, pitch pointing, yaw pointing, vertical translation, lateral translation, and flightpath control using thrust vectoring (excluding V/STOL flight).

[2] Establish the ranges and increments of the following variables to be tested for their influence on high-AOA flight characteristics:

a. Configuration

b. Gross weight

c. C.g.

d. Flight control system status

e. Loadings, both with internal and with external stores; critical combinations of aerodynamic and inertial loadings to include:

   1) Symmetric, fuselage heavy

   2) Symmetric, wing heavy

   3) Asymmetric (maximum allowable asymmetry)

   4) Any other loadings found critical in preliminary test and analysis

f. Entry speed, altitude, and attitude

g. Thrust and engine gyroscopic effects.

Power settings shall include:

a. Take-off (TO) configuration:

   1) All engines at TO thrust

   2) Critical engine inoperative, others at TO thrust (stall approach, Test Phase A only)

b. Power approach (PA) configuration:

   1) All engines at normal approach thrust

   2) Critical engine inoperative, others at required approach thrust

c. Climb (CL) configuration:

   1) All engines at normal climb thrust

   2) Critical engine inoperative, others at normal climb thrust

d. Cruise (CR) configuration:

   1) All engines at thrust for level flight (TLF)

   2) All engines at idle thrust

e. Combat (CO) configuration:

   1) All engines at military rated thrust (MRT)

   2) All engines at maximum augmented thrust (MAT).

Throttle settings for those cases where flameouts or compressor stalls occur shall include:

a. Throttle retarded to idle from the maneuver entry setting position for a malfunctioning engine (for MAT, MRT, TLF).

b. Throttle left at the entry setting position until the entry has been accomplished (for MAT, MRT, TLF) unless compliance would result in exceeding engine operating limitations.

Flight control system configurations shall include:

a. All modes (normal or degraded) of flight control systems that have a reasonable probability of being engaged during or previous to flight at high AOA.

b. Degraded, reversion, reconfiguration, and backup modes that can be engaged during flight at high AOA.

The test air vehicles shall be configured so that these modes can be safely engaged during flight test.

The air vehicles shall be trimmed [controls and throttle(s)] at settings consistent with the maneuver tasks. The effects of each designated flight test variable shall be determined individually in each required Test Phase or until such effects are definitely established and predictable for succeeding Test Phases. Variables need to be tested in combination only when that variable could possibly yield less conservative results from those obtained by individual testing.

[3] Smooth, 1-g entries shall be approached using a slow control rate which would produce a speed deceleration of approximately one knot per second for normal stalls (1g). Smooth, accelerated entries shall be approached using a control rate to achieve an AOA rate of approximately ½ degree per second.

[4] Accelerated entries, encompassing a representative range of Mach number, dynamic pressure, and allowable load factor, shall include wind-up turns, constant altitude turns, and wings-level pullouts from dives appropriate to the air vehicle Class and mission.

[5] In the required abrupt entries, the entry AOA rate may be limited by maximum control deflections and rate. The magnitude of the abrupt entry rates may be graduated in Test Phases A through C, commensurate with the increasing severity of control requirements, but the stated minimum AOA rates shall be achieved in Test Phase C.

[6] These entries shall be initiated from offensive/defensive, ground attack, or other tactical maneuvers associated with the capability and Class of the air vehicle. The maneuvers, conducted with a suitable AOA rate, may include:

a. Inverted stalls and aborted vertical reversements, loops, or Immelmans to investigate inverted out-of-control events

b. High-AOA turn reversals with roll control only, with coordination attempted, and with yaw control only

c. High pitch attitudes (greater than 45 degrees)

d. Head-out-of-cockpit air combat maneuvering or ground attack maneuvering

e. High-g, supersonic turns/transonic decelerations

f. Sudden idle power/speed brake decelerations

g. Sudden asymmetric thrust transients prior to stall.

[7] Misapplied controls shall consist of moving controls in the most critical directions an amount significantly greater than that expected during operational use. This shall generally require somewhat less than full deflection depending upon the mission and expected pilot reactions.

[8] In addition to the demonstration of satisfactory spin, out-of-control, and deep stall recovery procedures, the effects of both premature and delayed application of these recovery procedures shall be investigated during the final phase of testing.

[9] The test pilot shall insure that routine familiarity with stalls, post-stall gyrations, and spins does not negate the intent of the delay/misapplication simulation and does not result in premature application of spin recovery controls before a developed spin has been attained (as subsequently confirmed by the flight records when necessary).

[10] This time requirement may be increased for air vehicles that do not exhibit a clear indication to the pilot of impending loss of control.

[11] With respect to spin attempts, “critical” control positions shall include, but not be necessarily restricted to, pro-spin settings. For some combinations of air vehicle state and entry test variables, the spinning motion may be sustained with controls in positions (neutral, out-of-control recovery settings, or stick forward, for example) other than full pro-spin positions. A recovery attempt with controls displaced from the former positions may result in recovery capability, duration, or reversal tendency materially different from that which would occur if recovery were initiated from the full pro-spin condition. The possibility of reversal or secondary stall should be investigated by holding full recovery control for a brief period after recovery is attained. If it appears possible to encounter these circumstances in service use, the “critical” controls may be any setting necessary to define out-of-control modes and determine recovery characteristics specifically applicable to operational users.

[12] For trainer air vehicles, recovery shall also be demonstrated from a fully-developed spin if such a spin is attainable within a limited number of turns after spin entry.

The following approach will be used to achieve the verification objectives:

a. Before flight test, analysis and simulation will be used to investigate predicted high-AOA flight characteristics for a range of configurations, maneuvers, control inputs, and flight conditions. An initial flight test plan shall be developed from the results of this study.

b. The flight test program will integrate flight demonstration, analysis, and simulation in a build-up approach to critical test points. At each step, analysis and simulation will be used to investigate predicted air vehicle response. Data from flight demonstration will be used to validate or update the analytical and simulation models.

Requirements 3.13.1 through 3.13.6.4 apply at speeds and AOAs which in general are outside the ROTH. These requirements apply for all air vehicle normal states and extreme states in straight unaccelerated flight and in turns and pullups with attainable normal accelerations up to n_L. These requirements also apply to air vehicle failure states that affect stall characteristics. Requirements 3.13.2 through 3.13.4.3 and 3.13.6.4 apply for all stalls, including stalls entered abruptly.

A full range of internal and external loadings should be tested. If modifications such as a spin chute or a flight test nose boom might change the aerodynamic characteristics, some testing might have to be repeated in the service configuration. AFFDL-TR-65-218, among others, indicates ranges of some of the critical inertial parameters that generally give certain spin and recovery characteristics. Former MIL-F-83691 (for the Air Force) and MIL-D-8708 (for the Navy) give further guidance.

A critical design review of the departure and spin characteristics should be performed using pilots who represent the contractor and the procuring activity in a manned simulation program. Prior to CDR, the contractor should develop an evaluation plan that

a. Indicates the range of air vehicle gross weight and c.g. positions, and air vehicle normal, extreme, and failure states associated with each flight phase.

b. Specifies maneuvers and control inputs to be evaluated for each flight phase. The control inputs evaluated should be broadly classed into four techniques:

Technique (1): Ordinary control inputs

Technique (2): Misapplied control inputs

Technique (3): Consecutive misapplied control inputs

Technique (4): Pro-spin control inputs (optional)

The plan should be tailored to the Class and structural design criteria of the air vehicle. Former MIL-S-83691 gives guidance. Aerodynamic data should be of sufficient quality and quantity to recognize at least the initial characteristics of divergence and spin. The piloted simulation should address the maneuvers associated with each flight phase, with some extra simulation time allotted to the pilots to allow them to evaluate entry maneuvers not covered by the plan.

Prior to flight test evaluation of departure and spin characteristics, installation of a recovery system on the flight test air vehicle is recommended to allow for recovery from out-of-control flight and to permit the air vehicle to be safely landed with the engines inoperable.

Typical emergency recovery systems used during high angle of attack and out-of-control flight testing, unless demonstrated to be unwarranted due to inherent system design and redundancy, include a spin recovery system, emergency battery electrical power system, emergency hydraulic power system, an emergency fuel boost pump, continuous engine ignition capability, APU scoop, liquid oxygen breathing system, and an enhanced crew restraint system. The spin recovery system should be capable of recovering the air vehicle from a spin or other out-of-control flight condition if normal techniques are not effective in recovering the air vehicle to a controlled condition. The recovery system should be installed such that it does not snag on the control surfaces, regardless of control surface deflection during or after deployment jettison. The essential cockpit instruments, displays, and controls, including radio communications, landing gear control, and emergency stores jettison functions should remain functional through use of emergency backup systems. Fuel pressure and APU pressure recovery must be adequate to achieve engine airstart at altitude. A reliable aircrew breathing system, that is not dependent on engine bleed air or air vehicle electrical power, should be available. Additional pilot restraint that does not adversely affect ejection seat operation or procedures may be required for high yaw rate or violent high angle of attack maneuvering. Additionally, cockpit indications of the condition of the emergency recovery systems should be available to the pilot.

A flight test plan similar to the one used for simulation should be developed before initiation of flight test. Through flight test, frequent procuring activity/contractor coordination meetings should be held to review results to date and determine the safest course to achieve program objectives. The initial flight test evaluation should include a careful buildup to the maneuvers of Technique (1) (ordinary control inputs) in addition to those maneuvers necessary to determine stability derivatives and calibration of the air data sensors. After evaluation of Technique (1), a careful buildup test to positive and negative AOAs and sideslip in excess of planned production limit settings is needed to verify and define stability derivatives. The simulator aerodynamic data, sensor effects, and subsystem effects (e.g., hydraulic/electrical power) should be updated. Continued piloted simulations should be performed to evaluate departure characteristics for Technique (2) control inputs (misapplied control inputs) and Technique (3) control inputs (the effects of consecutively misapplied control inputs). The effects of Technique (2) control inputs should then be test flown. The results of flight test and updated simulation results should be utilized for system refinement and pilot handbook information. After completion of the departure phase of the F-15 program, a spin recovery program was initiated using Technique (4) maneuvers.

VERIFICATION LESSONS LEARNED (4.13)

A survey of 33 air vehicle manufacturers, research and test agencies, and operational commands and squadrons (AFWAL-TR-81-3108) provides considerable information on “mission phases or tasks involving high-AOA flight, past or present flying qualities problems, stall/departure/spin encounter, future desires, etc.” While information was sought on all classes of air vehicle, most of the concern dealt with departure/spin resistance for Class IV, highly-maneuverable air vehicles. It is realized, however, that this is very important for all classes. Mission requirements such as initial pilot training, forward air control, increased gross weight, or high-altitude start of long-range cruise (to name just a few) expose Class I, II, and III air vehicles to any departure tendency. Concern of operational pilots covered “inadequate cues, flight control system limiters which obviously remove the pilot from control, and adequate control power.”

A major consensus derived from the AFWAL-TR-81-3108 survey is that, for Class IV air vehicles:

> … high-AOA maneuvering in combat, although spectacular or glorious, is not a primary tactic. It is definitely a subordinate area, but one which should not limit use of the aircraft. High-AOA is equated with high energy loss, slowing velocity, and becoming an easy target for the opponent's gun or missile. It is much more desirable to maintain high specific energy by avoiding hard maneuvering. High-AOA combat generally results from pitting aircraft of similar performance and maneuvering capabilities against one another. If the opponents have dissimilar performance capabilities, the fight generally will not last long enough to degenerate to high-AOA. Thus most high-AOA flight results from air combat maneuver (ACM) training against the same type of aircraft. It generally involves gun fighting, and new weapon systems coming into the inventory are counted on to reduce gun fighting.
>
> Thus considering that high-AOA maneuvering is subordinate to the primary mission but should not limit the air vehicle's usefulness, the major expressed concern involved departure/spin resistance, flight cues, and the role of the flight control system.

More recently still, we have seen a renewed interest in extreme AOAs for air combat maneuvering. This need is one matter that must be settled at the outset of a design, since it can have a great impact on the configuration.

Typically Class I air vehicles have much lighter wing loadings than the rest. Most are designed to meet FAA regulations (FAR Part 23), then adapted for military operations; so high-AOA flight is looked at differently for their usage. Similarly, due to the very large inertias and limited maneuvering of Class III air vehicles in all axes, high-AOA departures or large uncommanded motions are not structural design considerations, so vehicle design should assure that such maneuvers are not likely to be encountered. The major concern for departures and spins (3.13.5, 3.13.6, and 3.13.6.4) is therefore Class IV air vehicles.

In terms of design philosophy, AFWAL-TR-81-3108 concludes that there are three separate schools of thought: aerodynamic dominance (e.g., the F-5), balanced aerodynamics and flight control system (F-15), and flight control system dominance (F-16). The military using agencies "expressed views advocating specification- and design-restraint…High-AOA flying qualities specification requirements should not dictate aircraft configuration, flight control system complexity, or even overly compromise primary mission performance." Despite this desire, recent designs (F-15, F-16, F-18, F-20 for example) owe some of their dominant external configuration features, considerable control system logic, or both, to high α considerations. These features were deemed necessary just to avoid excessive occurrences of loss of control.

The reader is referred to AFWAL-TR-81-3108's excellent summary for additional references and more detail on high-AOA requirements, characteristics, and criteria.

On the F-15 and some other air vehicles for which vortices off the nose are prime contributors to the high-AOA characteristics, the flight test nose boom had a marked effect on departure. External stores and store or internal fuel asymmetries have also been found to influence some air vehicles' high-AOA characteristics significantly.

FTC-TD-73-2 provides additional guidance and lessons learned on flight test demonstration of departure resistance and post-departure characteristics.

The availability of valid air vehicle simulation models and other prediction tools is critical to the safe conduct of flight test operations and the reduction of the actual flight tests necessary to document air vehicle characteristics. During preparation for high angle of attack flight testing of the F/A-18E air vehicle, the test team sought to optimize flight testing, minimize resource expenditures, and expedite decisions and schedules by ensuring the fidelity of the high angle of attack simulation model. High confidence in the flight simulation allowed much of the build-up to be eliminated and the interval between test points to be increased. A key to the test team's approach was that the F/A-18E high angle of attack testing was conducted in four phases. During the first phase air vehicle flying qualities at high angle of attack were qualitatively evaluated during benign maneuvering and flight data were gathered to verify and correct the aerodynamic database used in the simulation. The second phase explored build-up to spin entry to confirm the recovery characteristics of the air vehicle from out-of-control conditions. The third phase was designed to determine the control inputs and flight conditions that would cause departures from controlled flight, document the departure boundaries, and demonstrate each type of departure. The test team made extensive use of off-line simulation in the third phase by performing tens of thousands of simulation runs evaluating all conceivable combinations of pilot input at hundreds of different flight conditions. Various loadings, asymmetric thrust conditions, aft center of gravity locations, and pitch attitudes were investigated. The flight test conditions were selected from the conditions identified as prone to departure in the simulation. Flight test results were then used to refine the aerodynamic database used in the simulator to allow for development and modification of control laws such that departures were minimized or eliminated. This approach to high angle of attack testing was also instrumental in revealing a major controllability problem with the air vehicle. Simulation demonstrated that simultaneous application of lateral and longitudinal stick at low angle of attack produced an inertial coupling yawing moment which saturated the rudder causing uncontrollable yaw. The test team was able to identify and correct this problem prior to actually performing the maneuver in flight, which served to eliminate the hazard and greatly reduced risk. The fourth and final phase consisted of dedicated spin testing to analyze spin recovery techniques. The extensive use of simulation and phased approach to flight test buildup served to minimize risk and instilled confidence in the effectiveness of the recovery controls and predictability of the departure conditions and modes.

C.3.13.1 Warning cues.

Warning or indication of approach to stall or loss of air vehicle control shall be clear and unambiguous.

REQUIREMENT RATIONALE (3.13.1)

The seriousness of the consequences of stalling, departure, or spinning demands clear, unambiguous cues to warn the pilot.

REQUIREMENT GUIDANCE (3.13.1)

To Be Prepared

REQUIREMENT LESSONS LEARNED (3.13.1)

This requirement is essentially identical to 3.2.2. Its addition here is based upon three observations: 1) the requirement of 3.2.2 is intended for any dangerous flight condition, not specifically for high-AOA flight; 2) there may be some instances (e.g., air combat maneuvering at high AOA) which should not be considered dangerous; and 3) warning cues provided on many recent air vehicles for high-AOA flight are considered inadequate.

Providing a consistent, useful warning cue to the pilot continues to be a problem, as shown by a survey of pilots of Class IV air vehicles (AFWAL-TR-81-3108). AFWAL-TR-81-3108 summarizes:

> Lack of adequate high-AOA maneuvering/stall non-visual (e.g., tactile) cues rank very high on the pilots' problem list. Such cues are a primary source of information when attention is directed away from the instruments – as is generally the situation surrounding stall encounter. Cues are equally important in air combat to establish maximum and/or optimum maneuver conditions. It appears that very few aircraft have adequate non-visual cues. In particular, single-crew aircraft require a separation of information channels which might be compared with the need for frequency separation in highly augmented aircraft with uncoupled modes of control. That is, artificial devices such as pitch or rudder pedal shakers can be (and are) masked by buffet; aural tones can be (and are) masked by radio communications or missile arming and lock-on tones. The preferred cues are buffet itself and possibly the most consistent and desirable tactile cues – stick force and position. These were stressed over and over by the operational pilots.
>
> The key cues which provide positive indication of changing aircraft AOA or energy state are:
>
> Stick force (per knot or g)
>
> Stick position
>
> Buffet level
>
> Uncommanded aircraft motion
>
> Artificial warning devices

It must be emphasized here that the intent of this requirement, like that of all the high-AOA requirements, is not to force an artificial limit on the air vehicle. The AFWAL-TR-81-3108 survey of using agencies concludes that:

> Prevention of dangerous flight conditions via maneuver limiters drew strong objections from a large segment of the military community. Such devices are viewed as double-edged swords; they inflexibly protect the aircraft (and crew) from inexperienced or inept piloting at the cost of an (arbitrary) imposed safety margin. In so doing they become a pilot equalizer, and make aircraft maneuvering performance predictable to the enemy. Finally, protective limit requirements generally vary with aircraft

> loading (external or internal) and therefore to be effective entail considerable complexity.

Additional information on the F/A-18A at high AOAs ("F/A-18A High Angle of Attack/Spin Testing") shows that it has inadequate buffet and natural stick force cues, though an α-feedback in the control augmentation system provides a good artificial stick force cue. A warning tone is also employed.

Artificial warnings have proven to be inadequate on many air vehicles. AFWAL-TR-81-3108 discusses the F-111/FB-111 in particular:

> It was designed to have (and does have) the very best flying and ride qualities throughout its operational flight envelope. It is described as the Cadillac of military aircraft. This is accomplished largely through the incorporation of:
>
> > High-gain authority command augmentation systems
> >
> > Maneuver enhancement devices (automatic configuration changes)
> >
> > Automatic series trim
>
> As a result, the flying qualities pertaining to stick force, stick position, and aircraft motion remain essentially invariant until stall or departure occurs. There is little buffet, and even this does not change appreciably with AOA. Thus, the aircraft suddenly falls off a "cliff". Three artificial cues – a stick shaker, a horn, and panel lights – are provided, which activate at 14 deg AOA, well below the departure AOA of 20-21 deg. However, these have met with little success in preventing stalls and loss of control. A control system modification is now being retrofitted which will restore the needed stick force/position cues.

The FB-111 control system modifications include a stall inhibitor, a sideslip reducer, and an increase in stick force cues as the AOA limit is approached. This system can be defeated at low airspeed by various combinations of control inputs.

C.4.13.1 Warning cues verification.

Verification shall be by demonstration in the flight tests of the tasks of 4.13. Proof of compliance in these demonstration tasks will consist of pilot comments. The comments shall indicate that the warning cues are clear and unambiguous.

VERIFICATION RATIONALE (4.13.1)

Due to the complex nature of high-AOA flight, final demonstration of compliance with this requirement will necessitate flight testing. Wind tunnel testing will give a preliminary indication of natural buffeting. If artificial warning cues are utilized, verification may include ground simulation. Pilots should evaluate the adequacy of the cues in operational-type maneuvering, as well as in test stall approaches.

VERIFICATION GUIDANCE (4.13.1)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.13.1)

The landing configuration at low weight may be critical because of a lower buffet intensity at the lower airspeed; or there may be less buffeting in the clean configuration.

Evaluation of pilot cues is inherently subjective. The warning should be evaluated by a number of pilots. If there is no consensus, acceptability should be based on adequacy for most service pilots in the intended missions.

C.3.13.2 Stall approach.

The onset of stall warning (3.13.1) shall occur within the speed limits of table C-XVV for 1-g stalls and within the lift limits of table C-XVVI for accelerated stalls, but not within the ROSH.

TABLE C-XVV. Speed range for onset of stall warning for 1-g stalls.

Flight Phase	Minimum speed for onset of warning	Maximum speed for onset of warning
Approach		
All others		

TABLE C-XVVI. Lift range for onset of stall warning for accelerated stalls.

Flight Phase	Minimum lift for onset of warning	Maximum lift for onset of warning
Approach		
All others		

C.3.13.2.1 Intensity of warning.

An increase in intensity of the warning with further increase in AOA shall be sufficiently marked to be noted by the pilot.

C.3.13.2.2 Duration of warning.

The warning shall continue until the AOA is reduced to a value less than that for warning onset.

C.3.13.2.3 Uncommanded oscillations prior to stall.

Prior to the stall, uncommanded oscillations shall not be so severe as to require the pilot's full attention to retain control in the maneuver.

C.3.13.2.4 Cockpit controls prior to stall.

At all AOAs up to the stall, the cockpit controls shall remain effective in their normal sense, and small control inputs shall not result in departure from controlled flight.

C.3.13.2.5 Stall warning.

Stall warning shall be easily perceptible and shall consist of__(1)__.

REQUIREMENT RATIONALE (3.13.2 through 3.13.2.5)

Approach to stall must always be clearly indicated to the pilot with a margin (airspeed or AOA) sufficient to recover from the incipient stall, yet small enough to be meaningful.

REQUIREMENT GUIDANCE (3.13.2 through 3.13.2.5)

Recommended values for table C-XVV:

Flight Phase	Minimum speed for onset of warning	Maximum speed for onset of warning
Approach	Higher of $1.05V_S$ or V_S + 5 knots	Higher of $1.10V_S$ or V_S + 10 knots
All others	Higher of $1.05V_S$ or V_S + 5 knots	Higher of $1.15V_S$ or V_S + 15 knots

Recommended values for table C-XVVI:

Flight Phase	Minimum lift for onset of warning	Maximum lift for onset of warning
Approach	82% of $C_{L_{stall}}$	90% of $C_{L_{stall}}$
All others	75% of $C_{L_{stall}}$	90% of $C_{L_{stall}}$

Recommend values for Blank 1.:
Stall warning shall be easily perceptible and shall consist of <u>buffeting or shaking of the air vehicle, shaking of the cockpit controls, or both</u>.

REQUIREMENT LESSONS LEARNED (3.13.2 through 3.13.2.5)

Even where the ROSH and ROTH coincide, as they may at the low-speed boundaries, there should be sufficient margin from stall that warning should still be required to occur outside the ROSH.

A requirement limiting uncommanded oscillations (as in 3.13.2.3) is quite subjective: one pilot may want no uncommanded motion associated with approach to stall, while another may consider some such motion a necessary evil or even a cue of occasional value, and so find oscillations acceptable. The results of the piloted simulations of AFWAL-TR-80-3141 suggest that a noticeable “g-break” indicated stall while any aperiodic uncommanded motion (in any axis) of greater than 20 deg/sec signified departure.

The accelerated stall margins are in terms of $C_{L_{stall}}$, as in MIL-F-8785C. They correspond to the airspeed stall margins for unaccelerated flight. That was a change from Interim Amendment-1 United States Air Force (USAF), which used AOA margins in recognition of the very shallow lift curve slope characteristic of low aspect ratio and swept wings in the stall approach region. Our C_L margin corresponds then to a rather wide α margin, thus tending to restrict the usable AOA range more than may be necessary. Nevertheless, upon reflection we were convinced that (a) accelerated stall warning requirements must be consistent with those for unaccelerated stalls (for which an error speed margin is both rational and well accepted); and (b) the large $\Delta\alpha$ does not provide enough extra lift to warrant more special consideration. For fighter pilots who want to extract that last little bit of g from their air vehicle in a dogfight or dive pullout, the required progressive warning should help. Perhaps it could be supplemented by a tone or some other indication of nearness to stall AOA.

With limited aerodynamic design capability and inadequate data on pilot desires, more detailed specification of stall warning margins seems unwarranted. However, gaining pilot acceptance of dynamic stall warning may require some additional tailoring of the air vehicle. Possibly the warning range desired for accelerated stall would be mission-dependent (for example, air-to-ground versus air-to-air), considering the average altitude available for recovery, the rapidity of speed bleed-off for the vehicle and weapon configuration, and departure susceptibility and severity. Data are insufficient to establish such mission-dependent criteria, and implementation on air vehicles would be difficult, so the requirements of MIL-F-8785C have been retained.

Adequate, timely warning is of paramount importance if the stall and post-stall characteristics are less than satisfactory. However, even if there is an effective stall limiter, a pilot needs a readily perceived indication of approaching an air vehicle limit.

See AFWAL-TR-80-3141 for more accounts of experience.

C.4.13.2 Stall approach verification.

Verification shall be by demonstration in the flight tests of 4.13. Proof of compliance in these demonstration tasks will consist of pilot comments and time histories of the stall approaches.

VERIFICATION RATIONALE (4.13.2)

While wind tunnel tests and analyses can provide estimates, final verification must be by flight test.

VERIFICATION GUIDANCE (4.13.2)

Verification of 3.13.2 through 3.13.2.5 apply for all stalls, including stalls entered abruptly.

Stall speed is defined herein as a steady state. To determine V_S and α_S the stall approach should be made slowly to eliminate any dynamic effects. At the one knot per second break rate called for by the FAR Part 23 and 25, an airspeed somewhat lower than the present V_S may be reached before the stall break. Trial will determine a rate that is slow enough for the particular air vehicle. (FAR Part 25 landing approaches, however are at 1.4 times the stall speed; while MIL-C-5011 called for landing approach at 1.3 times a somewhat higher V_S, which may be comparable to the FAR approach speed.) Nevertheless, rapid stall entries are also to be evaluated.

Suitability of the warning should be evaluated in operational conditions. Beyond low subsonic speeds, V_S and α_S are functions of Mach number.

VERIFICATION LESSONS LEARNED (4.13.2)

Stall buffet will be less intense at lower speeds, corresponding to lightweight and high-lift configurations (unless the high-lift configuration enhances the stall buffeting).

C.3.13.3 Stall characteristics.

In the unaccelerated stalls of 3.13.2, the pilot should be able to keep roll, yaw, and downward pitch excursions within __(1)__ degrees of the stall attitude. No pitch-up tendencies shall occur in stalls, unaccelerated or accelerated, except a) in the unaccelerated stalls of 3.13.2 mild nose-up pitch is acceptable if no pitch control force reversal occurs and no dangerous, unrecoverable, or intolerable flight conditions result, and b) in the accelerated stalls of 3.13.2, a mild nose-up tendency is acceptable if the operational effectiveness of the air vehicle is not compromised and the air vehicle has adequate stall warning, pitch control effectiveness is such that it is possible to stop the pitch-up promptly and reduce the AOA, and at no point during the stall, stall approach, or recovery, does any portion of the air vehicle exceed structural limit loads.

REQUIREMENT RATIONALE (3.13.3)

In order for an air vehicle to be controllable in a developed stall, uncommanded angular excursions must be of a manageable magnitude, and, in the case of pitch excursions, should be in a direction that will enhance controllability.

REQUIREMENT GUIDANCE (3.13.3)

Blank 1. Recommended values:

Air Vehicle Class:	Excursion limit:
Classes I, II, and III	20 deg
Class IV	30 deg

These limits are the amount of attitude change at stall.

REQUIREMENT LESSONS LEARNED (3.13.3)

The stated tolerance of mild pitch-up is a concession to allow configurations giving significant performance benefits not to be penalized unduly for their stall characteristics. The designer should make every reasonable attempt to avoid pitch-up or, failing that, to minimize it.

There is no mention of angular rates, which may be more important to the pilot at stall. The transients due to failure of the primary flight control system (3.6) are recommended to be less than ±0.5 g laterally or longitudinally and ±10 degrees per second roll rate within two seconds. A similar constraint could be defined for unaccelerated stalls. For particular applications, such as air combat fighters, the intended mission may dictate tighter limits, or even prohibit such excursions, whether open- or closed-loop.

AFWAL-TR-80-3141 and AFFDL-TR-74-61 point out that cases exist in which a pilot's attempts at stabilization do not help, but actually induce instability. For example, with the A-7, aerodynamic coupling between the longitudinal and lateral-directional motions while sideslipping is shown to be the cause of departure from controlled flight. While sideslip is not specifically mentioned in these requirements, some sideslip is common, even unavoidable at high AOAs. However, air vehicles rarely have a decent zero sideslip reference. The contractor should consider whether a sideslip requirement is appropriate.

This requirement legislates against severe pitch-up tendencies, but some non-violent pitch-down which can be arrested often is a desirable characteristic. For large (Class III) air vehicles, excessive nose-down pitching is undesirable, according to AFWAL-TR-81-3108, because of:

> "…the very large inertias involved and the excessive altitude loss which is incurred before recovery. The regions where stall is most usually encountered may also be important, e.g., pitch-down due to stall at cruise ceiling could lead to Mach overspeed, while pitch-down in the landing pattern could easily lead to a non-recoverable dive. The preferred recovery sequence is to set the aircraft nose on the horizon, add full power, and wait for the aircraft to regain flying speed. The preferred metric is the dwell time between recovery initiation and regaining of flight speed. Altitude loss due to settling is less than that due to a diving recovery."

This preference obviously depends on the drag characteristics at stall AOA. The technique described is consistent with training procedures used for civil transport air vehicles. For example, "Out of a Spin" describes the stall series used in Boeing 747 training and recurrent checks:

> "…a V_{ref} (final approach) speed is computed for the landing weight and a bug position next to this number on the airspeed gauge. The first stall is made clean with wings level, the next in a 20-degree bank with 10 degrees of flaps, and the third straight ahead with the gear down and landing flaps (30 degrees). In each exercise the engines remain spun up but at low thrust settings. These configurations approximate those seen in near airport maneuvering.
>
> "The recovery from each is the same: at buffet or stick shaker, apply go-around thrust, lower the nose to five degrees above the horizon, and level the wings. When properly executed, the 747 will resume normal flight with little or no loss of altitude. Rough handling insures a secondary buffet or shaker, or both, and substantial altitude loss."

C.4.13.3 Stall characteristics verification.

Verification shall be by demonstration in the flight tests of 4.13. Proof of compliance in these demonstration tasks will consist of pilot comments and time histories of the stalls.

VERIFICATION RATIONALE (4.13.3)

While wind tunnel tests and analyses can provide estimates, final verification must be by flight test.

VERIFICATION GUIDANCE (4.13.3)

The flight test program should be conducted cautiously, with a build-up from less severe configurations, loadings, entries, and failure states, to more severe ones.

VERIFICATION LESSONS LEARNED (4.13.3)

Stall characteristics generally tend to deteriorate as the c.g. moves aft. External stores may affect the aerodynamic or inertial characteristics significantly, and any asymmetries which can reasonably expected should be test flown.

The extent of required stall penetration during flight testing has been argued extensively. Civil and military definitions of V_S differ – see 4.13.2 Verification Guidance. Also, the desired degree of penetration depends to an extent on intended use, which may be more severe for military than for civil use. In general, even military cargo and transport air vehicles should be taken at least to a stall break that is discernible on the flight records.

C.3.13.4 Stall prevention and recovery.

It shall be possible to prevent the stall by moderate use of the pitch control alone at the onset of the stall warning.

C.3.13.4.1 Stall recovery.

It shall be possible to recover from a stall by simple use of the pitch, roll, and yaw controls with cockpit control forces not to exceed __(1)__, and to regain level flight without excessive loss of altitude or build-up of speed. Throttles should remain fixed until an angle of attack below the stall has been regained unless compliance would result in exceeding engine operating limitations.

C.3.13.4.2 Control power for stall recovery.

In the straight-flight stalls of 3.13.2, with the air vehicle trimmed at an airspeed not greater than 1.4 V_S, pitch control power shall be sufficient to recover from any attainable AOA.

C.3.13.4.3 One-engine-out stalls.

On multi-engine air vehicles it shall be possible to recover safely from stalls with the critical engine inoperative and thrust on the remaining engines at the following settings:

Flight Phase	Thrust
____(2)___	__(3)__
__________	______
__________	______

REQUIREMENT RATIONALE (3.13.4 through 3.13.4.3)

Except for practice or test, stalling is generally an unexpected and potentially dangerous event. Therefore, recovery must be easy and instinctive. Some multi-engine air vehicles exhibit violent, unacceptable rolling or yawing tendencies in engine-out stalls, while the need to maximize air vehicle performance for recovery from an engine failure increases the possibility of stalling.

REQUIREMENT GUIDANCE (3.13.4 through 3.13.4.3)

Blank 1. Recommended values for Blank 1. in 3.13.4.1:

Control type	Pitch (lb)	Roll (lb)	Yaw (lb)
Sidestick	20	15	
Centerstick	50	25	
Wheel			
(two-handed tasks)	75	40	
(one-handed tasks)	50	25	
Pedal			175

Blanks 2 and 3. Recommended values for columns (2) and (3) in 3.13.4.3:

Flight Phase	Thrust
TO	Take-off
CL	Normal climb
PA	Normal approach
WO	Waveoff

REQUIREMENT LESSONS LEARNED (3.13.4 through 3.13.4.3)

Prevention of and recovery from the stall must always be simple for the pilot. MIL-F-8785C included the requirement that throttles remained fixed until “speed has begun to increase”. This has been removed in recognition of the method of stall recovery used for both light trainer (Class I) and heavy (Class III) air vehicles: release back pressure on the wheel, lower the nose to the horizon, and add power – whether airspeed has begun to increase or not.

As long as the wing is unstalled, the addition of power will aid in flying out of the stall with minimal altitude loss. If stalling may produce engine flameout, however, recoveries with appropriate thrust (or lack of it) should be investigated. Also note that control to balance propeller torque may limit the application of power for recovery at very low airspeed.

A potential quantitative criterion for specifying stall recovery for Class III air vehicles is dwell time (AFWAL-TR-81-3108). As mentioned in 3.13.3 Requirement Lessons Learned, this is the time between occurrence of the stall and recovery of flying speed. The criterion is in accordance with standard practice for stall recovery: keeping the nose at the horizon and adding thrust, rather than letting the nose fall through the horizon before thrust is applied.

AGARD-CP-260 shows that for three Class III air vehicles (S-3A, L-1011, and C-5A) maximum nose-down pitch acceleration at the stall was less than or equal to 0.08 rad/sec^2 for 90% of the stalls. It therefore suggests that a pitch recovery criterion that the pitch control produce $\ddot{\theta}$ greater than 0.08 rad/sec^2.

During stall testing of the F-16A/B with aft c.g., pitch-up to an upright deep-stall was encountered, requiring a spin chute for recovery. Figure C-5 shows a time history of a deep stall. Analysis of the F-16 flight control system suggests that the deep stall

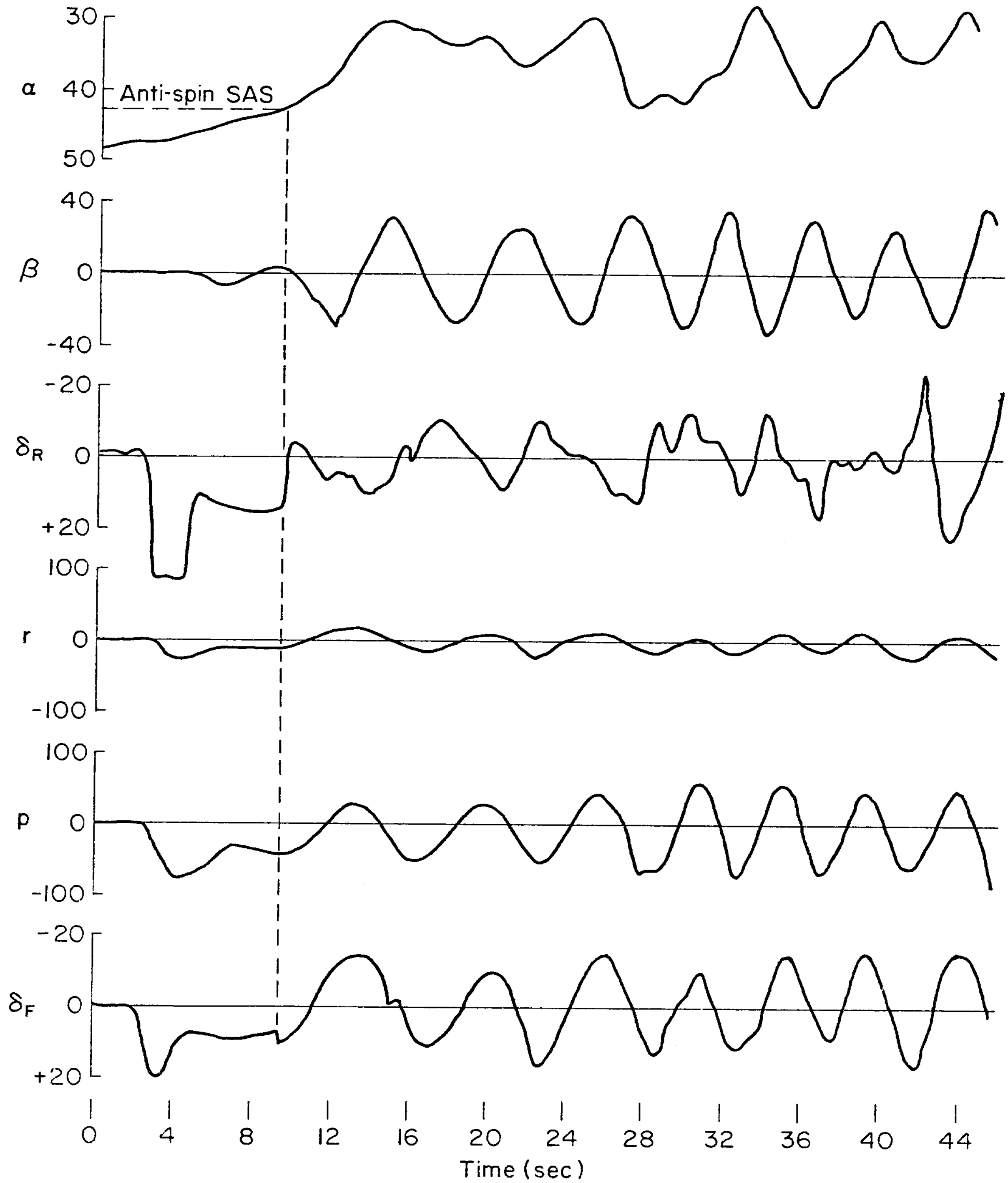

FIGURE C-5. Time history of aft c.g. deep stall encountered by F-16B (AFFTC-TR-79-18).

condition may have been aggravated by anti-spin stability augmentation (SAS), (figure C-6) which is activated at $\alpha \geq 29$ deg, combined with a longitudinal stick gain to remove the pilot from the loop. Figure C-5 shows the point at which the anti-spin SAS became active (t = 10 sec, δ_F is differential flaperon deflection). A lateral limit cycle oscillation developed, possibly caused by the anti-spin SAS, and cross-axis coupling caused the air vehicle to pitch to still higher α and subsequent deep stall, with full nose-down stabilator deflection.

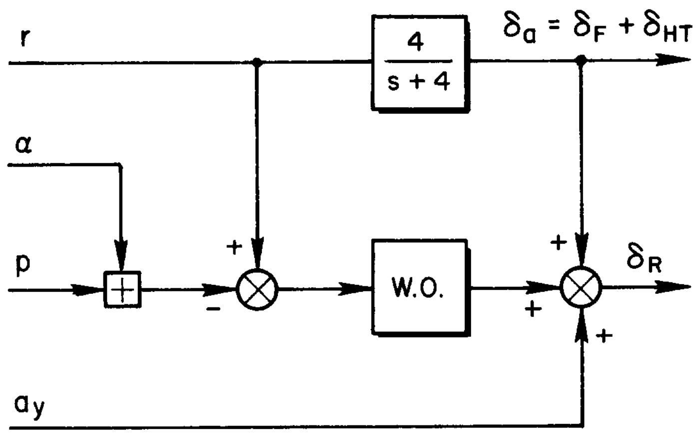

FIGURE C-6. Anti-spin SAS for F-16B ($\alpha \geq 29$ deg).

Recovery from this deep stall (which might arguably be termed a post-stall gyration but certainly is prohibited by 3.3.13.3) without a spin chute requires a manual pitch override (MPO) in the longitudinal SAS (AFFTC-TR-79-18):

> A manual pitch override system was installed in the test aircraft to allow pilot control of the stabilator in a deep stall condition (upright or inverted), and thus allow the aircraft to be "rocked out" of the deep stall…. This pitch override system required the pilot to hold a toggle switch, located on the left console, in the OVRD position during usage. The switch was spring loaded to the NORM position. When selected, the pitch override (a) eliminated the negative g limiter to allow TED stabilator control and (b) for AOA greater than or equal to 29 degrees, eliminated the AOA limiting and pitch integrator functions to allow trailing edge up (TEU) stabilator control.

An MPO switch was included in production air vehicles, but according to AFFTC-TR-79-18, its operational utility is questionable:

> The MPO was an effective upright deep stall recovery device when utilized properly…. However, the ability of the operational pilot to properly and readily adapt to the usage of the MPO remains a concern. During flight tests with pilots who were extremely familiar with the deep stall environment, as many as four total cycles of stick were required before an

> effective cycle was achieved. The primary difficulty encountered involved improper phasing with existing pitch oscillations. Proper phasing became much more difficult when severe roll oscillations existed. The rolling tendency (to as much as 90 degrees bank angle) masked the pitching motion of the aircraft.

Such phasing between stick and air vehicle motion could be considered a violation of this requirement: that is, this is not a “simple” use of the pitch control. What is expedient as a “fix” is not necessarily acceptable for specification use.

Loss of an engine in low-speed flight will often lead to a stall, especially in a critical flight phase such as take-off. The large yawing and rolling moments produced by an engine-out situation can then induce a spin if recovery from the stall is not immediate.

For civil air vehicles, FAR Part 25 requires that recovery be possible “with the remaining engines at up to 75% of maximum continuous power, or up to the power at which the wings can be held level with the use of maximum control travel, whichever is less”. FAR Part 23 is more severe in that it has the additional requirement that the air vehicle not display any undue spinning tendency during the single-engine stall demonstration.

Throttling back on the operative engine(s) during recovery is allowable.

There is some evidence that stalls with one-engine inoperative and the other(s) at high power have led to departures and, in some cases, an out-of-control flat spin. This has occurred on contemporary fighter air vehicles as well as on light twin-engine air vehicles, usually as a result of delayed recovery controls. It is conjectured that several C-133 air vehicles lost at sea had suffered an engine failure at the start of long-range cruise, at or above the service ceiling, where stall margin is minimal. Artificial stall warning, having been found undependable, was sometimes turned off; and poor roll control and a severe roll-off accompanied stall, more so with only three engines.

C.4.13.4 Stall prevention and recovery verification.

Verification shall be by demonstration in the flight tests of 4.13. Proof of compliance in these demonstration tasks will consist of pilot comments and time histories of the stall preventions and stall recoveries.

VERIFICATION RATIONALE (4.13.4)

While wind tunnel tests and analyses can provide estimates, final verification must be by flight test.

VERIFICATION GUIDANCE (4.13.4)

Both stall approaches broken off at stall warning and complete stalls to an AOA great enough to identify V_S are to be performed – with caution and careful build-up at a safe altitude, as with all high-AOA testing. Again, the degree of stall penetration depends to an extent on the intended use of the air vehicle. On air vehicles for which high-AOA testing does not proceed beyond the stall AOA, verification of control to recover from any attainable AOA may be by analysis of wind tunnel data.

VERIFICATION LESSONS LEARNED (4.13.4)

These and other high-AOA tests should be preceded by thorough study of available model tests and simulation results for the particular air vehicle.

For one-engine-out stalls, the same precautions should be observed as in testing other stalls, only more so. These tests will normally follow the symmetric thrust stalls, incrementally increasing good engine thrust on successive stalls. Where propellers or fans direct airflow over the wing, the side with reduced thrust will generally stall first. Lateral control effectiveness may also be reduced by lessened dynamic pressure or even local stalling at the ailerons or spoilers.

C.3.13.5 Departure from controlled flight.

The air vehicle shall be __(1)__ to departure from controlled flight, post-stall gyrations, and spins.

C.3.13.5.1 Departure warning.

Adequate warning of approach to departure (3.13.1) shall be provided.

C.3.13.5.2 Uncommanded motions.

The air vehicle shall exhibit no uncommanded motion which cannot be arrested promptly by simple application of pilot control.

C.3.13.5.3 Departure avoidance following sudden asymmetric loss of thrust.

At all AOAs within the ROSH, following sudden asymmetric loss of thrust from the most critical factor, it shall be possible to avoid departure without exercise of exceptional pilot skill.

REQUIREMENT RATIONALE (3.13.5 through 3.13.5.3)

Departure resistance is a prime concern for high-AOA flight. So far it has been difficult to arrive at an agreed upon method of predicting departure susceptibility.

REQUIREMENT GUIDANCE (3.13.5 through 3.13.5.3)

Recommended words for Blank 1. in 3.13.5:

Normal air vehicles: resistant to departure

High-AOA air vehicles: extremely resistant to departure

For certain training air vehicles, the procuring activity may further designate that the air vehicle shall be capable of a developed spin and consistent recovery.

REQUIREMENT LESSONS LEARNED (3.13.5 through 3.13.5.3)

The definitions of departure susceptibility and resistance from former MIL-S-83691 are pertinent here:

Extremely susceptible to departure: departure from controlled flight will generally occur with the normal application of pitch control alone, or with small roll and yaw control inputs.

Susceptible to departure: departure from controlled flight will generally occur with the application or brief misapplication of pitch and roll or yaw controls that may be anticipated in operational use.

Resistant to departure: departure from controlled flight will only occur with a large and reasonably sustained misapplication of pitch and roll and yaw controls.

Extremely resistant to departure: departure from controlled flight can only occur after an abrupt and inordinately sustained application of gross, abnormal or pro-departure controls.

On a pragmatic basis, the normal requirement would be for an air vehicle to be resistant to departure. If the high-AOA region is particularly important, the air vehicle may be required to be extremely resistant. Also, the procuring activity may further designate that certain (training) air vehicles shall be capable of a developed spin and consistent recovery – so that pilots will not experience such phenomena cold on some later air vehicle.

The requirement is intended to apply to all air vehicles. The terms large, reasonably sustained, abrupt, and inordinately sustained, however, are to be interpreted according to the air vehicle Class and mission. MIL-F-8785C required the air vehicle to be “extremely resistant”; we recommend reducing this in most cases to “resistant”. In the words of AFWAL-TR-81-3108, “The requirement of ‘extremely resistant to departure’ can be expected to dictate aircraft configuration or flight control system complexity, or both – precisely what the using commands warn against. Their preference is that the aircraft be departure/spin resistant.” See also 3.13 Requirement Lessons Learned. Easing this requirement also allows for those (admittedly rare) occasions when pilots of Class IV air vehicles want to use departure as a last ditch evasive maneuver during air combat. The major difference, reflected in the definitions above, is in requiring “reasonably sustained application of … controls” and “inordinately sustained application of gross, abnormal, pro-departure controls” for producing a departure. This difference should not be important except during air-to-air combat.

A requirement for a departure warning (see 3.13.1) reflects pilots’ concerns. According to AFWAL-TR-81-3108:

“Warning is needed which is separate and distinct from stall warning. Margins (maximum and minimum) between warning onset and actual departure should be dependent upon pitch control power (how rapidly the aircraft can transit the warning region), departure severity, spin susceptibility, and aircraft mission.”

C.4.13.5 Departure from controlled flight verification.

Verification shall be by demonstration in the flight tests of 4.13. Proof of compliance in these demonstration tasks will consist of pilot comments and time histories of the departures.

VERIFICATION RATIONALE (4.13.5)

When the post-stall region is not banded by structural design considerations, flight testing is a necessity since it is difficult to define an accurate aerodynamic model for post-stall flight.

VERIFICATION GUIDANCE (4.13.5)

Engineering preparation for departure and spin tests should be done with care. Tasks include:

a. Determination of recovery devices necessary for departure/spin program.

b. Effect of these devices on the aerodynamic characteristics and inertial characteristics of the vehicle.

c. The limits of operation of these devices.

d. A sensitivity analysis of the aerodynamic characteristics and their influence on departure and spin susceptibility. This should be done on the manned simulator as it may influence the flight test technique used to explore the AOAs where unfavorable aerodynamic nonlinearities are expected.

e. Go/no-go criteria should be established; i.e., if a control surface position, sideslip angle, AOA, or rate differs by a defined amount from a predicted value, then testing should be discontinued until further analysis is performed.

VERIFICATION LESSONS LEARNED (4.13.5)

See FTC-TD-73-2 for a comprehensive discussion of considerations for a stall, post-stall, and spin flight test program.

In any simulation, the designer may prefer fixed-base over moving-base to avoid problems with confusing or unrealistic motions that might influence pilots' perceptions. Even for Class III air vehicles, which will have no spin flight tests, stall/post-stall wind tunnel tests and analysis are in order.

Stall AOA (or $C_{L_{max}}$) is dictated by performance requirements. However, experience with the F-5 series air vehicles and the F-15 leads to the conclusion that a sharp increase in longitudinal stability, starting slightly below stall AOA, allows the pilot full use of the transient pitch performance for air combat maneuvers. This aerodynamic characteristic limits AOA overshoots during abrupt pullup and rolling maneuvers. It also provides rapid recovery at low dynamic pressure with neutral pitch control. Though yaw departures occur in a limited portion of the flight regime, the F-15 does not continue into a spin, but pitches down due to its inherent longitudinal stability at high AOA.

A configuration that is longitudinally unstable at or above stall is undesirable for Class IV air vehicles. AOA limiters are usually implemented in this case; limiters can be defeated, however, during low speed maneuvers such as zoom climbs and high-AOA rolls. To preclude AOA overshoots as the limit is approached, a rate anticipation system is usually incorporated into the flight control system. This feature reduces the transient maneuvering performance of the vehicle. Pitching moment curves with a strong unstable break are poor for Class IV applications. When departure occurs, it is violent and can preclude safe ejection of the crew. Even if there is a large amount of nose-down control power, the low dynamic pressure encountered as the air vehicle pitches up results in slow nose-down recovery.

Wind tunnel data that present rolling moment (C_l) and yawing moment (C_n) as functions of AOA for zero sideslip should be evaluated to ensure that no excessively large moment values occur (e.g., from asymmetric vortex shedding from the nose) that could cause departures. The aerodynamic effect of the flight test boom, if located on the nose, should be determined.

An aggressive analytical approach to evaluate and design for departure resistance was taken for the F-5E, F-15, F-16, and YF-17 programs. This approach included obtaining good quality wind tunnel data to 90 degrees AOA at M = 0.2 and above the stall AOA at M = 0.6, 0.9, and 1.2. These data included longitudinal and lateral-directional stability and control data with store configurations. Due to aerodynamic nonlinearities at large positive and negative AOAs, data points should be closely spaced (approximately 3 degrees apart in AOA and sideslip). These data were used to optimize flap schedules and evaluate buffet onset, and as input data for five-degree- and six-degree-of-freedom analyses of large amplitude maneuvers. The control laws were then determined and optimized for flying qualities and departure resistance. Maneuvers included bank-to-bank rolls at maximum AOA, rolls at negative AOAs, pushovers, pullups, and other maneuvers chosen for analysis of departure and spin characteristics. The F-15 program also used free-flight model tests to evaluate departure and spin resistance. Low Reynolds number data were used to correlate with model drop tests. This provided confidence in the analyses of the departure resistance that used high Reynolds number data. New wind tunnel techniques to enhance our analysis capability are emerging. Rotary balance tests can be used to obtain the dynamic derivatives for a more accurate analysis of stall, departure, and spin resistance. After these analyses are performed, manned simulation should be used to verify control laws, flying qualities, and departure resistance prior to flight, and as an adjunct to flight testing.

AGARD-CP-199 presents a number of aspects and views on stall/spin problems. Research contracts sponsored by the Air Force have generated information into the causes of departures and spins. Some of these are discussed in AFFDL-TR-78-171; examples of resulting reports include AFFDL-TR-74-61, AFWAL-TR-80-3141, ASD-TR-72-48, and AFWAL-TR-81-3108.

In the fixed-base piloted simulation of AFWAL-TR-80-3141, various maneuvers (bank-to-bank and wind-up turns, and pullups) were performed with and without a target air vehicle. The simulated air vehicle was based upon an F-4J, and aerodynamic parameters were varied to assess the effects of these parameters on handling qualities. Evaluations of departure susceptibility or resistance (based upon the MIL-F-83691 definitions) were different for the two pilots.

Although generally flight evaluations have been made with limiters operating, it has generally been found that these limiters could be defeated, tricked into allowing penetration to higher angles. Asymmetric loadings, either intentional or naturally occurring can affect post-stall behavior. An increase in control power or a decrease in stability (say, in pitch) can allow attainment of conditions theretofore unreachable.

C.3.13.6 Recovery from post-stall gyrations and spins.

The proper recovery technique(s) shall be readily apparent to the pilot, be simple and easy to apply under the motions encountered, and shall provide prompt recovery from all post-stall gyrations, incipient spins, and developed spins.

C.3.13.6.1 Turns and altitude loss for recovery.

For all modes of spin that can occur, these recoveries shall be attainable within __(1)__, measured from the initiation of recovery action.

C.3.13.6.2 Avoidance of spin reversal.

Avoidance of a spin reversal or an adverse mode change shall not depend upon precise pilot control, timing, or deflection.

C.3.13.6.3 Control forces for recovery.

Safe and consistent recovery and pullouts shall be accomplished without exceeding the following forces: __(2)__, and without exceeding structural limitations.

C.3.13.6.4 Operation of automatic stall, departure, spin prevention, or recovery devices.

Operation of automatic stall, departure, and spin prevention, or recovery devices and flight control modes shall not interfere with the pilot's ability to prevent or recover from stalls and departures.

REQUIREMENT RATIONALE (3.13.6 through 3.13.6.4)

Recovery from post-stall gyrations and spins must be possible and prompt, with simple control application. Even for air vehicles in which flight demonstration is not feasible, the post-stall characteristics need to be known in order to give guidance for inadvertent encounters.

REQUIREMENT GUIDANCE (3.13.6 through 3.13.6.4)

Blank 1. Recommended values for Blank 1. in 3.13.6.1:

Air Vehicle Class	Flight Phases	Turns for Recovery	Altitude Loss*
I	Categories A & B	1-1/2	1000 ft
I	PA	1	800 ft
Other classes	PA	1	1000 ft
Other classes	Categories A & B	2	5000 ft

*Not including dive pullout

Blank 2. Recommended values for Blank 2 in 3.13.6.3:

Control type	Pitch (lb)	Roll (lb)	Yaw (lb)
Sidestick	20	15	
Centerstick	50	25	
Wheel			
(two-handed tasks)	75	40	
(one-handed tasks)	50	25	
Pedal			175

Where requirements exist for spin recovery parachute systems, standard design practices should be followed as found in the Deployable Aerodynamic Decelerator subsection (JSSG-2010-12) of JSSG-2010 Crew Systems Spec Guide and Handbook.

REQUIREMENT LESSONS LEARNED (3.13.6 through 3.13.6.4)

AFWAL-TR-81-3109 describes the evolution of these requirements:

> Prior to Amendment 1 to MIL-F-8785B there had been no general requirements on post-stall gyrations, as distinguished from spins. MIL-F-8785B had only a reference to the then-current spin demonstration requirements of the Air Force (MIL-S-25015) and the Navy (MIL-D-8708). For aircraft to be spun, MIL-S-25015 required ready recovery from incipient and fully-developed spins (5 turns, 1 turn spins for landing, 2 turns inverted). MIL-F-8785B Amendment 1 kept the MIL-S-25015 numbers of turns for spin recovery and added more bounds on altitude loss during recovery. The Class I requirements are similar to those of FAR Part 23 for the Aerobatic Category. Amendment 2 deleted all altitude bounds, on the premise that wing loading and drag are set by other considerations, leaving only turns for recovery to determine altitude loss, and that these bounds and turns for recovery could not reasonably be reduced further. Amendment 2 also deleted a number of Amendment 1's specifics on departure techniques, as well as an Amendment 1 requirement that the start of recovery be apparent within 3 seconds or 1 spin turn. Those specification features indicated desirable tests and characteristics but added considerable detail in areas where design capability is lacking. That material is felt to be more pertinent to a flight demonstration specification such as MIL-S-83691.

Changes from MIL-F-8785C reflect pilots' views on spin recovery. The specification of recovery in terms of altitude loss, as in Amendment 1 of MIL-F-8785B, based upon what the pilot really is concerned about, was considered. For example, the piloted simulation of AFWAL-TR-80-3141 included an air vehicle model that would not spin, but showed a:

> …low-frequency wallowing that masked departure. At the same time, the wallowing does not generate sufficiently rapid motion to excite inertia coupling and PSG. All pilots tend to continue fighting to maintain control well past full stall, incurring excessive altitude loss. However, if controls were released at any time, the aircraft would immediately go into a nose-low spiral and recovery by itself.

High-AOA characteristics were otherwise considered quite good, but the excessive loss of altitude was unacceptable: “Pilot commentary indicated the overall departure ratings were heavily influenced by altitude loss and mission phase.” Specification of altitude loss was however deemed impractical.

AFWAL-TR-81-3108 also shows preference for an altitude-based metric:

> Altitude loss per turn can vary drastically with different spin modes (e.g., steep versus flat), and a given vehicle may exhibit more than one spin mode. The allowable altitude loss, which is highly mission related (e.g., air-to-ground versus air-to-air), appears to be a more appropriate recovery metric than turns for recovery.

However, with a rate of descent in a spin roughly proportional to wing loading, W/S, it would seem extremely difficult for a high-W/S fighter to recovery in much less altitude than presently required. Ideally the altitude loss requirement would also be a function of altitude above the ground, since a PSG at 80,000 ft would not be as critical as one at 2,000 ft above the ground. Although air density variations exert some influence on the motions, such a requirement is not felt to be practical.

It is best if the same technique, or very similar techniques, can be used to recover from all post-stall gyrations, incipient spins, and developed spins. A recovery technique independent of the direction of motion – releasing or centering the controls for example – is very desirable because pilots easily become disoriented in violent post-stall motions. Such recovery characteristics, however, may not be achievable without some automation. A “panic button” has been suggested.

The F-4 series of air vehicles serve as excellent examples of what is good and bad with this requirement. AFFDL-TR-70-155 summarizes a wide body of experience in spin testing of the F-4. The air vehicle was predicted by model tests to have steep erect and inverted oscillatory modes, as well as a flat spin mode. AFFDL-TR-70-155 quotes flight test reports concerning spin testing. For the F-4B:

> A typical spin was initiated by applying pro-spin controls at the stall which resulted in the airplane yawing in the direction away from the applied aileron. After the initial yaw the airplane would pitch nose down to about 60 deg to 80 deg at the ¼-turn position followed by an increase in yaw rate. After ½ turn in yaw the airplane would pitch up to near level and in some cases 10 deg to 20 deg ANU, depending upon the energy conditions at entry. The yaw rate was usually at a minimum when the pitch attitude (and AOA) was at a maximum. The airplane was concurrently oscillating 60 deg in roll with no apparent relationship to pitch or yaw. The motions were extremely oscillatory for the first 2 to 3 turns. After 3 to 4 turns steady state conditions were approached and although the oscillations remained, the amplitude and period became constant.… Pro-spin controls were held for up to 4½ turns. The characteristics of the spin were similar for both left and right spins; however, each spin was different in some aspect from the others even under apparently identical entry conditions.

Standard recovery from incipient undeveloped spins was consistent and effective in all but flat spins. Also the recovery requirement was not met, since the pilot had to determine the direction of the motion and timing was critical:

> The recovery technique used after one turn in the incipient stage and in the fully-developed spin was full aft stick, full rudder against the spin, and full aileron with the spin. This technique would generally affect recovery in ½ to 1½ turns…. The primary visual cue that recovery had been effected was the cessation of yaw. As the yaw rate stopped, the controls had to be neutralized rapidly to prevent a reversal. The time at which controls were neutralized was critical. If controls were neutralized before the yaw rate ceased, the airplane would accelerate back into the spin…, and if they were not neutralized within the one second after the yaw rate stopped, the spin direction would reverse… in most cases, the recovery was indistinct because of residual oscillations, particularly in roll. Even though the yawing had been arrested and the AOA was below stall the aircraft would roll up to 540 deg in the same direction as the terminated spin. The residual oscillations were easily mistaken for a continuation of the spin.

A flat spin led to loss of the air vehicle (figure C-7). The air vehicle was stalled with throttles idle and pro-spin controls. It entered a post-stall gyration, but did not progress to an incipient spin. "After 15 seconds the pilot attempted to terminate the post-stall gyration by neutralizing the rudder and aileron and by placing the stick forward of neutral"; control motions in keeping with the requirement that the recovery not be dependent on determination of the direction of motion. However, according to AFFDL-TR-70-155:

> A left yaw rate developed, and the airplane entered a left incipient spin. After 1-2 turns the oscillations diminished and the flat spin mode became apparent. Anti-spin controls were applied but had no significant effect on the spin characteristics. The drag chute was deployed at 33,000 ft, but again it streamed, did not blossom, and had no effect on the spin. At 27,000 ft the emergency spin recovery chute was deployed, but it also streamed. As a last resort the flight controls were cycled in an attempt to induce oscillations in the spin motions and/or to change the weight characteristics between the airplane and the spin chute. The only apparent effect of the control cycling was an increase in yaw rate to above 100 deg/sec.

These results serve to emphasize the importance of approaching spin testing with great care.

Recovery from the F-16 deep-stall (3.13.4 Requirement Lessons Learned) required both a manual pitch SAS override switch and proper application of longitudinal stick to "rock" the air vehicle out of the stall – an action which required the pilot to determine the direction of motion, albeit in pitch and not yaw.

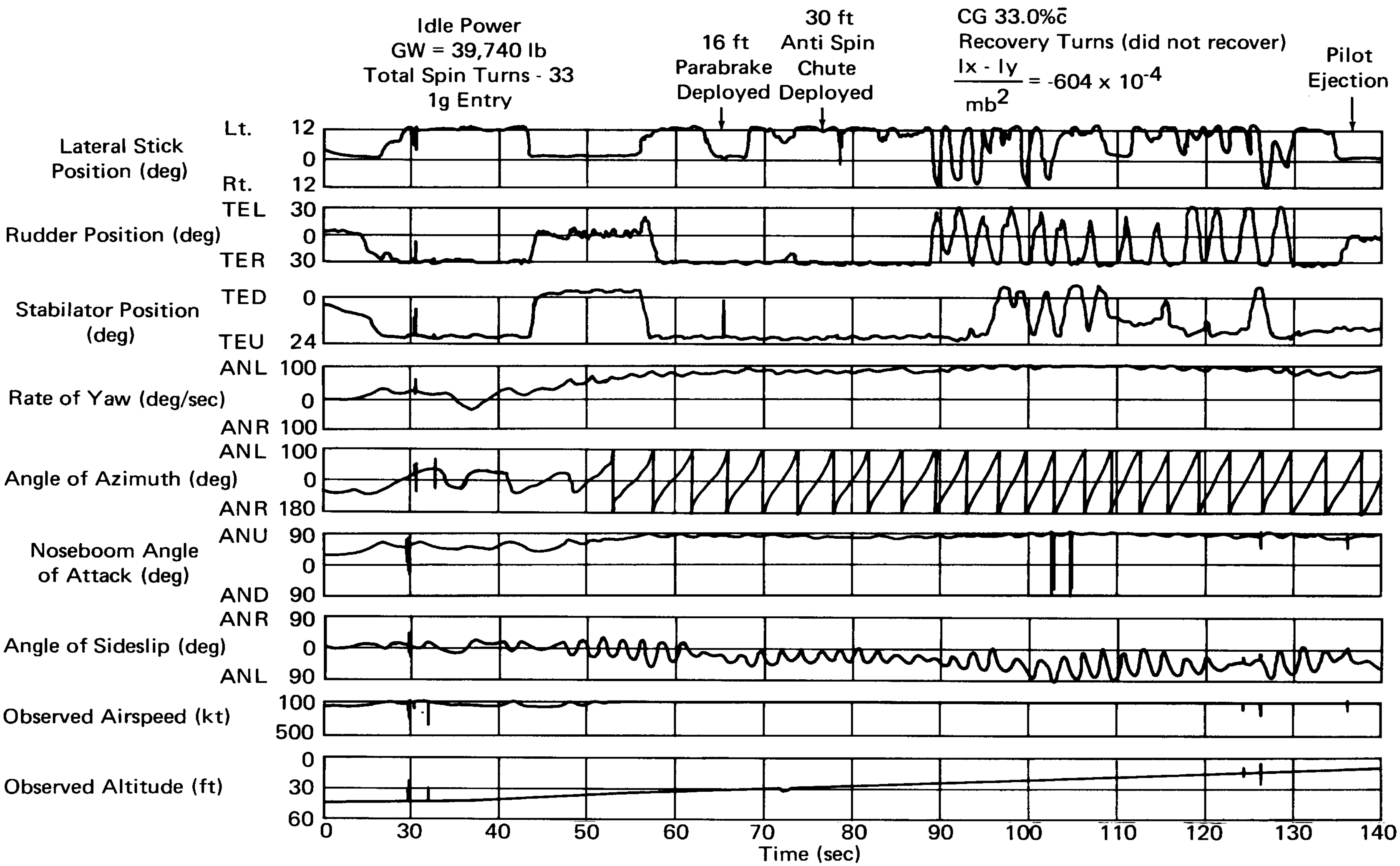

FIGURE C-7. Left flat spin, F-4B (from AFFDL-TR-70-155).

High-AOA testing of the F-18 ("F/A-18A High Angle of Attack/Spin Testing") has uncovered spin modes not unlike those of the F-4:

> A low yaw rate spin was identified using asymmetric thrust to force the entry. It was characterized by yaw rates between 20 deg and 40 deg per second, and angle of attack between 50 deg and 60 deg, a steep nose-low attitude, and fairly smooth pitch and roll rates.
>
> An oscillatory intermediate mode with yaw rates between 50 deg and 80 deg per second and an angle of attack between 60 deg and 80 deg.
>
> A smooth flat mode at 90 deg to 140 deg per second yaw rate with an angle of attack between 80 deg and 85 deg.
>
> The latter two modes were entered by defeating the Control Augmentation System (CAS) and removing all feedback control limiting.
>
> During these tests, 150 entries were attempted with over 100 resultant spins. Since the low-α mode could be entered with CAS on, a manual CAS defeat switch was installed to allow pilot access to maximum control authority for recovery. Using this switch and lateral stick into the spin, a single recovery technique was identified for all three spin modes.

The low-α mode spin has an aspect like the F-16's deep stall, and recovery with a CAS defeat switch is similar. Again, recovery from all three spin modes required determination of the direction of motion to apply lateral stick into the spin.

The 40 pounds allowed for wheel forces is a carryover from MIL-F-8785C. It is based on the use of two hands, a rare occurrence in most flying tasks since one hand is on the throttle(s) during maneuvering. AFFDL-TR-72-141, a validation of MIL-F-8785B using a Class III air vehicle (P-3B) indicates pilot support for the limits for Class III air vehicles. The sidestick forces are based upon both the maximum forces on the F-16 movable stick (AFFTC-TR-79-40) and results of the USAF Test Pilot School evaluations (AFFDL-TR-79-3026). The forces chosen are 70-90 percent of the forces used.

The F-16 and F-18 have fly-by-wire control systems incorporating (respectively) manual pitch override or spin recovery mode switches which change the SCAS feedbacks. However, flight test experience has shown that employment of this type of technology can lead to difficulties associated with the anti-spin flight control system mode interfering with or delaying post-stall gyration spin recovery. As noted earlier, automatic engagement of the F-16 anti-spin stability augmentation system may have aggravated the deep stall condition. For the F/A-18, the flight control system is designed to automatically revert to the ASRM if in a spin. The pilot is given anti-spin control authority should he desire to use it – anti-spin control inputs are not automatically applied. During initial F/A-18 operational evaluation testing, an F/A-18 crashed in a low yaw rate spin because the ASRM did not engage and provide the pilot with full anti-spin control authority. Also, there were occurrences during which the special cockpit displays for spin recovery provided incorrect information. There are no specific requirements presently with regard to the safe operation of the automatic/manual post-stall recovery modes of a flight control system or of associated display operation. Some points to consider are:

> Engagement/disengagement thresholds of automatic spin recovery flight control modes should be designed such that they do not inhibit or prevent recovery.
>
> Displayed recovery information should always present the correct flight control system status (e.g., mode) and recovery control information.

A successful spin test was completed on the F-15 clean and with external stores. Recovery was defined as an absence of yaw rate and a steadily decreasing AOA at an AOA of 20 degrees. Data was cut off. It was later found out that recovery to a safe airspeed in level controlled flight varied with store loading. When the air vehicle was configured with stores, it wallowed more during recovery and took significantly more altitude to regain flying speed than the clean configuration. Furthermore, the pilots recommend slower control inputs during the dive pullout than with the clean configuration. Such information should be determined as a part of analysis and test, and incorporated into the pilot's manual.

C.4.13.6 Recovery from post-stall gyrations and spins verification. Verification shall be by demonstration in the flight tests of 4.13. Proof of compliance in these demonstration tasks will consist of pilot comments and time histories of the departure recoveries.

VERIFICATION RATIONALE (4.13.6)

When the post-stall region is not banded by structural design considerations, flight testing is a necessity since it is difficult to define an accurate aerodynamic model for post-stall flight.

VERIFICATION GUIDANCE (4.13.6)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.13.6)

This requirement will be verified in flight test only for air vehicles that must be designed to withstand the forces of post-stall gyrations and spins. For other air vehicles the requirement is only to determine that post-stall and spin characteristics are satisfactory by appropriate wind tunnel, spin tunnel, or free-flight model testing and analysis. This should provide some confidence in the pilots' handbook material and thus help to save the air vehicles when they inadvertently get beyond prescribed flight limits. The requirement then has implications for design of the structure and other subsystems. The designer should weight the benefits of assured recovery against any design penalties so as not to unduly compromise the air vehicle.

In addition to analysis, common verification techniques include high-AOA wind tunnel tests (e.g., in the NASA Ames 12-ft wind tunnel which has a rotary mount in addition to a high-AOA sting), free-flight model tests in NASA Langley full-scale tunnel, drop model tests with a more or less elaborate flight control system, and (where structural design permits) flight testing. Tests at NASA facilities, such as the Langley spin tunnel, of course need NASA approval. The procuring activity should see that, contractually, results of all such testing are to be made available to their project office.

Detailed analysis and model testing should precede flight verification to determine the characteristics of the particular design. Conditions investigated will be those of 4.13.5.

A wide variety of test philosophies has been applied to recent air vehicles. Of course the severity of control abuse is a function of air vehicle type and missions. There has been controversy in applying the qualitative guidance of former MIL-F-83691. For fighters, testing generally has progressed to the stage of finding ways to defeat any limiters, without turning them off. The F-18 test program went further, exploring limiters off behavior. The first high-AOA tests of the Mirage 2000 were made with the limiter off because the pilots did not trust limiters. However, the F-15 spun nicely after just manipulating the stick to trick the limiter into allowing large pro-spin control surface deflections. For the F-15, loading asymmetries (internal fuel, external stores) caused significant variations in spin characteristics.

Small changes in aerodynamic or inertial configuration have in some cases profoundly affected entry or recovery characteristics. While there are those who for safety rely completely on analysis and model tests to predict recoverability prior to flight tests (for example the Mirage 2000, Mathe in AGARD-CP-333), in this country we have insisted on an additional recovery device for flight verification: a spin chute or spin recovery rockets. The latter have been used on the T-28 and supplemental spin testing on the F-100. Care must be taken that the recovery device does not change the air vehicle motion characteristics.

C.3.14 Ride qualities.

The following short term and applicable long term vertical and lateral axis Ride Discomfort Index (6.4.6) levels shall not be exceeded at any crew station during flight in the turbulence level specified in table C-XVVII.

TABLE C-XVVII. Ride discomfort index limits.

Flight Phase	RMS Turbulence Intensity	Exposure Time	Maximum Ride Discomfort Index
Terrain Following	Up to 1,000 ft AGL σ_w = 3.5 ft/sec, σ_v = 4.0 ft/sec, σ_u = _______	Over 3 hrs From 1.5 to 3 hrs From 0.5 to 1.5 hrs	___________ ___________ ___________
Terrain Following	Up to 1,000 ft AGL σ_w = 7.0 ft/sec, σ_v = 8.0 ft/sec, σ_u = _______	Less than 0.5 hrs	___________
Normal flight, climb, cruise, and descent	Up to 7,000 ft $\sigma_w = \sigma_v = (1.75\text{x}10^{-8})h^2 - (6.05\text{x}10^{-4})h + 3.40$ σ_u = _______ Above 7,000 ft $\sigma_w = \sigma_v = 0.0$, σ_u = _______	Over 3 hrs From 1.5 to 3 hrs From 0.5 to 1.5 hrs	___________ ___________ ___________

Flight Phase	RMS Turbulence Intensity	Exposure Time	Maximum Ride Discomfort Index
Normal flight, climb, cruise, and descent	Up to 10,000 ft $\sigma_w = \sigma_v = (-4.96 \times 10^{-8})h^2 - (4.26 \times 10^{-4})h + 6.40$ σ_u = _______ From 10,000 ft to 37,000 ft $\sigma_w = \sigma_v = (-2.10 \times 10^{-4})h + 7.82$ σ_u = _______ Above 37,000 ft $\sigma_w = \sigma_v = 0.0$, σ_u = _______	Less than 0.5 hrs	___________

REQUIREMENT RATIONALE (3.14)

The intent of this requirement is to specify the ride experienced by the crew. Soft seats or other isolation techniques used should be considered in meeting this requirement. Care must be taken that relative motion between the crew member and his controls and instruments, resulting from isolation techniques, does not degrade crew performance. Visual problems, for example, can be aggravated by relative motion.

REQUIREMENT GUIDANCE (3.14)

Recommendation for table C-XVVII:

Flight Phase	RMS Turbulence Intensity	Exposure Time	Maximum Ride Discomfort Index
Terrain Following	Up to 1,000 ft AGL σ_w = 3.5 ft/sec, σv = 4.0 ft/sec, σ_u = 0.0	Over 3 hours From 1.5 to 3 hours From 0.5 to 1.5 hours	0.10 0.13 0.20
Terrain Following	Up to 1,000 ft AGL σ_w = 7.0 ft/sec, σ_v = 8.0 ft/sec, σ_u = 0.0	Less than 0.5 hours	0.28
Normal flight, climb, cruise, and descent	Up to 7,000 ft $\sigma_w = \sigma_v = (1.75 \times 10\text{-}8)h^2 - (6.05 \times 10\text{-}4)h + 3.40$ $\sigma u = 0.0$ Above 7,000 ft $\sigma_w = \sigma_v = \sigma_u = 0.0$	Over 3 hours From 1.5 to 3 hours From 0.5 to 1.5 hours	0.10 0.13 0.20
Normal flight, climb, cruise, and descent	Up to 10,000 ft $\sigma_w = \sigma_v = (-4.96 \times 10\text{-}8)h^2 - (4.26 \times 10\text{-}4)h + 6.40$ $\sigma u = 0.0$ From 10,000 ft to 37,000 ft $\sigma_w = \sigma_v = (-2.10 \times 10\text{-}4)h + 7.82$, $\sigma_u = 0.0$ Above 37,000 ft $\sigma_w = \sigma_v = \sigma_v = 0.0$	Less than 0.5 hours	0.28

For some STOL applications longitudinal gusts should be considered.

REQUIREMENT LESSONS LEARNED (3.14)

There are several sources of literature available on ride smoothing. AIAA 72-772 describes development of the B-1 ride smoothing system which was synthesized using the ILAF concept. AFFDL-TR-65-190, AIAA 66-999, AIAA 68-1067, Wykes, J. H., Proceedings of AGARD 34th Flight Mechanics Panel, and Mori, A., Proceedings of NAECON 1972, describe the development of the ILAF concept. NASA CR-2158 describes a study of modal suppression on the YF-12A air vehicle.

The production B-1 ride smoothing system used a vertical long-term index near 0.10. The lateral B-1 requirement was more stringent. Commercial feasibility studies have used much more conservative design goals. NASA CR-2276, for example, used an unweighted index of 0.03 in 0.01 turbulence. This is equivalent to an unweighted index of 0.015 in 0.20 turbulence at low level, and is roughly a factor of 10 more stringent than the criterion recommended here. Of course, for specific procurements it may be necessary to specify different values of the Ride Discomfort Index based on unique mission requirements.

The B-52 was known for its marginal ride during low-level penetrations. When compared to this long-term criteria (3 hours = 0.10), the B-52 exceeds the criterion for medium and light gross weights and satisfies the criterion for heavier gross weights. Thus, for the initial penetration flight phase the B-52 ride is acceptable. For later phases the ride is unacceptable if the remaining low-level phase exceeds 3 hours.

The figure 6.4.6-7 acceleration weighting functions are based on the MIL-STD-1472 human sensitivity curves, ISO/DIS 2631, as extrapolated to lower frequencies by an Aerospace Medical Research Laboratory (AMRL) Memo, 8 July 1974. The extrapolations below 1.0 Hz, especially for lateral vibration, are supported by a minimum of data. However, the values defined represent the best consensus of experts within the 6750th Aerospace Medical Research Laboratory, and reflect the current US recommendation to the International Organization for Standardization for human exposure to vibration from 0.1 to 1.0 Hz. The weighting functions defined are truncated at 0.1 Hz and at high frequencies.

The reason for weighting function truncation is the limitations of test equipment used to generate data upon which these curves are based. Moving-base simulators can be used to simulate air vehicles at low frequencies; however, the data obtained below 0.1 to 0.2 Hz is of questionable value since continuous oscillations at these frequencies do not normally occur in flight. In many cases, the pilot or Automatic Flight Control System (AFCS) will control low frequency motions, effectively smoothing these oscillations and reducing the truncation error resulting from this approach (see Hoblat, F. M., 37th Meeting of AGARD Structures and Materials Panel, 1973). Note that attitude-hold or other pertinent modes are to be simulated to satisfy this requirement. These modes should approximate pilot or AFCS suppression of low-frequency responses. Truncation at higher frequencies is permitted since the gust spectrum has very little power beyond 30 Hz. Since structural modes seldom extend to 30 Hz, in practice integration is normally stopped near the frequency of the highest aeroelastic mode modeled. The requirement is to include significant effects to the truncation frequency. Due to gust filter roll-off, integration beyond 15 Hz seldom affects the integral value significantly.

C.4.14 Ride qualities verification.

The requirements apply, separately, to each of the vertical and lateral axes. For the lateral axis requirement only lateral gusts apply and for vertical acceleration only vertical gusts apply. Effects of altitude hold or other pertinent Automatic Flight Control System (AFCS) modes shall be included where used.

VERIFICATION RATIONALE (4.14)

Ride requirements are stated in terms of probabilities, since the ride discomfort addressed by this requirement is generated by random turbulence. The exceedance probabilities and corresponding Ride Discomfort Index values specified are based on the recommendations of ASD-TR-70-18 and ASD-TR-72-64. Generally these requirements should provide ride quality equal to or better than that existing in currently operating air vehicles within the USAF inventory.

VERIFICATION GUIDANCE (4.14)

The turbulence intensities to be used are determined by the exceedance probabilities specified for Ride Discomfort Index. Generally, the system is required to reduce ride discomfort to the levels specified while flying in turbulence with a cumulative exceedance probability equal to or less than the probability specified. System nonlinearities must be considered. System dead zone and other nonlinearities must not be so large that ride discomfort exceeds the 0.10 or other pertinent long-term limits in Common turbulence. System saturation must not be so severe in turbulence at the 0.01 exceedance level that the 0.28 ride discomfort limit is exceeded. The designer should note that the cumulative exceedance probabilities for turbulence are stated in terms of stationary probabilities rather than the nonstationary probabilities used in reliability work. Turbulence exceedance probabilities are tabulated in table 6.4.6-IV.

A stationary probability or cumulative probability of exceedance for turbulence encounter means that at a randomly selected time during flight, the probability of being in turbulence at or above the stated intensity is of a given value. This does not define the probability of exceeding a given level of turbulence during a given flight or flight segment. On a fleet lifetime basis, this probability can be interpreted as the portion of total flight time to be spent above the stated intensity. Since the statistics upon which these probabilities are based were measured over extended operating times, the temptation to convert these values to hours per hour or hours per individual flight should be resisted.

VERIFICATION LESSONS LEARNED (4.14)

The levels of ride discomfort specified are based on short-term tolerance and long-term tolerance. Data from ASD-TR-70-18, ISO/DIS 2631, and NASA TM-X-2620, indicate that below a ride discomfort index of 0.07, little or no degradation in crew performance or passenger comfort is expected. Above a ride discomfort index of 0.28 the USAF references indicate crew action must be initiated to reduce the acceleration environment by changing flightpath, altitude, and/or airspeed.

There is disagreement in the literature on the proper approach for evaluating combined axis accelerations. ASD-TR-70-18 recommends a method for evaluating combined axis accelerations based on USAF experience. ISO/DIS 2631, the ISO standard, recommends that accelerations in separate axes be considered separately; and Boeing D3-7600-14, a commercial air vehicle study, recommended another method for combined axis acceleration evaluation.

Due to the lack of agreement on method and limited test data available on combined axis accelerations, this requirement follows the ISO recommendation and places requirements only on vertical and lateral axis accelerations, separately. The designer should note that vertical ride discomfort is to be evaluated due to vertical axis turbulence only and lateral ride evaluated due to lateral turbulence only. No requirement is specified for roll gusts or longitudinal gusts, although for some STOL applications longitudinal gusts should be considered.

C.3.15 Carrier operations.

In addition to the preceeding requirements, carrier-based air vehicles shall meet the requirements of 3.15.1 through 3.15.6.

REQUIREMENT RATIONALE (3.15)

Carrier-based air vehicles are required to be launched from catapults, landed in arresting gear, and operated from aircraft carriers of a variety of sizes. The carrier-based air vehicle must have deck handling qualities and flying qualities compatible with the shipboard environment.

REQUIREMENT GUIDANCE (3.15)

To Be Prepared

REQUIREMENT LESSONS LEARNED (3.15)

To Be Prepared

C.4.15 Carrier operations verification.

Verification shall be via the requirements of 4.15.1 through 4.15.6.

VERIFICATION RATIONALE (4.15)

See 3.15 Requirement Rationale.

VERIFICATION GUIDANCE (4.15)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.15)

To Be Prepared

C.3.15.1 Deck handling.

The air vehicle shall have ground handling characteristics that allow operation from the constricted spaces aboard ships in degraded environmental conditions.

REQUIREMENT RATIONALE (3.15.1)

Carrier-based air vehicles are required to taxi expeditiously, in confined spaces with various obstacles, and execute precise lineup on the catapult. The deck handling characteristics of the air vehicle can have a significant affect on the launch cycle time.

REQUIREMENT GUIDANCE (3.15.1)

Factors that affect deck handling include power required to initiate air vehicle movement, engine acceleration characteristics, braking characteristics, pivoting of wheels, overshoots, steering effectiveness, and turn radius. Precise directional control and speed control are essential for shipboard operations.

REQUIREMENT LESSONS LEARNED (3.15.1)

To Be Prepared

C.4.15.1 Deck handling verification.

Verification shall include shorebased evaluations followed by testing aboard an aircraft carrier. Deck handling characteristics shall be demonstrated when operating in the tight confines of the carrier hangar and flight deck, during flight deck taxiing, during shipboard long taxi, while performing final alignment on the catapult and tight turns, during low speed taxi on a pitching deck, and when clearing the landing area following shipboard arrested landings.

VERIFICATION RATIONALE (4.15.1)

Shorebased evaluations will allow for a preliminary evaluation of ground handling but shipboard verification is required to confirm that the deck handling characteristics of the air vehicle are actually compatible with the carrier environment, which includes deck surfaces, confined spaces, obstacles, degraded weather conditions, and ship movement.

VERIFICATION GUIDANCE (4.15.1)

All shipboard testing should strive to simulate rapid, expeditious operations aboard the aircraft carrier to evaluate handling qualities under the most representative conditions.

VERIFICATION LESSONS LEARNED (4.15.1)

During initial shipboard trials of the F/A-18A, the air vehicle was discovered to be prone to roll back when taxiing at very low speed on a pitching deck. The pilot had to use continuous throttle inputs to prevent the air vehicle from rolling backwards and subsequent brake input to maintain controlled low speed. Precise speed control utilizing this technique during catapult hook-up and maneuvering close to the edge of the flight deck was complicated by imprecise brake pedal pressure feedback cues to the pilot. Objectionable time lag between pilot braking action and brake system response during carrier deck taxi operations combined with excessive sensitivity of nose wheel steering around neutral to create a deficiency in deck handling characteristics.

C.3.15.2 Catapult launch.

With __(1)__ wind over deck (WOD), Level 1 flying qualities shall be achieved during catapult launches from all in-service catapult types, for all operating weights and center of gravity location combinations, subject to constraints on catapult minimum end speed. Sink off bow shall be no more than __(2)__ and pitch rate shall be no more than __(3)__ following catapult launch.

REQUIREMENT RATIONALE (3.15.2)

The carrier-based air vehicle must be suitable for catapult launching from all catapult positions on various class aircraft carriers under operationally representative environmental conditions.

REQUIREMENT GUIDANCE (3.15.2)

Blank 1. Enter the minimum acceptable WOD for the class ship(s) from which the air vehicle will operate.

Blank 2. Enter the maximum acceptable distance that the air vehicle should sink (in feet) following catapult launch.

Blank 3. Enter the maximum acceptable pitch rate following catapult launch.

REQUIREMENT LESSONS LEARNED (3.15.2)

Experience has demonstrated that pilots prefer stick free catapult launches where control inputs are not required during the catapult launch and pilot input is only required after launch to correct any excessive rates, the angle of attack, or sink off bow.

C.4.15.2 Catapult launch verification.

Simulation and shore-based testing shall be used to predict the minimum airspeed for catapult launches and to demonstrate the flying qualities characteristics approaching the minimum airspeed predicted prior to flying in the carrier environment. The minimum speed to maintain acceptable flying qualities and low speed handling characteristics shall be verified in the carrier environment. Flying qualities shall be evaluated during shipboard catapult launches from each unique catapult type and location (waist and bow). The effects of lateral and longitudinal center of gravity, excess airspeed, and crosswinds on longitudinal trim requirements, rotation and flyaway characteristics during catapult launching shall be evaluated.

VERIFICATION RATIONALE (4.15.2)

Catapult launches must be safely demonstrated on shorebased equipment prior to deploying in the more hazardous environment of the carrier. The compatibility of the air vehicle must be demonstrated for all of the carriers and catapults from which the air vehicle will be expected to operate.

VERIFICATION GUIDANCE (4.15.2)

The rotation to flyaway attitude should be such that settle off the bow is kept to a minimum while avoiding excessively high pitch rates which can be disconcerting and disorienting to the pilot. Dynamic overshoots of the flyaway attitude should be minimized, and any resultant automatic nose-down correction should be small and not uncomfortable for the pilot. The effects of stored energy in the nose and main landing gear should not cause undesirable pitch characteristics. Lateral-directional flying qualities should allow an aggressive clearing turn shortly after launch. It should not be necessary to rapidly retrim the air vehicle or to use large longitudinal control movements immediately after launch.

VERIFICATION LESSONS LEARNED (4.15.2)

To Be Prepared

C.3.15.3 Carrier approach and landing.

Level I flying qualities shall be achieved during approach and landing on carrier decks for all recovery weights, with airspeed slow enough to require a WOD of no more than __(1)__.

REQUIREMENT RATIONALE (3.15.3)

Flying qualities during approach and landing are important in preventing engagement at speeds beyond arresting gear capability, ensuring touchdown within the narrow landing area is consistently achievable, and responding to turbulence around the carrier and pitching and rolling of the carrier deck.

REQUIREMENT GUIDANCE (3.15.3)

Blank 1. Enter the maximum acceptable WOD for the class ship(s) from which the air vehicle will operate.

The air vehicle flying qualities should allow the air vehicle to satisfactorily integrate with existing carrier recovery approach and landing procedures and be compatible with normal recovery patterns. Flying qualities during the carrier approach and landing phase should be satisfactory to allow optimum shipboard recovery with reasonable pilot workload.

REQUIREMENT LESSONS LEARNED (3.15.3)

Experience has shown that the best approach characteristics in the carrier environment are dependent on the stability of angle of attack and attitude and the characteristics of engine response. The visual cueing provided to the pilot is also important in achieving satisfactory handling qualities. The head-up-display has proven to be an extremely helpful tool in the carrier approach and landing environment. Important factors that affect the characteristics of the approach are the field of view, lineup control, gust sensitivity, and flight control input required with power application.

C.4.15.3 Carrier approach and landing verification.

Flying qualities during the carrier approach and landing phase shall be analyzed using simulation, demonstrated using shorebased facilities, and finally verified through shipboard testing. General approach and landing characteristics shall be evaluated during approach and arrested landings, initially in the power approach configuration in level flight and on the glide path during field carrier landing practice. Qualitative evaluation tasks that shall be used to evaluate approach and landing characteristics in the carrier environment include airspeed control, heading control, altitude control, angle of attack control, roll attitude control, heading capture, lineup control, and glideslope control. All applicable types of arrested landings shall be demonstrated including on center, off center, and free flight engagement. The flying qualities shall be evaluated qualitatively over the speed band while making glide path corrections by changing rate of descent at constant thrust and by varying thrust while maintaining constant angle of attack.

VERIFICATION RATIONALE (4.15.3)

The shipboard environment is inherently more dangerous than shorebased operations and, therefore, air vehicle shipboard suitability testing should be preceded by simulation analysis to determine minimum speeds and associated flying qualities at the minimum speeds, and shorebased testing to evaluate the air vehicle in a nearly representative environment. The final determination of optimum approach and landing technique and verification of flying qualities can only be determined aboard carriers.

VERIFICATION GUIDANCE (4.15.3)

Testing should confirm suitability of recommended approach angle of attack and associated airspeeds for the approved landing gross weights. The glideslope, angle of attack, and lineup must be easily controllable within precise limits. Airspeed and altitude control on the downwind leg should be adequate to ensure the proper interval between air vehicles and to increase the likelihood of initiating the final approach at the correct speed and glideslope. Bank control during the approach turn should be adequate to minimize lineup errors at rollout. Deviations from glideslope should be easy to correct to maintain sufficient clearance above the ramp and to touchdown repeatably within the arresting wires. Control of angle of attack is critical to prevent engagement at speeds beyond arresting gear capability, and to prevent excursions into regions of potentially poor flying qualities. Lineup control is critical to ensure touchdown within the narrow landing area. The flying qualities, especially glide path control, should be demonstrated to remain satisfactory when subjected to the considerable turbulence aft of the ship, unpredictable roll gusts, and the pitching and rolling carrier deck. All normal and emergency approach configurations should be considered. Verification must include the effects of minimum recovery headwind, wind–over–deck as high as possible to evaluate burble effects, crosswind recovery, different glide slope angles, and different high lift device positions.

VERIFICATION LESSONS LEARNED (4.15.3)

Glide path corrections are typically made with initial longitudinal control inputs, therefore, it is desirable that the air vehicle have maneuvering capability at a constant thrust setting for small changes in angle of attack. For making large corrections to glide path, it is desirable that the change in thrust required decrease for an increase in angle of attack. The typical correction technique is to correct to the glide slope with longitudinal control, readjusting to the approach angle of attack and then adjusting thrust to correct for the original erroneous thrust setting so that rapid glide path corrections are possible. Experience shows that airspeed instability is the most undesirable single characteristic in the carrier approach.

C.3.15.4 Bolter.

From a four degree glideslope at velocity for power approach, it shall be possible to achieve nosewheel liftoff and attain flyaway attitude by the end of the angle deck, assuming the arresting hook just misses the last wire on the class carriers from which it is required to operate.

REQUIREMENT RATIONALE (3.15.4)

Adequate flying qualities must exist to allow the air vehicle to continue flight when the arresting hook does not engage the arresting cable, because of hook bounce or touchdown outside of the landing area, when attempting an arrested landing.

REQUIREMENT GUIDANCE (3.15.4)

Adequate longitudinal control power should be sufficient to offset the nose-down pitching moment caused by the main landing gear touchdown. The pilot should be able to easily capture the flyaway attitude, with no unusual or excessive control inputs and negligible pilot-induced-oscillation tendency.

REQUIREMENT LESSONS LEARNED (3.15.4)

To Be Prepared

C.4.15.4 Bolter verification.

Flying qualities during a bolter shall be evaluated during shorebased and shipboard touch-and-go landings in all landing flap configurations and with simulated single engine failure. Bolters shall be performed with the air vehicle in an operationally representative loading which produces the most critical nose-heavy moment and with thrust at, or below, an intermediate setting. Bolter technique shall employ aggressive use of aft stick to capture pitch attitude for flyaway.

VERIFICATION RATIONALE (4.15.4)

Flying qualities during a bolter must be demonstrated in the shipboard environment in order to assess the impact of degraded environmental conditions, ship motion, and the variation of pilot gain and technique due to increased risk of hazard to the air vehicle and pilot.

VERIFICATION GUIDANCE (4.15.4)

Flyaway attitude should be reached by the end of the angle deck with a combination of fuel and stores loading which produces the most critical nose-heavy moment with thrust not exceeding an intermediate setting. A normal bolter is defined as one where the entire angle deck landing area beyond the last crossdeck pendant is available for the maneuver. There should be no tendency for pitch oscillations during the bolter. Rotation rates should be uniform and predictable. There should not be any tendency for air vehicle overrotation or pilot-induced-oscillations. Adequate bolter performance must be demonstrated for carriers with the shortest distance between the last available arresting cable and the angle deck round down at air vehicle forward center of gravity positions with minimal wind-over-deck. A preliminary guideline developed by a joint NASA/Navy test team suggests that the air vehicle should be able to generate a pitch acceleration of at least ± 0.20 rad/sec/sec within the first second of pilot maximum longitudinal stick command, at a dynamic pressure for aerodynamic stall, the most critical center of gravity, and with control effectors deflected to maintain stability.

VERIFICATION LESSONS LEARNED (4.15.4)

To Be Prepared

C.3.15.5 Waveoff.

The air vehicle shall possess __(1)__ flying qualities and __(2)__ in order to enable timely and safe termination of a shipboard approach.

REQUIREMENT RATIONALE (3.15.5)

The air vehicle is required to fly out of the carrier approach pattern due to foul deck or incorrect glide path to the ship and, therefore, must possess the flying qualities that are necessary to prematurely terminate a approach to shipboard landing.

REQUIREMENT GUIDANCE (3.15.5)

Blank 1. Enter the required level of flying qualities. Level I is recommended.
Blank 2. Enter required level of performance. Suggested entry would be " a loss of altitude of no more than 30 feet following wave-off initiation.

The altitude lost during a waveoff and the time required to regain a positive rate of climb should be minimized to permit waveoffs in close proximity to landing. The pilot should be able to easily capture the flyaway attitude, with no unusual or excessive control inputs and no tendency for pilot-induced-oscillations. Automatic or manual configuration or control law changes should not cause any undesirable response.

REQUIREMENT LESSONS LEARNED (3.15.5)

To Be Prepared

C.4.15.5 Waveoff verification.

Flying qualities during a waveoff shall be evaluated during shorebased and shipboard approaches to landing in all landing flap configurations and with simulated single engine failure. Waveoff flying qualities shall be demonstrated through attitude captures and angle of attack control tasks. Safe termination of a shipboard approach shall be demonstrated by maintaining the approach angle of attack throughout the maneuver until a positive rate of climb is established or maintaining constant pitch attitude to eliminate the increase in pitch attitude and the likelihood of an in-flight engagement. Waveoff shall be demonstrated for angles of attack above the recommended approach angle of attack.

VERIFICATION RATIONALE (4.15.5)

Flying qualities during a waveoff must be demonstrated in the shipboard environment in order to assess the impact of degraded environmental conditions, ship motion, and the variation of pilot gain and technique due to increased risk of hazard to the air vehicle and pilot.

VERIFICATION GUIDANCE (4.15.5)

A preliminary guideline developed by a joint NASA/Navy test team suggests that the air vehicle should be able to generate a pitch acceleration of at least ± 0.20 rad/sec/sec within the first second of pilot maximum longitudinal stick command, at a dynamic pressure for aerodynamic stall, the most critical center of gravity, and with control effectors deflected to maintain stability.

VERIFICATION LESSONS LEARNED (4.15.5)

To Be Prepared

C.3.15.6 Single engine failure.

At the minimum catapult end airspeed, in configuration for power approach, and 5 knots below the airspeed for power approach for the landing conditions, the dynamic response following engine failure shall not prevent the pilot from controlling the air vehicle with reasonable inputs to reach steady state single engine flight conditions.

REQUIREMENT RATIONALE (3.15.6)

A multi-engine carrier-based air vehicle must have adequate flying qualities to allow for safe completion or termination of a catapult launch or shipboard approach and landing following a single engine failure.

REQUIREMENT GUIDANCE (3.15.6)

To Be Prepared

REQUIREMENT LESSONS LEARNED (3.15.6)

To Be Prepared

C.4.15.6 Single engine failure verification.

Single engine flying qualities during waveoff and bolters shall be demonstrated during shorebased and shipboard touch-and-go landings in all appropriate configurations, thrust settings on the operating engine, and gross weights from a stabilized approach on glide slope. Flying qualities during a dynamic simulated engine failure shall be approximated during simulated single engine operations at a stabilized catapult take-off flyaway attitude.

VERIFICATION RATIONALE (4.15.6)

Since a dynamic single engine failure will likely end in a bolter or waveoff, it must be demonstrated that these maneuvers can be safely executed. Single engine operations can be adequately simulated with the critical engine retarded to idle.

VERIFICATION GUIDANCE (4.15.6)

The air vehicle shall be safely controllable throughout the ensuing motions and, following the transients, the rudders and lateral control surfaces shall be capable of holding zero yawing and rolling velocities, while achieving and maintaining straight flight parallel to the centerline of the angle deck. During the wave–off, angle of attack shall be maintained constant at the original angle of attack until the target pitch attitude is attained. Control forces required should not be excessive.

VERIFICATION LESSONS LEARNED (4.15.6)

To Be Prepared

C.3.16 V/STOL specific requirements.

In addition to the preceeding requirements, V/STOL air vehicles shall meet the requirements of 3.16.1 through 3.16.2.3.

REQUIREMENT RATIONALE (3.16)

The following sections address V/STOL specific operational requirements and flying qualities, and are not meant to be stand-alone requirements. Rather, they are meant to provide requirements above and beyond all other portions of this document that are applicable to all fixed-wing military aircraft, whether they are CTOL, CV, or V/STOL aircraft. More specifically, for all airspeeds above the speed at which the V/STOL aircraft has fully converted to wing-borne flight (the conversion airspeed), all applicable portions of this entire document apply. Although the following sections are meant to address requirements and verification techniques for flight at all speeds below the conversion airspeed (i.e., the powered-lift flight regime), there are still many other sections of this document, outside of the following sections, which are applicable and pertinent to flight at speeds below the conversion speed.

REQUIREMENT GUIDANCE (3.16)

See MIL-F-83300, and AFFDL-TR-70-88.

REQUIREMENT LESSONS LEARNED (3.16)

To Be Prepared

C.4.16 V/STOL specific requirements verification.

Verification shall be via the requirements of 4.16.1 through 4.16.2.3.

VERIFICATION RATIONALE (4.16)

The rationale for verification of V/STOL operational requirements stems from Mission Area Assessments, Mission Need Statements, Concept of Operations and other documentation from USMC, USA, and other armed services requiring V/STOL capabilities to perform their missions.

VERIFICATION GUIDANCE (4.16)

Verification of V/STOL flying qualities requirements is based on NASA Technical Paper 3356, NASA TM 104021, and NADC Report No. 82146-60.

VERIFICATION LESSONS LEARNED (4.16)

To Be Prepared

C.3.16.1 V/STOL operations.

It shall be possible to operate the air vehicle from __(1)__.

REQUIREMENT RATIONALE (3.16.1)

See 3.16 Requirement Rationale.

REQUIREMENT GUIDANCE (3.16.1)

Blank 1.
All air vehicles: austere basing sites
Ship-based air vehicles: LHA, LHD, and CV type ships as well as austere basing sites.

REQUIREMENT LESSONS LEARNED (3.16.1)

To Be Prepared

C.4.16.1 V/STOL operations verification.

Verification shall be via the requirements of 4.16.1.1 through 4.16.1.9.

VERIFICATION RATIONALE (4.16.1)

See 4.16 Verification Rationale.

VERIFICATION GUIDANCE (4.16.1)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.16.1)

To Be Prepared

C.3.16.1.1 Short take-off (STO).

It shall be possible for the air vehicle to accomplish a maximum performance take-off with minimal pilot compensation, with a goal of using only a single pilot input for lift-off. Tracking centerline (or reference line) shall be easy for __(1)__.

REQUIREMENT RATIONALE (3.16.1.1)

See 3.16 Requirement Rationale.

REQUIREMENT GUIDANCE (3.16.1.1)

Blank 1. Recommended value:
All air vehicles: runway take-offs
Ship-based air vehicles: both ship and runway take-offs. It is desirable to have the same configuration for ship-based or land-based STO. Deck minimum endspeed for STO shall meet the constraints of Performance.

REQUIREMENT LESSONS LEARNED (3.16.1.1)

To Be Prepared

C.4.16.1.1 Short take-off (STO) verification.

Verification shall be performed through appropriate usage of analysis, demonstration, simulation (offline, piloted fixed-base, piloted motion-based, and piloted in-flight, if possible), and flight test using appropriate mission-representative STOs.

VERIFICATION RATIONALE (4.16.1.1)

See 4.16 Verification Rationale.

VERIFICATION GUIDANCE (4.16.1.1)

For ship-based air vehicles, “appropriate mission-representative STOs” includes STOs for both ship-borne and land-based decks/runways.

VERIFICATION LESSONS LEARNED (4.16.1.1)

To Be Prepared

C.3.16.1.2 Vertical take-off (VTO).

At weights up to a maximum vertical-take-off weight, it shall be possible for the air vehicle to accomplish a vertical take-off within the conical section defined as follows: during ascent from a maximum thrust vertical take-off, the aircraft position shall be maintained over the take-off point such that the c.g. remains within a conical section by circle with a diameter of __(1)__ at the surface and a concentric circle with a diameter of __(2)__ at a height of __(3)__. It shall be possible to maintain take-off attitude throughout the ascent and stabilize in a hover at __(4)__. Attitude control and flying qualities shall be satisfactory from lift-off through the transition to wing-borne flight.

REQUIREMENT RATIONALE (3.16.1.2)

See 3.16 Requirement Rationale.

REQUIREMENT GUIDANCE (3.16.1.2)

Recommended values for 3.16.1.2:

Blank 1.: 5 feet
Blank 2: 20 feet
Blank 3: 50 feet
Blank 4: 100 feet

REQUIREMENT LESSONS LEARNED (3.16.1.2)

It is a goal that wind conditions cause no change in pilot technique, although workload may increase.

C.4.16.1.2 Vertical take-off (VTO) verification.

Verification shall be performed through appropriate usage of analysis, demonstration, simulation (offline, piloted fixed-base, piloted motion-based, and piloted in-flight, if possible), and flight test using appropriate mission-representative VTOs.

VERIFICATION RATIONALE (4.16.1.2)

See 4.16 Verification Rationale.

VERIFICATION GUIDANCE (4.16.1.2)

For ship-based air vehicles, “appropriate mission-representative VTOs” includes VTOs from both ship-borne and land-based spots’

VERIFICATION LESSONS LEARNED (4.16.1.2)

To Be Prepared

C.3.16.1.3 Shipboard recovery.

During approach and landing pattern tasks, the air vehicle shall satisfactorily integrate with existing shipboard recovery procedures, including compatibility with the Case I, II, and III recovery patterns. Deceleration capability shall be adequate to be able to slow to pattern airspeed following a high-speed overhead break turn. Airspeed and altitude control on the downwind leg shall be adequate to ensure the proper interval between aircraft and to increase the likelihood of initiating the final approach at the correct speed and glideslope. Bank control during the approach turn shall be adequate to minimize lineup errors at rollout.

REQUIREMENT RATIONALE (3.16.1.3)

See 3.16 Requirement Rationale.

REQUIREMENT GUIDANCE (3.16.1.3)

This requirement applies to ship-based air vehicles only. Shipboard recovery procedures are outlined in the LHA/LHD NATOPS Manual and the CV NATOPS Manual.

REQUIREMENT LESSONS LEARNED (3.16.1.3)

To Be Prepared

C.4.16.1.3 Shipboard recovery verification.

Verification shall be performed through appropriate usage of analysis, demonstration, simulation (offline, piloted fixed-base, piloted motion-based, and piloted in-flight, if possible), and flight test.

VERIFICATION RATIONALE (4.16.1.3)

See 4.16 Verification Rationale.

VERIFICATION GUIDANCE (4.16.1.3)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.16.1.3)

To Be Prepared

C.3.16.1.4 Powered-lift landing.

It shall be possible for the air vehicle to accomplish a landing with ground roll for weights at which a vertical landing is not possible.

REQUIREMENT RATIONALE (3.16.1.4)

See 3.16 Requirement Rationale. The need for a requirement on powered-lift landing will be defined in the appropriate Joint Operational Requirement Document (JORD).

REQUIREMENT GUIDANCE (3.16.1.4)

To Be Prepared

REQUIREMENT LESSONS LEARNED (3.16.1.4)

To Be Prepared

C.4.16.1.4 Powered-lift landing verification.

Verification shall be performed through appropriate usage of analysis, demonstration, simulation (offline, piloted fixed-base, piloted motion-based, and piloted in-flight, if possible), and flight test using appropriate mission-representative powered-lift landings.

VERIFICATION RATIONALE (4.16.1.4)

See 4.16 Verification Rationale.

VERIFICATION GUIDANCE (4.16.1.4)

For ship-based air vehicles, “appropriate mission-representative powered-lift landings” includes both ship-borne and land-based powered-lift landings

A suggested task is to establish the appropriate aircraft configuration at a height of 1,000 feet that yields the slowest approach speed consistent with precise flightpath and touchdown control. A glideslope from 3 to 8 degrees is to be assumed with or without a flare depending on maximum gear sink rate limits. At touchdown, the pilot shall use control inputs and maximum braking to minimize ground roll. This task shall be at all weights from minimum to a maximum defined powered-lift landing weight. Further, all near-ground operation shall be at conditions calculated to be Foreign Object Damage (FOD)-free, i.e. the intent is that the aircraft have the flexibility to avoid FOD on austere surfaces by means of rolling take-offs and landings.

VERIFICATION LESSONS LEARNED (4.16.1.4)

To Be Prepared

C.3.16.1.5 Hover.

In normal operation, it shall be possible for the V/STOL air vehicle to ascend and descend to any nominal hover height and to maintain any chosen height in that range. For station keeping in normal operation, it shall be possible to maintain the touchdown reference point within the conical section defined in paragraph 3.16.1.2. It shall be possible to translate the aircraft at essentially constant height to acquire the touchdown point to the same accuracy. It shall also be possible to __(1)__. It is a goal that wind conditions cause no change in pilot technique, although workload may increase.

REQUIREMENT RATIONALE (3.16.1.5)

See 3.16 Requirement Rationale.

REQUIREMENT GUIDANCE (3.16.1.5)

Blank 1. Recommended value:

For ship-based air vehicles: It shall also be possible to stabilize a hover abeam from a translating ship, and at any instant translate the aircraft laterally to acquire the touchdown point to the same accuracy described above, while maintaining small forward airspeed to keep up with the ship. This shall be accomplished while maintaining satisfactory attitude and height control with no undesirable coupling between any axes.

If the air vehicle is not required to be ship-based, Blank 1. is not applicable.

REQUIREMENT LESSONS LEARNED (3.16.1.5)

To Be Prepared

C.4.16.1.5 Hover verification.

Verification shall be performed through appropriate usage of analysis, demonstration, simulation (offline, piloted fixed-base, piloted motion-based, and piloted in-flight, if possible), and flight test using appropriate mission-representative hover tasks.

VERIFICATION RATIONALE (4.16.1.5)

See 4.16 Verification Rationale.

VERIFICATION GUIDANCE (4.16.1.5)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.16.1.5)

To Be Prepared

C.3.16.1.6 Vertical landing (VL).

It shall be possible for the air vehicle to start a vertical landing from a stabilized hover out of ground effect (nominally a height of 50 feet) and perform a controlled descent to the __(1)__ while maintaining thrust margin plus spatial and attitude control capabilities sufficient for safe operations. In normal operation at weights up to maximum vertical landing weight (MVLW), the vehicle shall be capable of maintaining a nominal sink rate of __(2)__ with minimal increase due to ground effects. This controlled descent shall be accomplished while maintaining satisfactory attitude control without any coupling into the vertical axis. It shall be possible to control touchdown reference point to the accuracy required to land on __(3)__. It shall be possible to accomplish a waveoff from a vertical landing with __(4)__ flying qualities from any point on a descent above __(5)__.

REQUIREMENT RATIONALE (3.16.1.6)

See 3.16 Requirement Rationale.

REQUIREMENT GUIDANCE (3.16.1.6)

Blank 1. Recommended value:
All air vehicles: ground
Ship-based air vehicles: ground or ship deck

Blank 2. Recommended value: 4 ft/sec

Blank 3. Recommended value:
All air vehicles: a V/STOL pad
Ship-based air vehicles: a shore-based V/STOL pad, or LHA, LHD, and CV type ships

Blank 4. Enter the required level of flying qualities; specify "Satisfactory" or "Tolerable."

Blank 5. Enter the minimum altitude required for waveoff, or “Minimum Descent Height.”

REQUIREMENT LESSONS LEARNED (3.16.1.6)

The AV-8B Harrier had problems with thrust response in the vicinity of the ground/deck environment during vertical landings. Specifically, there was a problem with bouncing up off of the ground/deck due to a time lag between commanded throttle cutback and actual thrust decrease. It is a goal that wind conditions cause no change in pilot technique, although workload may increase.

C.4.16.1.6 Vertical landing verification.

Verification shall be performed through appropriate usage of analysis, demonstration, simulation (offline, piloted fixed-base, piloted motion-based, and piloted in-flight, if possible), and flight test using appropriate mission-representative vertical landings to __(1)__.

VERIFICATION RATIONALE (4.16.1.6)

See 4.16 Verification Rationale.

VERIFICATION GUIDANCE (4.16.1.6)

Blank 1. Recommended value:
All air vehicles: a VL spot
Ship-based air vehicles: both ship-borne and land-based VL spots

VERIFICATION LESSONS LEARNED (4.16.1.6)

To Be Prepared

C.3.16.1.7 Ground handling.

Air vehicle __(1)__ handling shall be satisfactory. Specifically, there shall be no objectionable aircraft motions after __(2)__ contact, and controllability shall not be in question.

REQUIREMENT RATIONALE (3.16.1.7)

See 3.16 Requirement Rationale.

REQUIREMENT GUIDANCE (3.16.1.7)

Blank 1. Recommended value:
All air vehicles: Ground
Ship-based air vehicles: Ground and deck

Blank 2. Recommended value:
All air vehicles: ground
Ship-based air vehicles: ground and ship-deck

REQUIREMENT LESSONS LEARNED (3.16.1.7)

See Concept of Operations for USMC (including Shipboard Operating Bulletins for LHA/LHD/CV type ships), etc.

The AV-8B had problems in the nose wheel steering gains used for ground/deck taxiing and centerline alignment during short take-offs and slow landings. Though the problems in nose wheel steering gains were not necessarily due to the V/STOL capabilities of the AV-8B, the problems do emphasize the importance of requiring satisfactory ground handling for V/STOL aircraft, especially when any thrust component is directed downwards, decreasing the effective weight of the aircraft and reducing the effectiveness of the tires to create sufficient traction on the ground/deck.

C.4.16.1.7 Ground handling verification.

Verification of ground handling shall be performed through appropriate usage of analysis, demonstration, simulation, and ground handling and taxi tests. Adequate ground handling shall be verified through appropriate ground handling tests and simulations under the most extreme conditions.

VERIFICATION RATIONALE (4.16.1.7)

See 4.16 Verification Rationale.

VERIFICATION GUIDANCE (4.16.1.7)

For ship-based air vehicles, the most extreme ground handling conditions should include rolling, pitching, heaving, wet, low-visibility shipborne environments and ground handling and taxi tests should include both land-based and ship-borne testing.

VERIFICATION LESSONS LEARNED (4.16.1.7)

To Be Prepared

C.3.16.1.8 Transition/conversion.

There shall be no objectionable air vehicle characteristics or aircraft limitations during the conversion process that would delay or adversely impact the normal launch and recovery processes, including loose formation flight. In addition, there shall be no need for precise programming by the pilot of engine power, attitudes, etc., in terms of speed or time. At maximum vertical take-off gross weight, it shall be possible to accelerate from hover to wing-borne flight with minimal pilot compensation.

REQUIREMENT RATIONALE (3.16.1.8)

See 3.16 Requirement Rationale.

REQUIREMENT GUIDANCE (3.16.1.8)

To Be Prepared

REQUIREMENT LESSONS LEARNED (3.16.1.8)

At any time during a transition in normal operation, including conversion, it is desirable for the pilot to be able to quickly and safely stop the maneuver and reverse its direction

C.4.16.1.8 Transition/conversion verification.

Verification shall be performed through appropriate usage of analysis, demonstration, simulation (offline, piloted fixed-base, piloted motion-based, and piloted in-flight, if possible), and flight test using appropriate mission-representative transition tasks.

VERIFICATION RATIONALE (4.16.1.8)

See 4.16 Verification Rationale.

VERIFICATION GUIDANCE (4.16.1.8)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.16.1.8)

To Be Prepared

C.3.16.1.9 Hover mode translation.

The air vehicle shall have satisfactory flying qualities and sufficient performance in the powered-lift terminal flight phase to precisely translate in any direction, without loss of altitude and without any adverse coupling effects between axes.

REQUIREMENT RATIONALE (3.16.1.9)

It should be easy to maneuver the aircraft while in a hover in any direction without loss of altitude.

REQUIREMENT GUIDANCE (3.16.1.9)

To Be Prepared

REQUIREMENT LESSONS LEARNED (3.16.1.9)

It is a goal that wind conditions cause no change in pilot technique, although workload may increase.

C.4.16.1.9 Hover mode translation verification.

Verification shall be performed through appropriate usage of analysis, demonstration, simulation (offline, piloted fixed-base, piloted motion-based, and piloted in-flight if possible), and flight test using appropriate mission-representative hover mode translation tasks.

VERIFICATION RATIONALE (4.16.1.9)

See 4.16 Verification Rationale.

VERIFICATION GUIDANCE (4.16.1.9)

For ship-based air vehicles, “appropriate mission-representative hove mode translation tasks” includes both shipborne and shore-based operations.

VERIFICATION LESSONS LEARNED (4.16.1.9)

To Be Prepared

C.3.16.2 V/STOL control power.

Air vehicle control power in V/STOL operations shall meet the requirements of 3.16.2.1 through 3.16.2.3.

REQUIREMENT RATIONALE (3.16.2)

See 3.16 Requirement Rationale.

REQUIREMENT GUIDANCE (3.16.2)

See 4.16 Verification Guidance.

REQUIREMENT LESSONS LEARNED (3.16.2)

To Be Prepared

C.4.16.2 V/STOL control power verification.

Verification shall be performed through appropriate usage of analysis, demonstration, simulation (offline, piloted fixed-base, piloted motion-based, and piloted in-flight if possible), and flight test using appropriate mission-representative tasks.

VERIFICATION RATIONALE (4.16.2)

See 4.16 Verification Rationale.

VERIFICATION GUIDANCE (4.16.2)

Verification of flying qualities requirements in V/STOL operations can be found in MIL-F-83300, AFFDL-TR-70-88, NASA Technical Paper 3356, NASA TM 104021, and NADC Report No. 82146-60.

VERIFICATION LESSONS LEARNED (4.16.2)

To Be Prepared

C.3.16.2.1 Control power in hovering flight.

The air vehicle shall be able to hover or keep station in winds from zero to __(1)__ from any direction.

REQUIREMENT RATIONALE (3.16.2.1)

See 4.16 Verification Guidance.

REQUIREMENT GUIDANCE (3.16.2.1)

Blank 1. Recommended value: 30 kts

REQUIREMENT LESSONS LEARNED (3.16.2.1)

The flying qualities and flight control system performance should meet the intent of paragraphs 3.2-3.2.5.4 of MIL-F-83300. The following subsections contain specific additions, revisions and modifications based on NASA Technical Paper 3356, NASA TM 104021, and NADC Report No. 82146-60. These additions, revisions, and modifications to MIL-F-83300's design guidelines pertain primarily to control power.

C.4.16.2.1 Control power in hovering flight verification.

Verification shall be performed through appropriate usage of analysis, demonstration, simulation (offline, piloted fixed-base, piloted motion-based, and piloted in-flight if possible), and flight test using appropriate mission-representative tasks.

VERIFICATION RATIONALE (4.16.2.1)

See 4.16 Verification Rationale.

VERIFICATION GUIDANCE (4.16.2.1)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.16.2.1)

To Be Prepared

C.3.16.2.2 Cross-axis coupling.

The air vehicle shall have no objectionable adverse coupling, that is any unwanted response in an axis not commanded by the pilot which requires secondary compensation by the pilot using a different inceptor. Favorable coupling may be used if it is integrated into the primary commanded response (e.g. attitude change to augment translation). Vertical landings shall be possible with no objectionable cross-axis coupling between attitude and height (vertical) control.

REQUIREMENT RATIONALE (3.16.2.2)

See 3.16 Requirement Rationale.

REQUIREMENT GUIDANCE (3.16.2.2)

To Be Prepared

REQUIREMENT LESSONS LEARNED (3.16.2.2)

To Be Prepared

C.4.16.2.2 Cross-axis coupling verification.

Verification shall be performed through appropriate usage of analysis, demonstration, simulation (offline, piloted fixed-base, piloted motion-based, and piloted in-flight if possible), and flight test using appropriate mission-representative tasks.

VERIFICATION RATIONALE (4.16.2.2)

See 4.16 Verification Rationale.

VERIFICATION GUIDANCE (4.16.2.2)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.16.2.2)

To Be Prepared

C.3.16.2.3 Angular (moment-generating) control power.

For all appropriate air vehicle weights, loadings, and centers of gravity, in steady winds, control power available shall be sufficient to produce at least the attitude changes of table C-XVVIII within 1 second from initiation of the relevant inceptor application. These values apply for angular rate and attitude control modes.

TABLE C-XVVIII. Attitude change in one second (degrees).

Level		Pitch	Roll	Yaw
Single-axis control application	Simultaneous pitch, roll and yaw control application			
1				
2	1			
3	2			

REQUIREMENT RATIONALE (3.16.2.3)

These requirements for control power for single-axis control application and simultaneous roll/pitch/yaw control application are minimum requirements. They are meant to specify control power available for maneuvering, which is excess control power above and beyond any control power needed for VTO, STO, hover, station-keeping, glideslope maintenance, and attitude control in crosswinds, turbulence, Hot Gas Ingestion (HGI), and ground effects.

REQUIREMENT GUIDANCE (3.16.2.3)

Recommended values for table C-XVVIII:

Level		Pitch	Roll	Yaw
Single-axis control application	Simultaneous pitch, roll and yaw control application			
1		3	6	4
2	1	2	3	3
3	2	2	2	2

REQUIREMENT LESSONS LEARNED (3.16.2.3)

Several AV-8As were lost as a result of having to use more than 50 percent of available roll control power to trim out a 30 knot crosswind. These requirements have been derived and validated through years of AV-8B/Harrier development, as well as independent simulation and analysis from NASA and other agencies.

C.4.16.2.3 Angular (moment-generating) control power verification.

Verification shall be performed through appropriate usage of analysis, demonstration, simulation (offline, piloted fixed-base, piloted motion-based, and piloted in-flight if possible), and flight test using appropriate mission-representative tasks.

VERIFICATION RATIONALE (4.16.2.3)

See 4.16 Verification Rationale.

VERIFICATION GUIDANCE (4.16.2.3)

To Be Prepared

VERIFICATION LESSONS LEARNED (4.16.2.3)

To Be Prepared

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AIR VEHICLE

JOINT SERVICE SPECIFICATION GUIDE

APPENDIX D

GLOSSARY OF DEFINITIONS, GROUND RULES, AND MISSION PROFILES FOR DEFINING PERFORMANCE CAPABILITY, AIR VEHICLE, FIXED WING

Note: A DRAFT military standard comprises the contents of the following Appendix D information (see D.1.0 through D.1.1.2).

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DRAFT
MIL-STD-XXXX

NOTE: This draft, dated **AUG 1997**, prepared by USAF (ASC/ENFT), NAVAIR (AIR 4.3.2.2), and the ARMY (AMSAT-R-EAA) has not been approved and is subject to modification. It is NOT approved for use as a MIL-STD, but is included in the Air Vehicle JSSG as an aid to help tailor JSSG requirements for use in development of a specific program specification.

MILITARY STANDARD

GLOSSARY OF DEFINITIONS, GROUND RULES, AND MISSION PROFILES FOR DEFINING PERFORMANCE CAPABILITY, AIR VEHICLE

DRAFT

MIL-STD-XXXX

FOREWORD

1. This draft military standard has not yet been approved for use by Departments and Agencies of the Department of Defense as a MIL-STD.

2. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to ASC/ENSS, Wright-Patterson AFB, OH 45433-6503, by using the self addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of the document or by letter.

D.1.0 SCOPE

D.1.1 Scope. This draft military standard (JSSG-2001 Appendix D) covers the definitions, ground rules, and mission profiles for determining the performance of fixed wing air vehicles.

D.1.1.1 Use of Appendix D. This draft military standard (JSSG-2001 Appendix D) should be used until subsequently replaced by a DoD-approved replacement document for the flight performance characteristics specified herein.

D.1.1.2 Tailoring the specification. The information contained herein is provided to assist in tailoring JSSG requirements for development of a specific air vehicle program specification. Table D-I provides the document user a linking tool to the paragraphs (digital viewers can click on the page number to hyperlink to the requirement). Table D-2 lists the symbols and abbreviations used herein.

D.1.2 Purpose. This draft military standard (JSSG-2001 Appendix D) establishes the definitions, ground rules, and mission profiles for determining the performance of fixed wing aircraft. Restrictions, limitations, or qualifications which apply to a particular item of performance are included. It is not, however, the purpose of this document to assign required levels of performance. The requirements are defined in the applicable program specifications.

D.1.3 Applicability. The subject matter contained in this draft military standard (JSSG-2001 Appendix D) applies to the flight performance of manned and unmanned fixed wing (non-rotary wing) aircraft. However, for unmanned aircraft the definitions, ground rules, and mission profiles may not be all inclusive. This draft standard may be applied to conventional, short takeoff and landing (STOL), and vertical/short takeoff and landing (V/STOL) capable aircraft. The sections of this document which specifically address the short takeoff of STOL and V/STOL aircraft also apply to short takeoff vertical landing (STOVL) aircraft. Furthermore, these definitions and groundrules apply equally to operations from large deck carriers and marine amphibious assault (“L” class) ships.

D.1.4 Application guidance. In determining the applicability of the definitions, ground rules, and mission profiles herein and tailoring them to a program, the following principles should be followed:

a. Every program is different.

b. Every design involves compromises among different desirable characteristics.

c. Programs must achieve a balance between operational need, performance, cost, and schedule.

d. The acquisition phase of the program should be considered.

TABLE D-I. Table of contents.

TABLE D-I. Table of contents. – Continued

TABLE D-I. Table of contents. – Continued

TABLE D-I. Table of contents. – Continued

TABLE D-I. Table of contents. – Continued

TABLE D-I. Table of contents. – Continued

TABLES

FIGURES

ANNEXES

ANNEX 1 TABLES

TABLE D-II. List of symbols and abbreviations.

A/B	Afterburner
AEO	All Engines Operating
BTU	British Thermal Units
b	Wing Span
CAP	Combat Air Patrol
CAS	Close Air Support
C_D	Aircraft drag coefficient
CEW	Catapult Equivalent Weight
CFL	Critical Field Length
C.G.	Aircraft center of gravity
C_L	Aircraft lift coefficient
$C_{L_{max}}$	Maximum lift coefficient
D	Aerodynamic drag
DLC	Direct Lift Control
DLI	Deck Launched Intercept
D_p	Propulsive drag
ECS	Environmental Control System
E_s	Specific energy
ΔE_s	Energy exchange
F	Fahrenheit
F_g	Gross thrust
F_n	Net thrust
FM	Cruise figure of merit
ft	Feet
g	Acceleration due to Earth's gravity
gal	Gallons
H	Geopotential altitude
H_d	Density altitude (geopotential)
Hg	Mercury
H_p	Pressure altitude (geopotential)
HT_{MAC}	Height of mean aerodynamic chord above the ground
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IGE	In Ground Effect
KCAS	Knots calibrated airspeed
kts	Knots
lb	Pounds
min	Minutes
n_l	Normal load factor (wind axes)
nm	Nautical mile
n_z	Normal load factor (body axes)
OEI	One-Engine Inoperative
OGE	Out of Ground Effect
P	Static pressure
P_s	Specific excess power
R	Height to span ratio
r	Radius of the earth
RCR	Runway Condition Reading

TABLE D-II. List of symbols and abbreviations. - Continued

R/C	Rate-of-Climb
R/D	Rate-of Descent
RF	Range Factor
S_c	Catapult power stroke
SEAD	Suppression of Enemy Air Defense
sec	Seconds
SR	Specific Range
STOL	Short Takeoff and Landing
STOVL	Short Takeoff/Vertical Landing
T	Temperature
TSFC	Thrust Specific Fuel Consumption
V	Velocity
V_A	Catapult endspeed including thrust effects
V_c	Catapult minimum end airspeed
V_{co}	Initial climb true airspeed
V_{cas}	Calibrated airspeed
V_{cef}	Critical engine failure speed
V_D	Dive speed
V_{DL}	Deadload velocity
V_e	Shipboard engaging speed
V_{eas}	Equivalent airspeed
V_{end}	Deck endspeed
$V_{end(m)}$	Deck minimum end airspeed
$V_{end(op)}$	Deck operational endspeed
VFR	Visual Flight Rules
V_H	Maximum level flight speed
V_{ias}	Indicated airspeed
V_L	Limit speed
V_{mca}	Air minimum control speed
V_{mcad}	Dynamic air minimum control speed
V_{mcas}	Static air minimum control speed
V_{mcg}	Ground minimum control speed
V_{obs}	Obstacle clearance speed
V_{op}	Catapult operational end airspeed
V_{pa}	Approach speed
V_{ref}	Refusal speed
V_{rot}	Rotation speed
V_s	Stall speed
V_{sl}	Stall speed (power-off, landing configuration)
V_{sp}	Stall speed, power-on
V_{spa}	Stall speed, power-on (power for level flight, landing configuration)
V_{spo}	Power-off stall speed
V/STOL	Vertical/short takeoff and landing aircraft
V_{tas}	True airspeed
V_{tdl}	Touchdown speed for land operations
V_{tdc}	Touchdown speed for carrier operations
V_{lo}	Liftoff speed
W	Aircraft weight

TABLE D-II. List of symbols and abbreviations. - Continued

WOD	Wind-Over-Deck
$\dot{W}_f$	Engine fuel flow
$\dot{W}_{fc}$	Fuel flow at initial climb speed at the thrust (power) for takeoff
$\dot{W}_{fo}$	Static fuel flow at the thrust (power) for takeoff
W_{fto}	Takeoff and acceleration fuel
W_{sys}	System weight
W_{TO}	Takeoff weight
Z	Goemetric altitude
Z_d	Density altitude (geometric)
Z_p	Pressure altitude (geometric)
α	Angle of attack (alpha)
α_{pa}	Approach angle of attack
γ	Flight path angle (gamma)
θ	Body pitch angle (theta)
ι	Thrust incidence angle (iota)
μ	Coefficient of friction (mu)
ρ	Atmospheric Density (rho)

D.2.0 APPLICABLE DOCUMENTS

D.2.1 Government documents.

D.2.1.1 Specifications, Standards, and Manuals. Unless otherwise specified, the following specifications, standards, and manuals of the issue listed in that issue of the Department of Defense Index of Specifications and Standards (DoDISS) specified in the solicitation form a part of this draft military standard to the extent specified herein.

SPECIFICATIONS

Military

MIL-T-5642	Turbine Fuel, Aviation, Grades JP-4, JP-5, and JP-5/JP-8 ST
MIL-T-83133	Turbine Fuel, Aviation, Kerosene Types, Grades NATO F-34 (JP-8) and NATO F-35
MIL-P-87107	Propellant, High Density Synthetic Hydrocarbon Type, Grade JP-10
MIL-W-25140	Weight and Balance Control System (For Aircraft or Rotorcraft)

STANDARDS

Military

MIL-STD-210	Climatic Information To Determine Design and Test Requirements for Military Systems and Equipment
MIL-STD-1797	Flying Qualities of Piloted Aircraft

MANUALS

Military

NAEC-MISC-06900	Aircraft Carrier Reference Data Manual

D.2.2 Non-Government Publications. Unless otherwise specified, the following documents are DoD adopted and listed in that issue of the Department of Defense Index of Specifications and Standards (DoDISS) specified in the solicitation. They form a part of this draft standard to the extent specified herein.

American Society for Testing and Materials Standards

ASTM D910	Standard Specification for Aviation Gasolines, Grades 80, 100, and 100LL
ASTM D1655	Standard Specification for Aviation Turbine Fuels, Grades Jet A or Jet A-1, and Jet B

D.2.3 Order of Precedence. 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 regulations unless a specific exemption has been obtained.

D.3.0 DEFINITIONS AND REQUIREMENTS

This section contains the definitions of terms needed to describe the performance of fixed wing aircraft along with the qualifications for their use. For the purpose of this document, the following shall apply:

a. All aircraft limitations and criteria, including structural, flying qualities and propulsion system, where more restrictive, shall take precedence over the performance criteria specified herein. Realistic constraints such as control surface rates, engine response to throttle transients, nozzle rotation rates, etc shall be applied.

b. Definitions assume the use of a point mass, flat non-rotating earth, constant gravity, standard day and zero wind. When conditions other than these are used, care should be taken to ensure the differences introduced by changes are taken into account. For instance, if non-standard day temperatures are used, parameters which are a function of density on standard day will be a function of pressure and temperature. A discussion of non-standard day temperatures and recommended temperature and pressure profiles for both standard and non-standard days are included in Annex 1. If winds are used, speed definitions will only be valid for airspeeds. A discussion of wind effects is included in Annex 1.

c. When performing calculations with an engine inoperative, the drag of the devices used to trim the aircraft, as well as the worst case engine out drag, shall be included. The determination of which inoperative engine is most critical shall include both controllability and loss of lift considerations.

d. Configuration refers to the center of gravity location, gear and flap position, external configuration of the vehicle, and normal mission segment engine bleeds.

e. Steady state refers to the instantaneous condition of equilibrium in which all forces and moments are balanced and the change in all velocities and rotational rates is zero.

f. The ground rules of section D.4.0 apply unless otherwise specified.

g. Many paragraphs include options to be used for calculating various parameters. These are included in sub-paragraphs and "Alternate Design Criteria", and are intended for use if the basic value is inappropriate for a given design or mission.

h. Figure D-1 provides a description of the force accounting used and the axis along which each force is assumed to act.

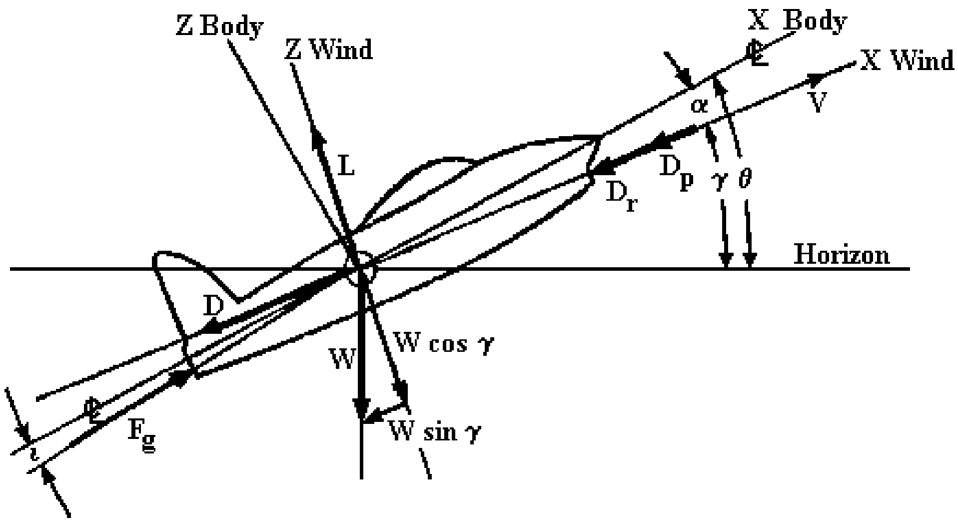

FIGURE D-1. Aircraft force balance diagram.

D.3.1 Missions.

D.3.1.1 Range. Range is defined as the distance (including the distance covered in climb) attainable on a one way flight with specified payload and fuel allowances. Payload, if any, shall be carried the entire distance unless otherwise specified. Distance in descent shall be as specified in Paragraph D.4.2.8. Unless otherwise specified, range missions will be conducted without inflight refueling.

D.3.1.2 Radius. Radius is defined as the distance (including distance covered in climb) to the midpoint of a mission having equal length legs from takeoff point to target and return. Distance in descent shall be as defined in Paragraph D.4.2.8. When the mission definition requires that payload be dropped or off-loaded, it shall be done at the midpoint with no distance credited. Unless otherwise specified, distance covered in combat, maneuvering, loiter, or patrol shall not be included in the radius, and radius missions will be conducted without inflight refueling.

D.3.1.3 Mission Types. The missions defined below are intended to portray the capabilities of the aircraft for specific mission conditions. The mission profiles for these missions, and for other representative operational missions, appropriate to each type aircraft, are given in Annex 2.

D.3.1.3.1 Design Mission. The design mission(s) is defined as the primary mission(s) for which the aircraft was developed. This mission will normally be defined in procurement documents such as the prime item development specification which will include the flight profile, fuel allowances, and payload to be used.

D.3.1.3.2 Clean Mission. The clean mission is defined as a radius mission conducted without payload to show the maximum radius capability of the aircraft. This mission is usually a high-high-high profile.

D.3.1.3.3 Ferry Mission. The ferry mission is defined as a range mission conducted without payload to show the maximum range capability of the aircraft. Auxiliary and external fuel tanks which maximize the range shall be used as authorized by the procuring activity. The ferry mission profile and allowances shown in Annex 2 shall be used unless otherwise specified. When an aircraft is being ferried as part of a deployment to another operating location, it carries the items of equipment included in operating weight (Paragraph D.3.10.3).

D.3.1.3.3.1 Alternate Design Criteria. The following information is provided for use when calculating operational trans-oceanic missions. Distances are for the longest legs encountered when crossing the Atlantic and Pacific oceans. Distances do not include factors to account for winds. When using these distances, the effects of prevailing winds must be considered.

a. Trans-Atlantic Ferry. New York to the Azores - 2100 nm (no wind). An alternate route is 1260 nm from St Johns, Newfoundland to the Azores.

b. Trans-Pacific Ferry. San Francisco to Honolulu - 2100 nm (no wind).

D.3.1.3.4 Inflight Refueled Mission. For aircraft capable of inflight refueling, the range for an inflight refueled mission is defined as the distance (range or radius) attainable through receipt of replacement fuel during flight. Multiple refueling operations may be used if necessary.

D.3.1.3.4.1 Rendezvous Refuel. Rendezvous refuel is defined as a refueling operation in which the tanker and receiver aircraft fly independent routes to a prearranged location. The ground rules stated in Paragraph D.4.2.7.1 shall be used unless otherwise specified.

D.3.1.3.4.2 Buddy Refuel. Buddy refuel is defined as a refueling operation in which the tanker and receiver depart from the same base at the same time and fly the same route at the same airspeed, in close proximity to each other, until the transfer of fuel occurs. The receiver shall not benefit from the wake of the tanker. The ground rules stated in Paragraph D.4.2.7.2 shall be used unless otherwise specified.

D.3.1.4 Mission Categories.

D.3.1.4.1 Combat Air Patrol (CAP). The combat air patrol mission is defined as a radius mission whose purpose is to defend a specific area. The mission profile and allowances shown in Annex 2 shall be used unless otherwise specified.

D.3.1.4.2 Close Air Support (CAS). The close air support mission is defined as a radius mission whose primary role is direct support of ground troops. The mission profiles and allowances shown in Annex 2 shall be used unless otherwise specified.

D.3.1.4.3 Suppression of Enemy Air Defenses (SEAD). The suppression of enemy air defenses mission is defined as a radius mission whose primary role is suppression or destruction of enemy ground to air defense systems, such as radar guided missiles. The mission profile and allowances shown in Annex 2 shall be used unless otherwise specified.

D.3.1.4.4 Interdiction. The interdiction mission is a radius mission whose purpose is destruction of enemy supply routes. The mission profiles and allowances shown in Annex 2 herein shall be used unless otherwise specified.

D.3.1.4.5 Intercept. The intercept mission is a radius mission whose purpose is to get to the combat area as soon as possible to engage enemy aircraft. The mission profiles and allowances shown in Annex 2 shall be used unless otherwise specified.

D.3.1.5 Times.

D.3.1.5.1 Mission Time. Mission time is defined as the time in the air starting at obstacle clearance and ending at touchdown.

D.3.1.5.2 Cycle Time.

a. Land Operations. Cycle time is defined as the time of flight from the start of initial climb (omitting takeoff time) to the time when the engines are stopped after landing.

b. Carrier Operations. Cycle time is defined as the time from first aircraft in first group takeoff (starting with catapult launch) to first aircraft in second group takeoff. (First group lands after second group takeoff.) For 1 + 45 cycle time (1 hour and 45 minutes) mission time is 2 hours, allowing 15 minutes for the second group to takeoff.

D.3.1.5.3 Block Time. Block time is defined as the total time from engine start before takeoff to engine stop after landing.

D.3.1.5.4 Intercept Time. Intercept time is defined as the time from engine start to initiation of combat at the intercept altitude and range. It includes the time required for takeoff and acceleration to climb speed.

D.3.2 Takeoff. Takeoff is defined as that phase of flight during which the aircraft leaves the ground and enters aerodynamic and thrust supported flight. It extends from starting engines to the start of the initial climb. Terminology used for the different portions of takeoff are shown in figure D-2.

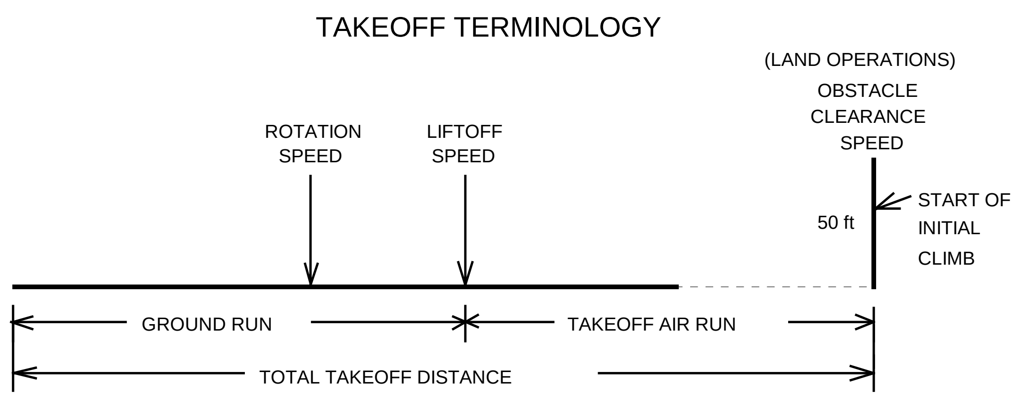

FIGURE D-2. Takeoff terminology.

D.3.2.1 Rotation Speed (V_{rot}). Rotation speed is defined as the speed at which body rotation is initiated from the ground run attitude to the liftoff attitude, for a specified altitude, weight, and configuration. Rotation speed must be equal to or greater than the ground minimum control speed. It must also be equal to or greater than the minimum speed at which the controls, including vectored thrust, if applicable, can generate sufficient moments to initiate rotation.

D.3.2.2 Stall Speed (V_s). Stall speed is defined (per MIL-STD-1797) at 1g normal to the flight path, for a specified altitude, weight, and configuration, as the highest of:

a. The speed for steady, straight and level flight at $C_{L_{max}}$, The first local maximum of the curve of lift coefficient vs. angle of attack which occurs as lift coefficient is increased from zero.

b. The speed at which uncommanded pitching, rolling, or yawing occurs.

c. The speed at which intolerable buffet or structural vibration is encountered.

NOTE: Although the local slope of the curve of lift coefficient vs. angle of attack should be at least zero or positive at all points less than $C_{L_{max}}$, a slightly negative local slope may be permissible if it can be shown by engineering analysis and simulation, and eventually verified by flight test, that no unsatisfactory flying qualities and/or performance characteristics will result.

D.3.2.2.1 Power-Off Stall Speed (V_{spo}). Power-off stall speed is defined as the stall speed without thrust (power). For propeller powered aircraft, power-off stall speed shall be without power and with propellers feathered.

D.3.2.2.2 Power-On Stall Speed (V_{sp}). Power-on stall speed is defined as the stall speed accounting for the stated thrust (power).

D.3.2.3 Liftoff Speed (V_{lo}). Liftoff speed is defined as the speed at which the aircraft leaves the ground for a specified altitude, weight, and configuration.

D.3.2.3.1 Land Operations. Liftoff speed shall be the highest of the following:

a. A speed corresponding to 110 percent of the out of ground effect power-off stall speed in the takeoff configuration. At the discretion of the procuring activity, a power-on stall speed will be considered in lieu of or in addition to the power-off stall speed. For STOVL aircraft, 110 percent of the power-on stall speed shall be used. For multi-engine STOVL aircraft, the effects of having the most critical engine inoperative shall be included.

b. A speed determined by the in ground effect lift coefficient in the takeoff configuration, power-on, for the maximum angle of attack allowable with the main landing gear oleo in the static position with the aircraft on the ground.

c. The minimum speed at which the aircraft has a climb gradient potential of 1/2 percent (0.005), with the thrust (power) setting being used for takeoff, flaps in the takeoff position, landing gear extended, out of ground effect. For multi-engine aircraft this potential shall be obtainable with the most critical engine inoperative (engine windmilling, propeller feathered).

d. 105 percent of the out of ground effect static air minimum control speed, or if flight test data is available, dynamic air minimum control speed. Both static and dynamic air minimum control speeds shall be as defined in MIL-STD-1797.

e. The minimum speed at which the aircraft can initiate rotation to the appropriate takeoff attitude, plus the speed change during rotation.

f. The minimum speed which permits attaining obstacle clearance speed, as defined in Paragraph D.3.2.4, at or before the aircraft clears a height of 50 ft. above the runway.

g. The minimum speed based on flight control limiting with margins applied as appropriate, subject to the approval of the procuring activity.

h. For STOVL aircraft, all propulsion induced forces and moments shall be accounted for.

D.3.2.3.1.1 Alternate Design Criteria. Subject to approval of the procuring activity, consideration may be made of alternate definitions of liftoff speed such as: a higher or lower percentage of stall speed, a higher climb gradient potential or other criteria which reflect the specific aircraft requirements or usage.

D.3.2.3.2 Carrier Operations.

D.3.2.3.2.1 Catapult Minimum End Airspeed (V_c). Catapult minimum end airspeed is defined as the airspeed required at the end of the catapult stroke to support the aircraft under the conditions of altitude loss, lift limit, pitch rate limit, and longitudinal acceleration specified for catapulting. The aircraft is in the launch configuration on an 89.8° F day, unless otherwise specified.

D.3.2.3.2.1.1 Computation Ground Rules. Catapult minimum end airspeed shall be the highest of the following:

a. An endspeed which results in the c.g. position of the aircraft sinking no more than 10 feet from its position at the end of the power stroke, with a deck run not to exceed 32 feet (distance from the end of the power stroke to round-down), with cockpit control position held either fixed or free or controls active (control position(s) during the catapult launch shall be as specified by the catapult flight control position requirements in MIL-STD-1797 as modified by the Design Specification).

b. The speed represented by 90 percent of the maximum lift coefficient, power-off, out of ground effect.

c. The minimum airspeed at which the aircraft has a longitudinal acceleration of .065 g (2.0913 ft/sec^2) at zero flight path angle.

d. 105 percent of the out of ground effect static air minimum control speed, or if flight test data is available, dynamic air minimum control speed. Both static and dynamic air minimum control speeds shall be as defined in MIL-STD-1797.

e. The endspeed which results in an aircraft maximum pitch rate not to exceed 12°/sec to prevent disorientation of the pilot.

f. The minimum speed based on flight control limiting with margins applied as appropriate, subject to the approval of the procuring activity.

D.3.2.3.2.2 Minimum Wind-Over-Deck (Catapult) (WOD). Minimum catapult wind-over-deck is defined as catapult minimum end airspeed minus catapult endspeed (including thrust effects). (Minimum WOD = V_c - V_A)

D.3.2.3.2.2.1 Operational Wind-Over-Deck (Catapult). Operational catapult wind-over-deck is defined as catapult operational end airspeed minus catapult endspeed (including thrust effects). (Operational WOD = V_{op} - V_A)

D.3.2.3.2.3 Catapult Operational End Airspeed (V_{op}). Catapult operational end airspeed is defined as the recommended airspeed required for operational use. Normally this is V_c + 15 kts.

D.3.2.3.2.3.1 Catapult Endspeed Including Thrust Effects (V_A). Catapult endspeed with thrust effects, in knots, is given by the following equation:

$$V_A = \sqrt{\frac{22.5888\frac{S_c(F_n - D)}{W_{sys}} + \sqrt{\left[22.5888\frac{S_c(F_n - D)}{W_{sys}}\right]^2 + 4V_{DL}{}^4}}{2}}$$

Where:

S_c	= catapult Power Stroke, ft
	= 302 ft for C13-1 and C13-2 catapults
	= 243 ft for C13 catapult
	= 247 ft for C7 catapult
	= 205 ft for C11-1 catapult
F_n	= net thrust = (F_g cos ($\alpha + \iota$) - D_r - D_p), lb
F_g	= gross thrust, lb
D_r	= ram drag, lb
D_p	= propulsive drag (other than ram drag), lb
α	= angle of attack
ι	= thrust incidence angle
D	= aerodynamic drag, lb
W	= aircraft weight, lb
CEW	= catapult equivalent weight, lb
	= 5500 lb (all except C13-2 catapults)
	= 6680 lb (C13-2 catapult)
W_{sys}	= system weight, lb = W + CEW
V_{DL}	= deadload velocity, knots (Catapult endspeed without thrust)

Notes: (1) V_{DL} is determined from NAEC-MISC-06900.
(2) Thrust and drag are to be evaluated at 0.7 V_{DL}.
(3) Use minimum engine for thrust calculations.
(4) Use primary mission configuration for drag calculations.

D.3.2.3.2.4 V/STOL Aircraft

D.3.2.3.2.4.1 Deck Minimum End Airspeed (Short Takeoff) ($V_{end(m)}$) Deck minimum end airspeed for a short, non-catapulted takeoff, is defined as the airspeed required at the end of the deck run to support the aircraft under the conditions of altitude loss, lift limit, pitch rate limit, and longitudinal acceleration specified for a short takeoff. The aircraft shall be in the launch configuration on an 89.8° F day, unless otherwise specified.

D.3.2.3.2.4.1.1 Computation Ground Rules. Unless otherwise specified, deck minimum end airspeed shall be the lowest airspeed which satisfies all of the following conditions:

a. The c.g. position of the aircraft shall sink no more than 10 feet from its position at the end of the deck roll.

b. The aircraft shall be limited to an angle-of-attack corresponding to 0.9 $C_{L_{max}}$ (power off).

c. The aircraft shall not exceed a pitch rate of 10 degrees per second.

d. The aircraft shall have a longitudinal acceleration of 0.065g at the completion of the dynamic maneuver (10 feet sink, aircraft rotation, flight control and thrust vectoring movement, etc.). Longitudinal acceleration shall not be negative during any portion of the dynamic maneuver.

e. The aircraft shall maintain its minimum control airspeed with margins applied as appropriate, subject to the approval of the procuring activity.

f. All propulsion induced forces and moments and all ground effects shall be accounted for.

D.3.2.3.2.4.2 Minimum Wind-Over-Deck (Short Takeoff). (WOD). Minimum wind-over-deck for a short takeoff is defined as deck minimum end airspeed minus deck endspeed. (Minimum WOD = $V_{end(m)}$ - V_{end})

D.3.2.3.2.4.2.1 Operational Wind-Over-Deck (Short Takeoff). Operational wind-over-deck for a short takeoff is defined as deck operational end airspeed minus deck endspeed. (Operational WOD = $V_{end(op)}$ - V_{end})

D.3.2.3.2.4.3 Deck endspeed (V_{end}). Deck endspeed for a short takeoff is defined as the speed achieved by the aircraft accelerating at takeoff thrust from the point of brake (or holdback) release to the beginning of the deck edge round-down.

D.3.2.3.2.4.3.1 Deck Operational End Airspeed ($V_{end(op)}$). Deck operational end airspeed is defined as the recommended airspeed required for operational use. Normally this is deck minimum end airspeed + 15 knots.

3.2.4 Obstacle Clearance Speed (V_{obs}). Obstacle clearance speed is defined as the flight path speed, with landing gear extended, with which the aircraft clears a 50 ft height above the runway during climb out, for a specified altitude, weight, and configuration. It shall be the highest of the following:

a. A speed corresponding to 120 percent of the out of ground effect power-off stall speed with flaps in the takeoff position. At the discretion of the procuring activity, a power-on stall speed will be considered in lieu of or in addition to the power-off stall speed.

b. 105 percent of the out of ground effect static air minimum control speed, or if flight test data is available, dynamic air minimum control speed. Both static and dynamic air minimum control speeds shall be as defined by MIL-STD-1797.

c. The minimum speed at which the aircraft has a climb gradient potential of 2.5 percent (0.025), with flaps in the takeoff position, landing gear retracted, with the thrust (power) setting being used for takeoff, out of ground effect. For multi-engine aircraft this potential shall be obtainable with the most critical engine inoperative (engine windmilling, propeller feathered).

d. If gear retraction results in a transient drag increase over that for gear down, the speed at which the aircraft has a 1/2 percent (0.005) climb gradient potential with flaps in the takeoff setting, gear in transit (most critical gear drag), with the thrust (power) setting being used for takeoff, out of ground effect. For multi-engine aircraft, the most critical engine shall be inoperative (engine windmilling, propeller feathered).

e. The minimum speed based on flight control limiting with margins applied as appropriate, subject to the approval of the procuring activity.

D.3.2.4.1 Alternate Design Criteria: Subject to approval of the procuring activity, consideration may be made of alternate limitations to the obstacle clearance speed such as: a higher or lower percentage of the stall speed, an increase in climb gradient potential or other criteria which reflect the specific aircraft requirements or usage.

D.3.2.5 Ground Minimum Control Speed (V_{mcg}). The ground minimum control speed is defined as the minimum speed during the ground takeoff run at which the most critical engine can fail and directional control can be maintained under the conditions and criteria specified by MIL-STD-1797 for a specified altitude, weight, and configuration.

D.3.2.6 Air Minimum Control Speed (V_{mca}).

D.3.2.6.1 Static Air Minimum Control Speed. (V_{mcas}) Static minimum control airspeed is defined as the minimum airborne speed with one engine inoperative, and the remaining engines at Takeoff (maximum) thrust (power), that balanced controlled flight can be maintained under the conditions specified in MIL-STD-1797, for a specified altitude, weight, and configuration.

D.3.2.6.2 Dynamic Air Minimum Control Speed. (V_{mcad}) Dynamic minimum control airspeed is defined as the minimum airborne speed with Takeoff (maximum) thrust (power) at which the engine most critical to control can fail and control can be maintained under the conditions and criteria specified by MIL-STD-1797, for a specified altitude, weight, and configuration.

D.3.2.7 Ground Run Distance. Ground run distance is defined as the distance from brake release (zero velocity) to main wheel lift off for a specified altitude, weight, configuration, and thrust (power) setting. Unless otherwise specified, ground run distance shall be calculated for zero wind, on a dry, hard surfaced runway (RCR = 23) with no slope. The liftoff speed criteria of Paragraph D.3.2.3 shall be used. Ground run distance can be dependent on pilot technique. If a technique is developed during flight testing which will be used in normal operations, ground run distance shall be calculated using that technique subject to approval of the procuring activity.

D.3.2.7.1 Alternate Design Criteria. Subject to approval of the procuring activity, consideration may be made of alternate definitions of ground run distance such as: alternate runway surfaces (sod, wet, ice, etc.), head or tail wind, or other criteria in keeping with the operational concept of the design or mission.

D.3.2.8 Total Takeoff Distance. Total takeoff distance is defined as the horizontal distance required for the aircraft, with the landing gear extended, to clear a 50 ft obstacle height above the runway for a specified altitude, weight, configuration, and thrust (power) setting. It shall be the sum of the ground run distance of Paragraph D.3.2.7 plus the airborne distance needed to accelerate and climb to clear the 50-ft height at the speed specified in Paragraph D.3.2.4. Total takeoff distance can be dependent on pilot technique. If a technique is developed during flight testing which will be used in normal operations, total takeoff distance shall be calculated using that technique subject to approval of the procuring activity.

D.3.2.9 Ground Effect. Ground Effect is defined as the alteration of the free air aerodynamic characteristics of the aircraft due to the presence of the ground.

D.3.2.9.1 Out of Ground Effect (OGE). Out of ground effect is defined as free air where there is no effect of the ground on the aerodynamic characteristics of the aircraft.

D.3.2.9.2 In Ground Effect (IGE). In ground effect is defined as that region where the presence of the ground alters the free air aerodynamic characteristics of the aircraft. This effect varies dependent on the distance of the wing from the ground. The change in ground effect with height can be calculated using the following method:

$$R = HT_{MAC} / b$$

Where: R = height to span ratio.

HT_{MAC} = height of the mean aerodynamic chord (MAC) above the ground, measured at the quarter chord. It is the sum of the height of the bottom of the wheels above the ground plus the height of the MAC above the bottom of the wheels, ft.

b = wing span, ft.

Ground effect (E) must be calculated twice; once with wheels on the ground (E_1), and once at the appropriate height (E_2).

If $R < 0.3$

$$E = 0.56 - 1.3 R + 0.45 / e^{20.75 R}$$

If $R > 0.3$

$$E = 0.45 / e^{3.2 R}$$

Then:

$$C_D = C_{D_{OGE}} (1- (E_2 / E_1)) + C_{D_{IGE}}(E_2 / E_1)$$

and

$$C_L = C_{L_{OGE}} (1- (E_2 / E_1)) + C_{L_{IGE}}(E_2 / E_1)$$

A graph of E vs R is shown below:

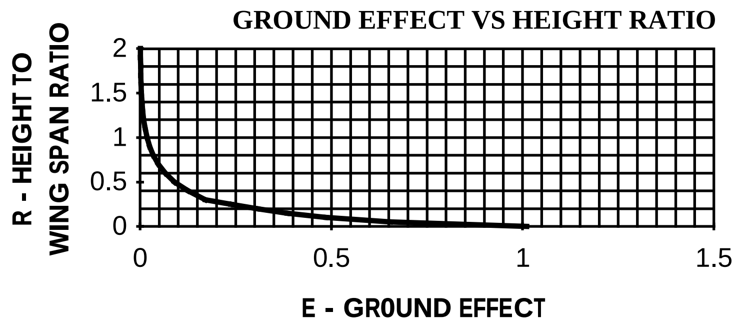

FIGURE D-3. Ground effect vs height ratio.

D.3.2.9.2.1 In Ground Effect (V/STOL Aircraft). Ground effects for V/STOL aircraft include hot gas re-ingestion, suckdown, fountain effects, and other propulsion induced forces and moments which may be affected by the presence of the ground. These effects are highly configuration dependent and vary with forward velocity, height above the ground, thrust vector angle(s), and power setting. Because of this, it is not possible to provide a single analytical or empirical method for calculating ground effect for V/STOL aircraft which would provide accurate results. Ground effects shall be estimated for V/STOL aircraft based on available flight test and wind tunnel test data, or appropriate analytical methods, and may be subject to approval by the procuring activity.

D.3.2.10 Critical Field Length (CFL). Critical field length is defined as the sum of the distance required to accelerate with all engines operating to critical engine failure speed (Paragraph D.3.2.11) plus the distance to accelerate to liftoff speed with the critical engine inoperative or to decelerate to a stop from critical engine failure speed in the same distance for a specified altitude, weight, configuration, and thrust (power) setting (see figure D-4).

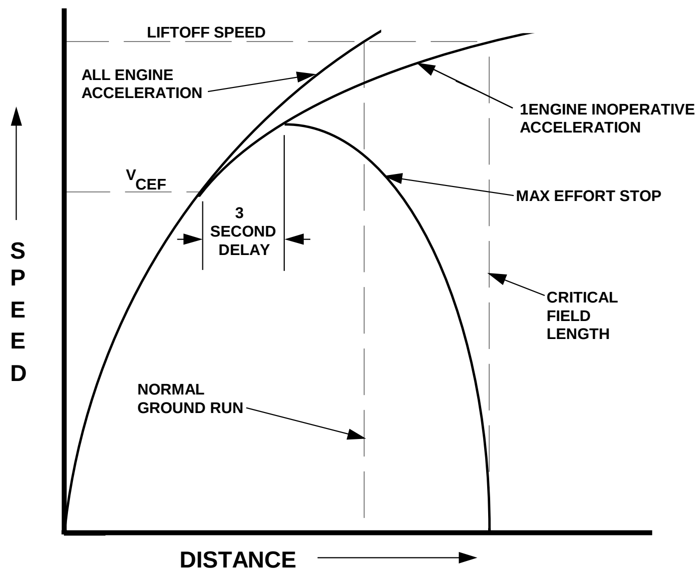

FIGURE D-4. Critical field length terminology.

D.3.2.10.1 Computation Ground Rules. The data basis for the computation of the stopping distance for critical field length shall be as follows (see figure D-5). Use of reverse thrust and deceleration devices shall be subject to the approval of the procuring activity.

a. At engine failure the aircraft shall continue to accelerate for 3 seconds with the operating engine(s) at the thrust (power) setting being used for takeoff, and with the inoperative engine at a drag level representing the most critical engine failure condition. This period is to account for recognition of the engine failure and initiation of a response.

b. At the end of the 3 second period, brakes shall be instantly applied (all brake and tire limits shall be observed), and action shall be initiated to reduce thrust (power) on the operating engine(s) to idle and to deploy deceleration devices. Sufficient time shall be allowed for full deployment of deceleration devices and decay of thrust (power) to idle before including their effects on deceleration. If time response data is available to more accurately model their effects, it shall be used, subject to the approval of the procuring activity.

c. Action to initiate reverse thrust, if available, shall be taken once the engine(s) has reached Idle thrust (power). Sufficient time shall be allowed for increase to full reverse thrust before including its effects on deceleration. If time response data is available to more accurately model its effect, it shall be used, subject to the approval of the procuring activity. If reverse thrust is used, it shall be limited to the amount which can be trimmed out by the rudder, asymmetric braking, nose wheel steering, etc.

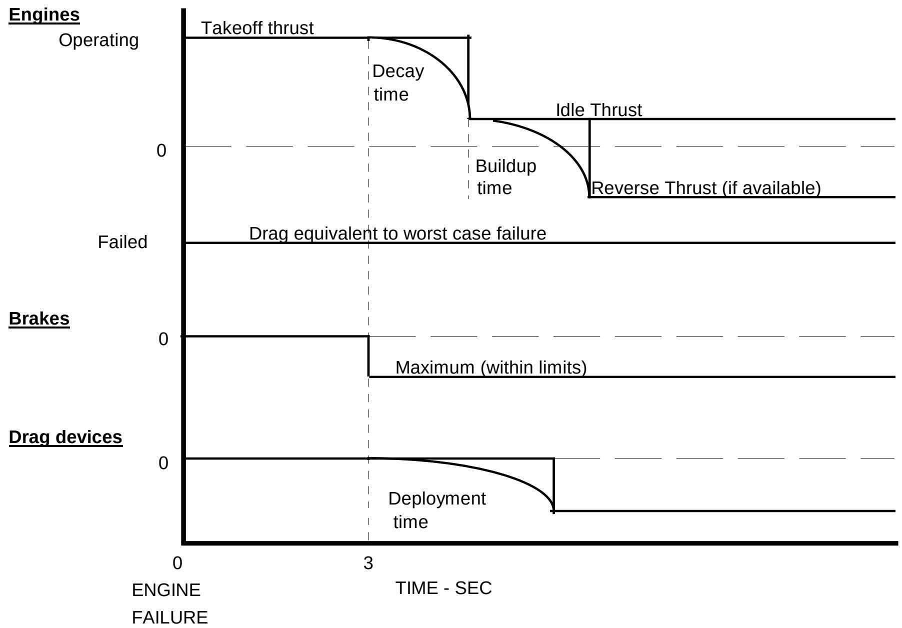

FIGURE D-5. Critical field length criteria.

D.3.2.10.2 Alternate Design Criteria. Subject to the approval of the procuring activity, consideration should be given to design features of the aircraft which allow use of a shorter period of time for recognition of a failure and initiation of a response.

D.3.2.11 Critical Engine Failure Speed (V_{cef}). Critical engine failure speed is defined as the speed during the takeoff run at which an engine can fail and the same distance is required to either liftoff or stop the aircraft, for a specified altitude, weight, configuration and thrust (power). Conditions for which this speed is calculated are specified in Paragraph D.3.2.10.1.

D.3.2.12 Refusal Speed (V_{ref}). Refusal speed is defined as the maximum speed during takeoff from which the aircraft can stop within the available remaining runway length for a specified altitude, weight, and configuration.

D.3.2.13 Refusal Distance. Refusal distance shall be defined as the distance required to accelerate to refusal speed for a specified altitude, weight, configuration, and thrust (power) setting.

D.3.2.14 Coefficient of Friction (μ).The coefficient of friction as used in this document, is defined as the ratio of the total retardation force of the wheels and braking system to the weight on the wheels (weight minus lift). The following values will be used unless aircraft test data is available:

a. 0.025 shall be used for the unbraked rolling coefficient of friction for a dry, hard surface for bias ply tires. 0.015 shall be used for the same conditions for radial tires.

b. 0.30 shall be used for the total braking coefficient of friction for a dry, hard surface without the use of anti-skid. 0.38 shall be used for the total braking coefficient of friction for a dry, hard surface with the use of anti-skid. For brakes designed to a 10 ft/sec^2 deceleration capability, the maximum braking coefficient of friction with anti-skid shall be 0.33. Brake torque limits and energy absorption rate limits shall be observed.

c. Values of coefficient of friction from tests on the specific aircraft or similar types may be used with the concurrence of the procuring activity.

D.3.2.14.1 Alternate Design Criteria. For design purposes, the following coefficient of friction values should be used for the conditions specified, on a hard surfaced runway:

TABLE D-III. Runway condition reading.

Runway Condition	RCR	Rolling Unbraked	Rolling Braked	Rolling Braked with Anti-Skid
Dry	23	.025*	.30	.38**
Wet	15	.05	.20	.25
Wet Snow	11	.09	.14	.18
Wet Ice	7	.05	.09	.12

* 0.015 for radial tires

** 0.33 for brake limited systems.

D.3.3 Climb. Climb is defined as that portion of flight when the aircraft is ascending from a lower geometric altitude to a higher geometric altitude.

D.3.3.1 Rate-of-Climb (R/C). Rate-of-climb is defined as a positive time rate of change of geometric altitude. It is equal to the vertical component of the flight path velocity.

D.3.3.1.1 Maximum Rate-of-Climb. Maximum rate-of-climb is defined as the maximum time rate of change of geometric altitude for a given configuration, weight, altitude, speed, and thrust (power).

D.3.3.1.2 Dynamic Rate-of-Climb. Dynamic rate-of-climb is defined as the rate-of-climb for which the aircraft is either accelerating or decelerating (true airspeed is not constant). Rate-of-climb is usually expressed in feet per minute, and is defined as follows:

$$R/C = 101.27 \frac{(F_n - D)V_{tas}}{W\left(1 + \frac{V_{tas}}{g}\frac{dV_{tas}}{dh}\right)}$$

Where:

- R/C = rate of climb, ft/min
- F_n = net thrust = (F_g cos ($\alpha + \iota$) - D_r - D_p), lb
- F_g = gross thrust, lb
- D_r = ram drag, lb
- D_p = propulsive drag (other than ram drag), lb
- α = angle of attack
- ι = thrust incidence angle
- D = aerodynamic drag, lb
- V_{tas} = true airspeed, knots
- W = aircraft weight, lb
- g = gravitational acceleration, ft/sec^2
- $\left(\frac{V_{tas}}{g}\frac{dV_{tas}}{dh}\right)$ = acceleration factor (V_{tas} and dV_{tas} are in feet per second)
- dV_{tas}/dh = change in velocity with altitude, 1/sec

D.3.3.1.3 <u>Steady State Rate-of-Climb</u>. Steady state rate-of-climb is defined as the rate-of-climb for which the acceleration factor is zero, climbing at a constant true airspeed, ($dV/dt = 0$). The rate-of-climb equation becomes:

$$R/C = dh/dt = 101.27 V_{tas} \sin\gamma = 101.27\left(F_n - D\right)V_{tas}/W$$

Where:

- R/C = rate of climb, ft/min
- V_{tas} = true airspeed, knots
- γ = flight path angle
- F_n = net thrust = (F_g cos ($\alpha + \iota$) - D_r - D_p), lb
- F_g = gross thrust, lb
- D_r = ram drag, lb
- D_p = propulsive drag (other than ram drag), lb
- α = angle of attack
- ι = thrust incidence angle
- D = aerodynamic drag, lb
- W = aircraft weight, lb
- dh/dt = time rate of change of altitude, ft/min

D.3.3.1.4 <u>Engine Out Rate-Of-Climb</u>. Engine out rate-of-climb is defined as climb with the most critical engine to control out (as defined by MIL-STD-1797) while the aircraft maintains a constant heading with up to 5° of bank into the failed engine. The engine failure condition (stopped rotor, windmilling, propeller feathered, etc.) shall be stated and the resulting drag of the failed engine, and trim devices shall be included in the calculation.

D.3.3.1.4.1 Alternate Design Criteria (Carrier). Subject to approval of the procuring activity, and subject to the consideration of operational constraints, satisfactory (adequate) engine out rate of climb may be defined as:

a. Catapult. The minimum rate of climb which is considered perceptible to the pilot and can provide a safe flyaway is 200 ft/min. This is calculated at a one engine inoperative emergency catapult end airspeed which is defined as catapult minimum end airspeed plus 10 kts (the normal catapult operational end airspeed minus 5 kts to account for the loss of engine thrust during the catapult stroke). For new aircraft designs, one engine out rate of climb is calculated with gear and takeoff flaps down. Since this is a stringent requirement for older aircraft, the one engine out rate of climb for some aircraft is calculated with takeoff flaps down, gear up if drag continues to decrease after initiation of gear up. If gear retraction results in a transient drag increase over that for gear down, the calculation of one engine inoperative rate of climb shall be as specified by the procuring activity.

b. Carrier Approach. The minimum rate of climb which is considered adequate to arrest the glide slope sink and provide adequate excess thrust for wave off is 500 ft/min. The configuration is landing flaps down, gear down, speed brakes (if required for approach) retracted, and the initial conditions are at the normal carrier approach speed on a 4° glide slope.

D.3.3.2 Climb Gradient. Climb Gradient is defined as the change in altitude per unit of horizontal distance traveled, expressed as a percentage. The gradient can also be defined as the tangent of the flight path angle. Climb gradient is given by the following equation:

$$\text{Climb Gradient (percent)} = (\Delta\text{Height} / \Delta\text{Horizontal Distance}) * 100 = (\tan \gamma) * 100$$

D.3.3.3 Flight Path Angle (γ).Flight path angle is defined as the angle between the local horizon and the aircraft velocity vector .

D.3.3.4 Initial Climb-Out. Initial climb-out is defined as the transition period beginning at the 50-ft obstacle and ending when the aircraft reaches climb speed.

D.3.3.5 En route Climb. En route climb is defined as any climb en route to the next flight phase.

D.3.3.5.1 Minimum Time to Climb. Minimum time to climb is defined as the shortest amount of time to climb from one speed/altitude condition to another. If only initial and final altitudes are specified, the initial and final speeds shall be assumed to lie on the minimum time to climb speed schedule.

D.3.3.5.2 Minimum Fuel to Climb. Minimum fuel to climb is defined as the smallest amount of fuel to climb from one speed/altitude condition to another. If only initial and final altitudes are specified, the initial and final speeds shall be assumed to lie on the minimum fuel to climb schedule.

D.3.3.6 Recovery Climb. Recovery climb is defined as a climb to the cruise conditions after withdrawal from the target has been accomplished.

D.3.3.7 Zoom Climb. Zoom climb is defined as a climb which converts kinetic energy (speed) to potential energy (altitude).

D.3.3.8 Combat Climb. Combat climb is defined as a climb at maximum rate-of-climb for combat conditions (weight, configuration, altitude, and thrust (power) setting).

D.3.3.9 Climb Speed. Climb speed is defined as the speed along the flight path at which climb is conducted for a specified altitude, weight, configuration, and thrust (power) setting.

D.3.3.9.1 Climb Schedule. Climb schedule is defined as the sequence of speed/altitude combinations to be used during a climb for a specified initial weight, configuration, and thrust (power) setting. The climb schedule is usually calculated to achieve maximum or optimum rates of climb, however, in operational usage an easily followed climb schedule of constant speed or Mach number which results in rates of climb close to the maximum or optimum may be desirable.

D.3.3.9.2 Best Climb Speed. Best climb speed is defined as the steady state speed that results in the maximum rate of climb for a specified altitude, weight, configuration and thrust (power).

D.3.3.9.3 Optimum Climb Speed. Optimum climb speed is defined as the climb speed within a climb schedule which optimizes some climb parameter such as minimum time to climb, minimum fuel used in climb, etc., for a specified altitude, weight, configuration and thrust (power).

D.3.4 Ceiling. Ceiling is defined as the highest altitude at which a specified steady state rate-of-climb can be achieved.

D.3.4.1 Absolute Ceiling. Absolute ceiling is defined as the altitude at which the maximum steady state rate-of-climb potential is zero feet per minute, for a specified configuration, weight, speed, and thrust (power) setting.

D.3.4.2 Service Ceiling. Service ceiling is defined as the altitude at which the maximum steady state rate-of-climb potential is 100 feet per minute for a specified configuration, weight, and speed, and thrust (power) setting. (P_s = 1.6667 feet per second at γ =0)

D.3.4.3 Cruise Ceiling. Cruise ceiling is defined as the altitude at which the maximum steady state rate of climb potential is 300 feet per minute at Maximum Continuous (Intermediate for augmented engine powered aircraft) thrust (power), for a specified configuration, weight, and speed. (P_s = 5.0 feet per second at γ =0)

D.3.4.4 Combat Ceiling. Combat ceiling is defined as the altitude at which the maximum steady state rate of climb potential is 500 feet per minute for a specified configuration, weight, speed, and thrust (power) setting. (P_s = 8.3333 feet per second at γ =0)

D.3.5 Cruise.

D.3.5.1 Cruise Altitude. Cruise altitude is defined as the altitude at which the cruise portion of the mission is conducted. For an unpressurized aircraft, the cruise altitude without oxygen masks shall not exceed 10,000 feet (H_p), with oxygen masks it shall not exceed 25,000 feet (H_p). For a pressurized aircraft, with extended time above 50,000 feet (H_p), a pressure suit is required. In no case shall cruise altitude exceed cruise ceiling.

D.3.5.2 Optimum Cruise Speed/Altitude. Optimum cruise speed/altitude is defined as the speed/altitude combination at which the aircraft attains the maximum nautical miles per pound of fuel for a specified configuration and weight.

D.3.5.3 Constant Altitude Cruise. Constant altitude cruise is defined as flight at a constant altitude during the cruise portion of flight.

D.3.5.4 Cruise Climb. Cruise climb is defined as a cruise while climbing so as to maximize nautical miles per pound of fuel as fuel is consumed.

D.3.5.5 Step Climb Cruise. Step climb cruise is defined as a cruise technique that is a compromise between constant altitude cruise and a cruise climb. In practice the desired gradual altitude increase of the cruise climb is approximated by increasing altitude in discrete steps.

D.3.5.6 Maximum Range Cruise Speed. Maximum range cruise speed is defined as the speed at which maximum nautical miles per pound of fuel is attainable at a specified configuration, weight, and altitude.

D.3.5.7 Long Range Cruise Speed. Long range cruise speed is defined as the higher of the two speeds which yields 99 percent of the maximum nautical miles per pound of fuel for a specified configuration, weight, and altitude. Optimum long range cruise takes place at the same altitude as the optimum value of maximum range cruise.

D.3.5.8 Average Cruise Speed. Average cruise speed is defined as the total distance covered in cruise portion of flight divided by the time for cruise.

D.3.5.9 Maximum Cruise Speed. Maximum cruise speed is defined as the highest level flight speed that can be maintained at the Maximum Continuous (Intermediate for augmented engine powered aircraft) thrust (power) setting at the specified configuration, weight and altitude.

D.3.5.10 Specific Range (SR). Specific range is defined as nautical miles per pound of fuel consumed. It is usually expressed in nm/lb, and is defined as follows:

$$SR = V_{tas} / \dot{W}_f$$

Where: SR = specific range, nm/lb
V_{tas} = true airspeed, knots
$\dot{W}_f$ = fuel flow, lb/hr

D.3.5.11 Range Factor (RF). Range factor is defined as weight multiplied by specific range. This fuel mileage term is another way of measuring the aircraft's cruise range capability. It is usually expressed in nm, and is defined as follows:

$$RF = SR * W$$

Where:
RF = range factor, nm
SR = Specific range, nm/lb
W = aircraft weight, lb

D.3.5.12 Cruise Figure of Merit (FM). Cruise figure of merit is a term used to compare the cruise efficiency of aircraft and is defined as follows:

$$FM = RF * TSFC/V_{tas}$$

Where:
FM = cruise figure of merit
RF = range factor, nm
TSFC = Thrust specific fuel consumption (uninstalled), per hour
V_{tas} = true airspeed, knots

D.3.5.13 Combat Altitude. Combat altitude is defined two ways:

a. The altitude over the target for an air-to-ground mission.

b. The altitude at which combat performance is calculated, for an air-to-air mission.

D.3.5.14 Penetration Speed. Penetration speed is defined as the speed at which the aircraft ingresses to the target at a specified altitude.

D.3.5.15 Withdrawal Speed. Withdrawal speed is defined as the speed at which the aircraft egresses from the target at a specified altitude.

D.3.5.16 Maximum Speed.

D.3.5.16.1 Level Flight Maximum Speed (V_H). Level flight maximum speed is defined as the highest speed attainable in steady-state, level flight, at a load factor of 1.0 n_l for a specified altitude, weight, configuration, and thrust (power) setting. Level flight maximum speed is determined by the intersection of the thrust (power) available and thrust (power) required curves with all applicable limitations applied.

D.3.5.16.2 Limit Speed (V_L). Limit speed is defined as the maximum allowable speed of the aircraft, with all applicable limitations applied, for a specified altitude, weight, and configuration. Limit speed is independent of thrust (power) available since it is not limited to level flight.

D.3.5.16.3 Dive Speed (V_D). Dive Speed is defined as the maximum authorized speed to intentionally dive the aircraft. The dive conditions taken into consideration are altitude, flight path angle, thrust (power) setting, deceleration device settings, recovery load factor, and any other pertinent factors.

D.3.6 Endurance. Endurance is defined as the level flight condition at which an aircraft holds in a particular portion of airspace (zero range gain) at a minimum fuel burn rate for a specified weight, altitude and configuration.

D.3.6.1 Maximum Endurance Speed. Maximum endurance speed is defined as the speed which yields minimum fuel flow attainable for a specified configuration, weight, and altitude.

D.3.6.2 Maximum Endurance Altitude. Maximum endurance altitude is defined as that altitude at which there is a minimum fuel flow for a specified configuration, weight, and speed.

D.3.6.3 Combat Loiter Speed. Combat loiter speed is defined as the speed selected to give the maximum endurance to accomplish a given mission task such as search, rendezvous, target acquisition, etc., where configuration and altitude are specified. Combat loiter differs from endurance in that speeds and altitudes flown are to satisfy mission requirements.

D.3.6.3.1 Alternate Design Criteria. When loitering in on near the combat area, loiter should be conducted at or slightly below corner speed (Paragraph D.3.9.7.2) instead of at maximum endurance speed so the aircraft can respond more readily to a threat or combat assignment.

D.3.7 Descent. Descent is defined as that portion of flight in which the aircraft is descending from a higher geometric altitude to a lower geometric altitude.

D.3.7.1 Rate-of-Descent (R/D). Rate-of-descent is defined as a negative time rate of change of altitude (negative rate-of-climb). Rate-of-descent is usually expressed in feet per minute, and is defined as follows:

$$R / D = -{}^{dh}\!/_{dt} = 101.27 V_{tas} \sin\gamma$$

Where:

- R / D = rate of descent, ft/min
- V_{tas} = true airspeed, knots
- γ = flight path angle (will always be negative).
- dh/dt = time rate of change of altitude, ft/min

3.7.2 Descent Speed. Descent speed is defined as the flight path airspeed during a descent to a lower altitude. The particular speed/altitude profile selected is based on the type of descent to be used: e.g., emergency or maximum range descents.

D.3.7.3 En route Descent. En route descent is defined as a descent used in normal operations when there is no emergency. The aircraft shall be configured appropriately: gear retracted, deceleration devices, flaps, and thrust (power) at the prescribed settings, speed schedule specified, etc.

D.3.7.4 Maximum Range Descent. Maximum range descent is defined as the best use of fuel to attain maximum range when descending from one altitude to another. Maximum range descent is made at or near maximum lift/drag speed. This descent is flown with thrust (power) at the prescribed setting, aircraft configured as required, gear retracted, deceleration devices retracted, and at a specified speed schedule.

D.3.7.5 Penetration Descent. Penetration descent is defined as a descent utilized when descending to start terrain following at low altitude and high subsonic speed. This descent is flown at Flight Idle thrust (power) setting, aircraft configured as required, gear retracted, deceleration devices deployed as required, and at a specified speed schedule. During descent other applicable placards must be observed.

D.3.7.6 Emergency (Minimum Time) Descent. Emergency descent is defined as a descent which provides maximum altitude loss in a minimum amount of time, without exceeding airspeed limits, in the event of some type of emergency. Thrust (power) rating is set to Flight Idle, with the speed schedule specified.

D.3.7.7 Alternate Design Criteria. Subject to approval of the procuring activity, consideration may be made of alternate descent speed schedules, configurations, and thrust(power) settings which utilize the unique capabilities of a particular design.

D.3.8 Landing. Landing is defined as that phase of flight during which the aircraft transitions from aerodynamic and thrust supported flight to being on the ground. It extends from end of descent to when the engines are shut off. Terminology used for the different portions of landing are shown in figure D-6.

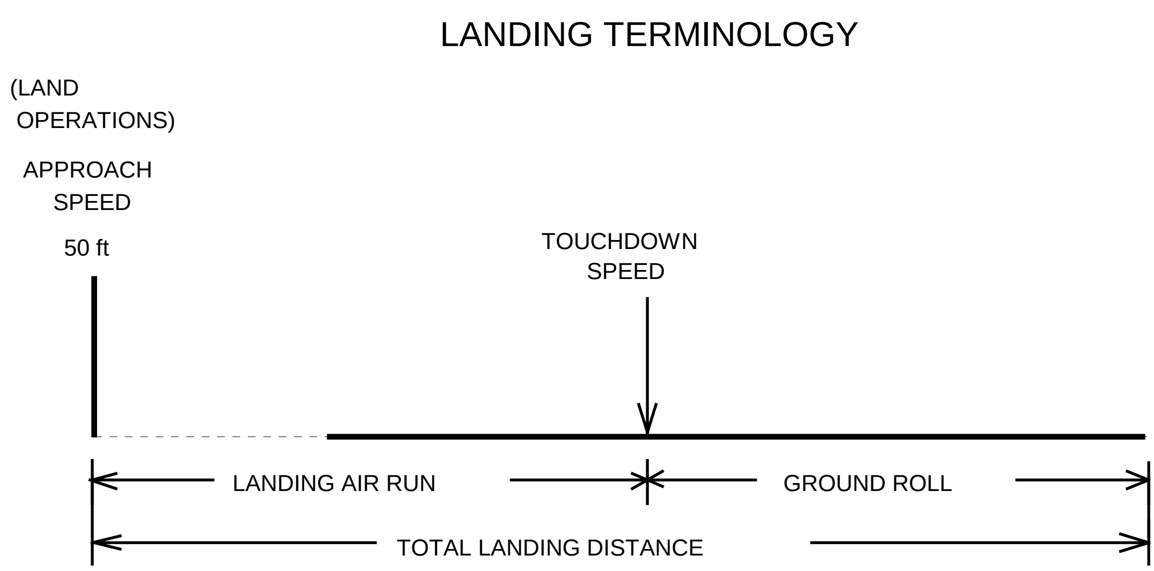

FIGURE D-6. Landing terminology.

D.3.8.1 Approach Speed (V_{pa}).

D.3.8.1.1 Land Based Aircraft. Approach speed is defined as the flight path velocity with which the aircraft clears a 50 ft height above the runway during the approach to a landing for a specified altitude, weight, and configuration. It shall be the highest of the following:

a. A speed corresponding to 120 percent of the out of ground effect power-off stall speed in the approach configuration, gear down.

b. 105 percent of static air minimum control speed or if flight test data is available, dynamic air minimum control speed as defined by MIL-STD-1797.

c. The minimum speed at which the aircraft has a climb gradient potential of 2.5 percent (0.025), with gear up, in the approach configuration, with Takeoff (maximum) thrust (power), out of ground effect. For multi-engine aircraft this potential shall be obtainable with the most critical engine inoperative (engine windmilling, propeller feathered).

d. The minimum speed based on flight control limiting with margins applied as appropriate, subject to the approval of the procuring activity.

D.3.8.1.1.1 Alternate Design Criteria: Subject to the approval of the procuring activity, consideration may be made of alternate definitions of approach speed such as: a higher or lower percentage of the stall speed or air minimum control speed, a higher climb gradient potential, alternate go-around power settings or other criteria which reflect the specific aircraft requirements or usage.

D.3.8.1.2 Carrier Based Aircraft. With the aircraft in the landing configuration and on a 4° glide slope on a 89.8°F day, zero wind, the approach speed shall be the highest of the airspeeds defined by the following:

a. The lowest speed at which it is possible to achieve a level flight longitudinal acceleration of .155 g (5 ft/sec^2) within 2.5 seconds after initiation of throttle movement and speed brake retraction.

b. 110 percent of the power-on stall speed using the thrust (power) required for level flight (V_{spa}) at 115 percent of V_{sl}, the power-off stall speed in the landing configuration.

c. The lowest level flight speed at which the pilot, at the design eye position, can see the stern of the carrier at the waterline when intercepting a 4° optical glide slope at an altitude of 600 feet. The origin of the glide slope is 500 feet forward of the stern and 63 feet above the waterline.

d. The lowest speed at which all stability and control requirements are satisfied (MIL-STD-1797).

e. The lowest speed at which the aircraft is capable of making a glide path correction from stabilized flight to a new glide path 50 feet above the original glide path within five (5) seconds after initiation of the maneuver. The maneuver shall be performed without change in thrust settings by the pilot, and the aircraft angle of attack during the maneuver shall not exceed that necessary to achieve 50 percent of the maximum positive delta lift available, based on static lift coefficient, at the initiation of the maneuver. Control rate input for simulation of V_{pa} shall not exceed control system limits. The maneuver shall be considered complete when a glide path correction of 50 feet has been reached. After completion of this maneuver, the aircraft shall be capable of maintaining a new glide path at least 50 feet above and parallel to the initial glide path, with the pilot permitted to change thrust setting as required.

f. To insure rapid aircraft response to step throttle commands corresponding to $\pm$ .120 g ($\pm$3.86 ft/sec^2) longitudinal acceleration, such throttle inputs shall result in achieving 90 percent of the commanded acceleration within 1.2 seconds. This requirement shall apply in the approach configuration throughout the range of all throttle settings required for operations over the usable approach configuration weight /drag levels while trimmed on a 4° glide slope.

g. The minimum speed based on flight control limiting with margins applied as appropriate, subject to the approval of the procuring activity.

Note: Calculation of V_{pa} shall be based on static lift coefficient. If direct lift control (DLC) is a design feature, all approach speed requirements will be met with DLC active except the visibility requirement (subparagraph c) which will be met with DLC inoperable.

D.3.8.2 Touchdown Speed.

D.3.8.2.1 Land Operations(V_{tdl}). Touchdown speed is defined as the speed at which the aircraft touches the ground, for a specified altitude, weight, and configuration. It shall be the highest of the following:

a. A speed corresponding to 110 percent of the out of ground effect power-off stall speed in the landing configuration.

b. A speed determined by the in ground effect lift coefficient in the landing configuration, power-off, for the maximum angle of attack attainable with the main landing gear oleo in the fully compressed position with the aircraft on the ground.

c. The minimum speed based on flight control limiting with margins applied as appropriate, subject to the approval of the procuring activity.

D.3.8.2.1.1 Alternate Design Criteria: Subject to the approval of the procuring activity, consideration may be made of alternate definitions of touchdown speed such as: geometry limited with oleos in the partial extended position, changes in the percentage of stall speed, or other criteria which reflect the specific aircraft requirements or usage. Selective use or alteration of the definitions of approach speed to reflect the unique operational features of V/STOL aircraft may be made with the approval of the procuring activity.

D.3.8.2.2 Carrier Operations (V_{tdc}). For design purposes touchdown speed is defined as that speed equal to 105 percent of carrier approach speed (V_{pa}). For operational aircraft, touchdown speed will be determined using fleet survey data.

D.3.8.2.2.1 Wind-Over-Deck (Landing). Landing wind-over-deck is defined as the difference between touchdown speed and shipboard engaging speed.

D.3.8.2.2.2 Waveoff. Waveoff is defined as an aborted landing attempt during which the aircraft does not touchdown. Waveoffs are divided into two categories: on glide slope, or above glide slope, depending on the aircraft's position when the waveoff is initiated.

a. Initial conditions for waveoff are:

(1) On glide slope. The aircraft will be on a 4° optical glide slope stabilized at V_{pa} and α_{pa}. Thrust will be as required to meet this flight condition. With a 0.7 second delay to account for pilot reaction time when the waveoff signal is displayed, the throttles are advanced to Intermediate/Maximum rated thrust (power), and speed brake (if used) retraction is initiated.

(2) Above glide slope. This condition is intended to represent the most severe environment for a waveoff. It reflects a gross glide slope correction from a high (1 ball) position. The aircraft will be on a 4° 20.45" optical glide slope stabilized at V_{pa} and α_{pa}. Thrust will be as required to meet this condition. The throttles are advanced to Intermediate thrust (power) and speed brake (if used) retraction is initiated.

b. The following criteria must be met for both categories for a waveoff to be considered acceptable:

(1) A time to zero sink speed not greater than 3.0 seconds with a longitudinal acceleration of 3.0 kts/sec on a 89.8° F day.

(2) Controllable change, if required, shall not go beyond 0.9 $C_{L_{max}}$.

(3) Level I flying qualities as defined by MIL-STD-1797 shall be maintained during all aspects of the waveoff.

(4) Engine spool up characteristics must be considered.

c. The following techniques are options for both categories:

(1) The maneuver shall be flown at constant α with increasing θ. This is the preferred technique.

(2) The maneuver shall be flown at constant θ with decreasing α.

(3) The maneuver shall be flown with simultaneous aircraft rotation (α and θ) and throttle advancement. α shall increase by no more the 3°.

The maneuver is complete after positive rate-of-climb has been achieved.

D.3.8.2.2.2.1 Alternate Design Criteria. Subject to the approval of the procuring activity, consideration may be given to alternate definitions of waveoff such as: 3.5° optical glide slope for aircraft with low wind over deck capability, constant angle-of-attack or pitch body angle during waveoff, time for engine spool down to change from high glide slope, etc.

D.3.8.2.2.3 Shipboard Engaging Speed (V_e). The shipboard engaging speed is defined as the arresting gear engaging speed measured relative to the ship.

D.3.8.2.2.4 Bolter. Bolter is defined as a missed wire landing attempt in which the aircraft touches down and then power is applied for a takeoff. It applies to both carrier landing operation and field carrier landing practice. The term bolter performance is used to denote the distance from landing touchdown to liftoff from a carrier/field.

D.3.8.2.2.4.1 Computational Ground Rules. The initial conditions and criteria used in the computation of bolter shall be as follows:

a. The initial conditions of bolter are:

(1) The aircraft will be on a 4° optical glide slope stabilized at V_{pa} and α_{pa} with the engine(s) stabilized at Flight Idle thrust (power) and the arresting hook point 6 inches above the landing surface.

(2) Throttles shall be advanced to Intermediate/Maximum thrust (power) 0.5 seconds after the main landing gear touch down.

(3) Longitudinal control inputs are to be made 1.0 seconds after touchdown to attain the desired fly-away attitude.

b. The following criteria must be met for a bolter to be considered acceptable:

(1) The angle-of-attack during fly-away shall be between α_{pa} and α_{pa} plus 3° but shall not go beyond 0.9 $C_{L\ max}$.

(2) Level I flying qualities as defined by MIL-STD-1797 shall be maintained during all aspects of the waveoff.

(3) Engine spool up characteristics must be considered.

(4) Thrust arrestment reduction system logic, if utilized, is reflected during the maneuver.

The maneuver is complete when the aircraft CG has achieved an altitude 50 feet above the landing height.

D.3.8.3 Ground Roll Distance. Ground roll distance is defined as the distance to decelerate from touchdown speed to a full stop. Ground roll is divided into two segments, transition and braking. The transition segment is the ground roll immediately following touchdown which allows for the change from the touchdown attitude to the taxi attitude. During transition the aircraft is brought from the landing configuration to the braking configuration (brakes on, deceleration devices deployed, throttles at idle position, drag chute(s) deployed, reverse thrust, etc.). Landing distance is calculated for a specified weight, altitude, and configuration. Unless otherwise specified, ground roll distance shall be computed for zero wind, on a dry hard surfaced runway (RCR = 23) with no slope.

D.3.8.4 Landing Air Run Distance. Landing air run distance is defined, for land based aircraft, as the horizontal distance from the 50-ft obstacle height to touchdown. Aircraft is in the landing configuration, at the specified thrust (power) setting, weight, and altitude.

D.3.8.5 Total Landing Distance. Total landing distance is defined as the sum of the landing air run distance and ground roll distance.

D.3.8.5.1 Alternate Design Criteria. Subject to the approval of the procuring activity, consideration may be given to alternate definitions of landing distance such as: alternate runway surfaces (sod, wet, ice, etc.), head or tail wind, maximum brake capacity, or other criteria in keeping with the operational concept of the design. For V/STOL aircraft the criteria shall be established by design requirements.

D.3.8.6 Maximum Brake Energy Speed. Maximum braking speed is defined as the highest speed from which the aircraft can be brought to a stop, with maximum braking, without exceeding the maximum design energy absorption capability of the brakes for a specified altitude, weight, and configuration.

D.3.8.7 Maximum Vertical Landing Weight (V/STOL Aircraft). The maximum vertical landing weight shall be the highest weight for which the aircraft can meet all of the following conditions.

a. The weight at which a vertical landing can be accomplished starting from a hover at 50 feet above the landing surface with a 4 ft/sec rate of vertical descent out of ground effect. In ground effect, prior to touchdown, the rate of vertical sink shall not exceed 5 ft/sec. During the descent, thrust (power) margin for both control and station keeping under the conditions specified in section D.3.8.7.1 shall be maintained.. Level I flying qualities as specified by MIL-F-83300 and MIL-STD-1797 (or as modified and approved by the procuring activity) shall be maintained.

b. The weight at which a 4 ft/sec vertical descent can be arrested (waveoff) starting at a decision height of 12 feet and achieving zero vertical velocity at a wheel height of 5 feet above the landing surface. Thrust (power) margin for both control and station keeping under the conditions specified in section D.3.8.7.1 shall be maintained. Level I flying qualities as specified by MIL-F-83300 and MIL-STD-1797 (or as modified and approved by the procuring activity) shall be maintained.

D.3.8.7.1 Thrust (Power) Margin - Control and Stationkeeping (V/STOL Aircraft).

a. Angular Control. Thrust (power) shall be held in reserve to provide the following attitude changes in one second following initiation of control input with the aircraft center-of-gravity at the most critical position. The magnitude of reserve thrust (power) for angular control shall be the largest required to satisfy either the single-axis or simultaneous three-axis attitude change.

Single-axis Control Application

Pitch	3 deg
Roll	6 deg
Yaw	4 deg

Simultaneous Three-axis Control Application

Pitch	2 deg
Roll	3 deg
Yaw	3 deg

b. Stationkeeping. Thrust (power) shall be held in reserve to provide stationkeeping over a fixed point on the landing surface under the following wind conditions:

Headwind (zero azimuth angle) 40 knots
Wind from the most critical direction* 15 knots

* Most critical direction means wind from the azimuth direction which is most demanding of thrust (power) margin for stationkeeping.

D.3.9 Maneuver. Maneuver is defined as the act of changing altitude, airspeed, and/or direction of flight. The maneuver diagram represents the performance capability and limits of an aircraft for a given set of flight conditions. Maneuverability defines the aircraft's capability to attain a maneuver state. Agility defines the manner in which an aircraft transitions from one maneuver state to another.

D.3.9.1 Flight Envelope. Flight envelope is defined as the boundary of altitude and speed combinations within which flight is possible for a given weight, load factor, and configuration.

D.3.9.2 Load Factor. Load factor is defined as the resultant force divided by the aircraft weight. All forces, aerodynamic, propulsive, and weight, must be taken into account in the appropriate axis system.

D.3.9.2.1 Normal Load Factor (body axis) (n_z). Normal load factor in the body axis system is defined as the resultant force normal to the xy body axis plane divided by the aircraft weight. This load factor is used when defining structural limitations.

D.3.9.2.2 Normal Load Factor (wind axis) (n_l). Normal load factor in the wind (stability) axis system is defined as the resultant force normal to the xy wind axis plane divided by the aircraft weight. This load factor is used when defining maneuver capability.

D.3.9.2.2.1 Sustained Load Factor. Sustained load factor is defined as the number of g's attainable, without a change in energy (P_s= 0), during steady state flight for a specified configuration, weight, altitude, speed, and thrust (power) setting. Care must be taken when applying structural limits since they are usually stated in body rather than wind axes.

D.3.9.2.2.2 Instantaneous Load Factor. Instantaneous load factor is defined as the number of g's attainable, during maneuvering flight allowing for changes in the energy state ($P_s \neq 0$), for a specified configuration, weight, altitude, and speed. Maximum instantaneous load factor, for a given speed, occurs when the maximum usablelift coefficient is achieved, except where limited by structural or other considerations. Care must be taken when applying structural limits since they are usually stated in body rather than wind axes. Dynamic overshoot(s) is not allowed in this definition. Dynamic overshoot is a condition where lift coefficient is increased for a short time as a result of pitch rate.

D.3.9.3 Specific Excess Power (P_s). Specific excess power (P_s) is defined as the time rate of change of specific energy and is a measure of the capability of the aircraft to change energy levels for a specified configuration, altitude, speed, and thrust (power) setting. Specific excess power is usually expressed in feet per second, and is defined as follows:

$$P_s = 1.6878 \frac{(F_n - D)\, V_{tas}}{W}$$

Where:

F_n = net thrust = (F_g cos ($\alpha + \iota$) - D_r - D_p), lb
F_g = gross thrust, lb
D_r = ram drag, lb
D_p = propulsive drag (other than ram drag), lb
α = angle of attack
ι = thrust incidence angle
D = aerodynamic drag, lb
V_{tas} = true airspeed, knots
W = aircraft weight, lb

D.3.9.4 Specific Energy (E_s) Specific energy (also known as energy height) is defined as the total energy (potential plus kinetic) divided by the weight for a specified speed and altitude. Specific energy is usually expressed in feet, and is defined as follows:

$$E_s = H + \frac{V_{tas}^2}{2g}$$

Where:

H = geopotential altitude, ft
V_{tas} = true airspeed, ft/sec
g = gravitational acceleration, ft/sec^2

D.3.9.5 Energy Exchange (ΔE). Energy exchange is defined as the amount of specific energy required during a maneuver to increase from one energy state to another. The calculation for the amount of fuel required to perform an energy exchange is shown in Paragraph D.4.2.5.b.

D.3.9.6 Combat Speed. Combat speed is defined as the highest speed attainable in level flight at combat weight with Takeoff (Maximum) thrust (power) at combat altitude.

D.3.9.7 Corner Speed.

D.3.9.7.1 Sustained Corner Speed. Sustained corner speed is defined as the speed at which the maximum sustained rate of turn can be achieved for a specified configuration, weight, altitude and thrust (power). It occurs where turn rate is the maximum attainable without an accompanying change in energy (P_s= 0), and is shown as point d on figure D-7.

D.3.9.7.2 Instantaneous Corner Speed. Instantaneous corner speed is defined as the speed at which the aircraft attains it highest rate of turn for a specified configuration, weight, altitude, and thrust (power) setting (point a on figure D-7). Other points of interest on figure D-7 are: the lowest speed at which the maximum lift and maximum structural load factor lines intersect (point b on figure D-7), and the speed which yields the minimum turn radius (point c on figure D-7). This later point is defined as the largest value of the quantity turn rate divided by speed.

ENERGY MANEUVER DIAGRAM

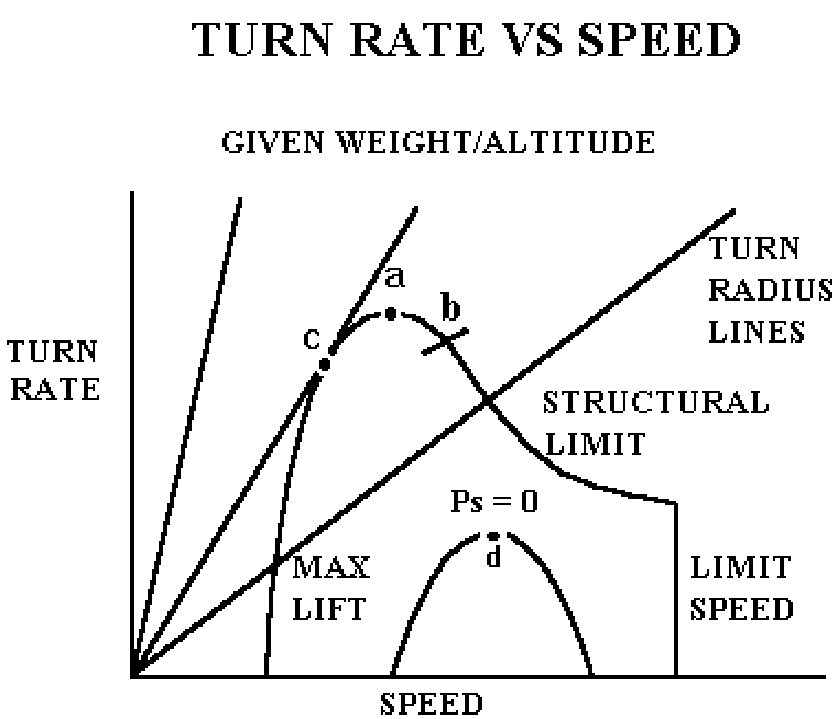

FIGURE D-7. Turn rate versus speed.

D.3.10 Weights. Weight definitions used for aircraft performance analysis shall be as specified herein. Weight status used shall be as directed by the procuring agency.

D.3.10.1 Weight Empty. Weight empty is defined as the weight of the aircraft, complete by model design definitions, dry, clean, and empty except for fluids in closed systems such as the hydraulic system. Weight empty includes total structure group, propulsion group, flight controls group, avionics group, auxiliary power plant group, electrical group, etc.

D.3.10.2 Basic Weight. Basic weight is defined as the weight empty adjusted for standard operational items such as unusable fuel, engine oil, oxygen, and all fixed armament.

D.3.10.3 Operating Weight. Operating weight is defined as the sum of basic weight and such things as crew, crew baggage, steward equipment, emergency equipment, special mission fixed equipment, pylons, racks, and other non expendable items not in basic weight. It is equivalent to takeoff gross weight less usable fuel, payload, and any items to be expended in flight.

D.3.10.4 Payload. Payload is defined as any item which is being transported and is directly related to the purpose of the mission as opposed to items that are necessary for the mission. Payload can include, but not be limited to, passengers, cargo, passenger baggage, ammunition, internal and external stores, and fuel which is to be delivered to another aircraft or site. Payload may or may not be expended.

D.3.10.5 Flight Design Gross Weight. Flight design gross weight (basic flight design gross weight) is defined as the highest flight weight authorized for the maximum positive and negative load factors for maneuvering flight.

D.3.10.6 Maximum Ground Weight. Maximum ground weight (maximum ramp weight/maximum taxi weight) is defined as the highest weight authorized for ramp, taxiway, and runway usage. It is usually a higher weight than the maximum takeoff gross weight defined in D.3.10.9.

D.3.10.7 Maximum Flight Weight. Maximum flight weight is defined as the highest weight authorized for flight. This weight may be greater than maximum takeoff gross weight as specified in D.3.10.9 if in-flight refueling is utilized.

D.3.10.8 Takeoff Gross Weight. Takeoff gross weight is defined as the sum of the operating weight, usable fuel weight, payload items required to perform a particular defined mission, and other items to be expended during flight. Takeoff gross weight shall be determined prior to starting engines for aircraft which have a maximum ground weight equal to maximum takeoff gross weight and shall be determined at liftoff for aircraft which have a maximum ground weight higher than maximum takeoff gross weight. In the latter case the fuel weight expended during warm-up, taxi, and takeoff are excluded.

D.3.10.9 Maximum Takeoff Gross Weight. Maximum takeoff gross weight is defined as the highest weight authorized at liftoff. An aircraft may have more than one maximum takeoff gross weight such as one for land based operations and one for carrier/catapult operations.

D.3.10.10 Mission Landing Weight. Mission landing weight is defined as the weight at the end of the mission as determined by the mission ground rules and shall include the fuel reserves.

D.3.10.11 Maximum Landing Weight. Maximum landing weight is defined as the greatest weight authorized for landing. An aircraft may have more than one maximum landing weight such as one for land based operations and one for carrier/arrested operations.

D.3.10.12 Combat Weight. Combat weight is defined as the weight at the target or combat area and is defined with fuel, air-to-ground ordnance, air-to-air ordnance, ammunition, expendable tanks, and cargo and other payload, except as noted below.

D.3.10.12.1 Mission Based Combat Weight. For a specified mission, combat weight is defined as follows:

a. Fighter - Shall be defined at two weight conditions. An ingress condition shall be presented which is immediately upon arrival at the combat area and a withdrawal condition shall be presented with the same fuel weight, with half of all air-to-air missiles (if carried) expended, and half of all ammunition expended.

b. Attack - Shall be defined at two weight conditions. A ingress condition shall be presented which is immediately upon arrival at the combat area and a withdrawal condition shall be presented with the same fuel weight, all air-to-air missiles (if carried) retained, and all ammunition retained but all air-to-ground ordnance (if carried) expended.

c. Tanker - Immediately after completion of fuel transfer.

d. Reconnaissance - Immediately after arrival at target (after dropping illumination devices, if carried).

e. Others (cargo-trainers) - Prior to start of return flight for radius missions and with reserve fuel only for range missions.

D.3.10.12.2 Non-mission Based Combat Weight. Without a specified mission, combat weight is defined as follows, unless otherwise specified:

a. Fighter - Shall be defined at two weight conditions. An ingress condition shall be presented with 50 percent of total initial fuel consumed and a withdrawal condition shall be presented with 50 percent of total initial fuel consumed, with half of all air-to-air missiles (if carried) expended, and half of all ammunition expended.

b. Attack - Shall be defined at two weight conditions. An ingress condition shall be presented with 50 percent of total initial fuel consumed and a withdrawal condition shall be presented with 50 percent of total initial fuel consumed, with all air-to-air missiles (if carried) retained, and all ammunition retained but with all other air-to-ground ordnance (if carried) expended.

c. All others - Shall be presented with 50 percent of total initial fuel consumed.

D.3.10.13 Carrier Bringback Weight. Carrier bringback weight is defined as the maximum combination of fuel and expendable payload an aircraft can land with, and not exceed its maximum landing weight. This is the maximum carrier/arrested landing weight less the operating weight.

D.3.10.14 Weight definition guide. For quick reference, the following guide (reference MIL-W-25140) is given to the above weight definitions:

WEIGHT EMPTY

+

Unusable fuel, engine oil, oxygen, and all fixed armament.

=

BASIC WEIGHT

+

Crew, crew baggage, steward equipment, emergency equipment, special mission fixed equipment, pylons, racks, and other non expendable items not in the basic weight.

=

OPERATING WEIGHT

+

Usable fuel, payload items required to perform a particular defined mission and other items to be expended during flight.

=

TAKEOFF GROSS WEIGHT

–

Load items expended in flight; such as fuel, stores, ammunition, cargo and paratroops.

=

LANDING WEIGHT

D.3.11 Propulsion. Propulsion performance (thrust, TSFC) prediction data is provided by a thermodynamic cycle computer model which represents a given engine's level of performance. The model simulates engine/component performance at specified altitudes, speeds, ambient conditions, and power settings, accounting for aircraft installation effects and fuel properties. A description of the propulsion model requires definitions of engine performance level, engine service time, and engine power setting.

D.3.11.1 Engine Performance Level

D.3.11.1.1 Engine Performance Level Definitions.

D.3.11.1.1.1 Specification Performance. Specification performance is defined as the level of performance guaranteed by an engine development or production specification. This is the minimum acceptable performance that must be demonstrated before an engine can be qualified or certified for service use.

D.3.11.1.1.2 Minimum Performance. Minimum performance is defined as the level of performance which represents a predetermined statistical variation below the status performance of a family of engines at a given time. This statistical variation is usually represented as the number of standard deviations from the average, i.e. minus 2 sigma or minus 3 sigma, which defines the minimum. Performance variation within a family of engines is due to manufacturing and control tolerances.

D.3.11.1.1.3 Status Performance. Status performance is defined as the statistical average or nominal level of performance for a specified family of engines. During a development program, this could be the predicted level of performance representing the average of all component rig and engine test data acquired at a point in time. Status performance can also be the average level of performance representative of a family of production or fleet engines at a given time.

D.3.11.1.2 Engine Performance Level Use Guidelines. During the life of an aircraft program, as knowledge of the performance to be expected of its engine(s) increases with increased testing, it is appropriate to update the engine performance level definition for some tasks. While some uses of aircraft performance data require that the minimum capability be shown (specification engine), it is more appropriate for others that some value closer to the average be used (minimum or status). Table D-IV provides guidance for determining which engine performance level to use for various tasks throughout the different phases of an aircraft program. Switching from use of the specification engine during the E&MD phase of the program assumes sufficient data is available from testing to provide an adequate definition of engine performance. If the testing has not provided adequate data, use of the engine specification shall be continued.

D.3.11.1.2.1 Lead-the-Fleet. Lead-the-Fleet is defined as a program which gathers engine deterioration data from actual fleet engines. This program is defined in the Joint Service Engine Specification E-87231.

D.3.11.1.2.2 Endurance Testing. Endurance Testing is defined as a program which gathers engine deterioration, durability, and operability data based on ground endurance and qualification testing. This program is defined in the Joint Service Engine Specification E-87231.

TABLE D-IV. Engine performance level use guidelines.

	Pre- Milestone 0	Phase 0	Phase I	Phase II				Phase III	Phase IV
		Concept Exploration and Definition	Demonstration and Validation	Engineering and Manufacturing Development (E&MD)				Production and Deployment	Operations and Support
				Engine Test Milestones					
PERFORMANCE TASKS					PFQ/IFR	LPQ/ISR	FPQ/OCR		
Aircraft Studies	Estimated E&MD Spec	Estimated E&MD Spec	Estimated E&MD Spec	E&MD Spec	E&MD Spec	LPQ Minimum	FPQ Minimum	Production Status w/Endurance Testing	Production Status w/Lead-the-Fleet
Aircraft Specification	Estimated E&MD Spec	Estimated E&MD Spec	Estimated E&MD Spec	E&MD Spec	E&MD Spec	E&MD Spec	E&MD Spec	Production E&MD Spec	N/A
Flight Clearances	N/A	N/A	Calibrated Preliminary Nominal Estimate	E&MD Spec	PFQ Status	LPQ Status	FPQ Status	Production Status w/Endurance Testing	Production Status w/Lead-the-Fleet
Flight Manuals	N/A	N/A	N/A	E&MD Spec	E&MD Minimum	LPQ Minimum	FPQ Minimum	Production Minimum w/Endurance Testing	Production Minimum w/Lead-the-Fleet
Projected Mid-Life Estimates	N/A	N/A	N/A	N/A	N/A	Limited Product Spec w/Endurance Testing	Limited Product Spec w/Endurance Testing	Production Spec w/Endurance Testing and Lead-the-Fleet	Production Status w/Lead-the-Fleet

PFQ/IFR - Preliminary Flight Qualification / Initial Flight Release
LPQ/ISR - Limited Production Qualification / Initial Service Release
FPQ/OCR - Full Production Qualification / Operational Capability Release

Note: All non-Specification engine data shall be subject to the approval of the procuring activity.

D.3.11.2 Engine Service Time Definitions.

D.3.11.2.1 New Engine. New engine is defined as a "zero time" engine. A new engine's performance is demonstrated during production acceptance, overhaul, etc. This overall level of performance is the best (most efficient) that the engine will deliver during service. Depending on the engine's control modes, an engine may deliver more power (thrust) over time, however specific fuel consumption will deteriorate from the level demonstrated by a new engine.

D.3.11.2.2 Deteriorated Engine. Deteriorated engine is defined as a "non-zero time" engine exhibiting degraded performance resulting from a given amount of service usage. Generally, a deteriorated engine will deliver worse (less efficient) performance than a new engine, with the exception of power (thrust), which is dependent on the engine's control modes. Deterioration effects include clearance rub-out, accumulation of foreign matter, bending of blades, seal wear, etc. Service time may be specified by phrases such as "50 hours", or "the end of one hot section life", etc.

D.3.11.3 Engine Power Setting Definitions. Engine power setting rating definitions, except Idle Thrust (Power), depend on the type of engine to which they apply. They are defined below and the non-afterburning definitions are illustrated in table D-V.

D.3.11.3.1 Idle Thrust (Power). Idle thrust (power) is defined as the minimum thrust (power) setting for stable low thrust (power) operation of the engine. The aircraft in which an engine is installed may require idle thrust (power) to be greater than that required by the engine. These additional factors are a function of whether the aircraft is in the air or on the ground, and are categorized as follows:

a. Ground Idle. While the aircraft is on the ground, idle thrust (power) may be further constrained by power extraction requirements or accessory generator speed requirements.

b. Flight Idle. While the aircraft is in the air, idle thrust may be further constrained by engine acceleration time requirements (go-around at low altitude), minimum combustor pressure limits (combustor blowout limits or minimum ECS bleed), or minimum inlet airflow requirements (inlet buzz avoidance at supersonic speeds).

D.3.11.3.2 Engine Type Specific Power Settings

D.3.11.3.2.1 Shaft Power Engines.

a. Maximum Power. Maximum power is defined as the maximum operating condition at which the engine is capable of operating for the incremental time duration specified in the engine specification, for a specified speed and altitude.

b. Intermediate Power. Intermediate power is defined as the maximum operating condition at which the engine is capable of operating for at least an incremental time duration of 30 minutes, for a specified speed and altitude.

c. Maximum Continuous Power. Maximum continuous power is defined as the maximum operating condition at which the engine is capable of operating continuously, for a specified speed and altitude.

D.3.11.3.2.2 Non-Augmented Jet Engines.

a. Takeoff (Maximum) Thrust (Power). Takeoff thrust (power) is defined as the maximum thrust certified for takeoff operation, for a specified speed and altitude. Operation at this rating is usually limited to five minutes per takeoff interval, unless otherwise specified in the engine specification.

b. Intermediate Thrust (Power). Intermediate thrust (power) is defined as the thrust which the engine will deliver when the power lever is placed in the Intermediate position, for a specified speed and altitude. Engine operation at Intermediate thrust may have an incremental duration time limit, but this limit shall be at least 30 minutes.

c. Maximum Continuous Thrust (Power). Maximum continuous thrust (power) is defined as the thrust which the engine will deliver for continuous operation, i.e. no time limit, when the power lever is placed in the Maximum Continuous position, for a specified speed and altitude.

D.3.11.3.2.3 Augmented Jet Engines.

a. Maximum Augmentation. Maximum augmentation is defined as the maximum thrust with afterburning, for a specified speed and altitude. This setting may or may not be time limited.

b. Minimum Augmentation. Minimum augmentation is defined as the lowest thrust at which the engine will operate with afterburning, for a specified speed and altitude. This setting may or may not be time limited.

c. Intermediate (Military) Power. Intermediate power is defined as the maximum thrust without afterburning, for a specified speed and altitude. The engine shall be capable of continuously operating at this setting.

TABLE D-V. Non-afterburning thrust (power) settings.

TIME LIMIT	SHAFT	NON-AUGMENTED JET	AUGMENTED JET
$\leq$30	MAXIMUM	TAKEOFF (MAXIMUM)	—
30	INTERMEDIATE	INTERMEDIATE	—
UNLIMITED	MAXIMUM CONTINUOUS	MAXIMUM CONTINUOUS	INTERMEDIATE (MILITARY)

D.3.12 Fuel. Fuel grade used for aircraft performance calculations shall be specified in the performance ground rules. The density and lower fuel heating value properties for the most commonly used fuels are shown below and represent the minimum values for each fuel grade. The densities presented in this Paragraph are for 59° Fahrenheit.

Aviation Fuel	Density	Fuel Heating Value
Gasoline in all grades (ASTM D910):	6.0 lb/gal;	18,700 BTU/lb.
JP-5 Jet fuel (MIL-T-5624):	6.6 lb/gal;	18,300 BTU/lb.
JP-8 Jet fuel (MIL-T-83133):	6.5 lb/gal;	18,400 BTU/lb.
JP-10 Jet fuel (MIL-P-87107):	7.8 lb/gal;	18,100 BTU/lb.
Jet A-1 fuel (ASTM D1655):	6.7 lb/gal;	18,400 BTU/lb.

If a design requires special fuels, refer to the appropriate military or commercial fuel specification.

D.3.12.1 Alternate Design Criteria. Subject to the approval of the procuring activity, consideration may be made to use the average fuel characteristics based on a sampling of the delivered fuel grade. This should be considered when aircraft performance calculations on operational aircraft, or comparison analysis between an operational and a conceptual design aircraft need to be done. The data below represents the average fuel characteristics for a specified fuel grade:

Aviation Fuel	Density	Fuel Heating Value
Gasoline in all grades (ASTM D910):	6.0 lb/gal;	18,700 BTU/lb.
JP-5 Jet fuel:	6.8 lb/gal;	18,450 BTU/lb.
JP-8/Jet A-1 Jet fuel:	6.8 lb/gal;	18,570 BTU/lb.
JP-10 Jet fuel:	7.8 lb/gal;	18,200 BTU/lb.

D.4.0 GROUND RULES

The paragraphs within this section contain the ground rules which define the conditions to be applied when calculating aircraft performance.

D.4.1 Computation Ground Rules. Unless otherwise specified, the following ground rules shall apply:

D.4.1.1 Speeds. All speeds defined within this document shall lie on or within the applicable flight envelope boundaries as defined in MIL-STD-1797.

D.4.1.2 Atmosphere. Unless otherwise specified, aircraft performance shall be calculated and presented for a standard day. Standard day atmospheric characteristics are shown in Annex 1, table D.1-I.

D.4.1.2.1 Alternate Design Criteria. When required by the procuring activity, consideration shall be given to the effect of atmospheric variations on aircraft performance. While standard day provides the common atmospheric conditions for which performance comparisons can be made, additional "atmospheres" are needed to determine the variation of performance across the extremes of expected temperatures. Polar and tropical atmospheres are included in Annex 1 tables D.1-III and D.1-IV to fill this need. These atmospheres provide the needed free air characteristics near the extremes of temperature. Table D.1-V in Annex 1 provides these same characteristics for hot conditions near the ground. Unlike the free air atmospheres (tables D.1-I, D.1-III, and D.1-IV), this atmosphere is a boundary of extreme conditions, is not representative of a realistic atmosphere, and cannot be used to calculate rate of climb. Its primary use is for takeoff calculations.

D.4.1.3 Wind. Unless otherwise specified, data shall be for a no wind condition. See Annex 1 for the effects of winds, when used.

D.4.1.4 Formation Flight. Data shall be for a single aircraft only.

D.4.1.5 Ordnance Expenditure. Unless otherwise specified, for the purpose of mission calculations, the following ground rules shall be used:

a. Air-to-Air Missions - Expend half of the ammunition and each type of onboard missile at the end of the combat segment.

b. Air-to Ground Missions - Expend all air-to-ground ordnance at the end of combat. Retain all air-to-air missiles and ammunition.

D.4.1.6 External Fuel Tanks. Unless otherwise specified, external fuel tanks, when carried, shall be retained.

D.4.1.7 Pylons/Racks. Pylons, bomb racks, etc. shall always be retained when the external stores are dropped. Unless otherwise specified, pylons shall remain installed on all stations on which stores are normally carried, whether or not stores are carried on them for a particular mission.

D.4.1.8 Change in Energy State at Intersection of Mission Segments. When the energy state at the start of a new mission segment is greater than at the end of the previous mission segment, fuel to increase the energy state must be accounted for. When the change in energy is negative (a decrease in the energy state), the change is assumed to be instantaneous with no change in time, distance, or fuel. Descents shall follow the guidance in Paragraph D.4.2.8.

D.4.1.9 Reduced Engine Operation. When applicable, flight with a minimum number of engines operating may be used to increase range or loiter time if such operation represents normal service usage. Such operation shall conform to Paragraph D.4.1.10.

D.4.1.10 Authorized Operation. No operational technique shall be utilized that is not included nor intended to be included as recommended procedure in the applicable flight manual. Authorization shall be subject to approval of the procuring activity.

D.4.1.11 Trainer Aircraft. The trainer missions defined in Annex 2 are applicable to basic and advanced trainer aircraft. Combat and tactical trainer aircraft fly the missions for the appropriate parent type aircraft.

D.4.1.12 Variable Geometry Wing Aircraft. For aircraft with variable sweep wings, the automatic sweep program will be clearly defined and used. If not automatic, the aircraft will be assumed to have wings in the unswept position for takeoff and subsonic flight, and fully swept for supersonic flight unless otherwise noted.

D.4.1.13 Fuel Consumption Tolerance. All fuel consumption data for aircraft/engine combinations which is not based on flight test shall be increased by 5 percent. Subject to approval of the procuring activity, once the aircraft/engine data has been verified by flight test, the 5 percent tolerance can be removed.

D.4.1.14 Fuel Consumption Corrections. Corrections to engine fuel flow shall be made for all engine bleeds and accessory drive losses appropriate to each phase of flight.

D.4.2 Mission Segment Ground Rules. The following paragraphs contain the ground rules and fuel allowances applicable to each phase of flight. Several options are given for each mission segment to allow for design innovations, information available during different phases of a program, different degrees of operational reality, and land based Vs carrier based operation. It is the responsibility of the procuring activity to evaluate/approve the appropriate options. In the case of comparisons between different aircraft, options which yield comparable performance must be used and the options chosen must be clearly stated with the performance data presentation. In general, allowances fall into three categories: task oriented for well defined requirements, fixed quantities for less well defined requirements, and others for undefined requirements or unconventional designs.

D.4.2.1 Warm-up and Takeoff. A quantity of fuel shall be allowed for ground operation including starting engines, warm-up of engines and electronics equipment, taxi, takeoff and acceleration to either obstacle clearance or enroute climb speed. It shall consist of one of the following:

a. Fuel burned for a specified time at a specified thrust (power) setting and altitude, at 0 Mach, plus an allowance for afterburner, if applicable.

(1) 4.6 minutes at Intermediate thrust (power) at sea level, standard day, plus 30 seconds at Maximum thrust sea level, standard day, if afterburner is used during takeoff.

(2) 5.0 minutes at Maximum Continuous (Intermediate for augmented engine powered aircraft) thrust (power) at sea level, standard day, plus 30 seconds at Maximum thrust, sea level, standard day, if afterburner is used during takeoff.

(3) or ___ minutes at ___________ thrust (power) at _______ ft, ______ day, plus __ seconds at Maximum thrust _____ ft, _____ day, if afterburner is used during takeoff.

b. Estimated fuel required to start the engine(s), warm up, taxi for a specified time at a specified thrust (power) setting and altitude, at 0 Mach and accelerate from brake release to obstacle clearance speed at a specified thrust (power) setting.

(1) 20 minutes at ground idle, sea level, standard day, plus 30 seconds at Takeoff (Maximum) thrust (power) (max A/B, if applicable).

(2) or ____ minutes at _________ thrust (power) at _______ ft, _________ day, plus ______ seconds at ________ thrust (power).

c. Fuel burned for a specified time at a specified thrust/weight ratio to account for starting the engine(s) and taxi plus a quantity of fuel, derived from the following equation, to account for takeoff and acceleration to obstacle clearance speed:

$$W_{fto} = 1.6878 \frac{V_{co} W_{TO}}{2g} \times \frac{\dot{W}_{fo} + \dot{W}_{fc}}{F_n - D}$$

Where:

W_{fto} = takeoff and acceleration fuel, lb
V_{co} = obstacle clearance speed, knots true airspeed
W_{TO} = takeoff weight, lb
$\dot{W}_{fo}$ = static fuel flow at the thrust (power) for takeoff, lb/sec
$\dot{W}_{fc}$ = fuel flow at initial climb speed at the thrust (power) for takeoff, lb/sec
g = gravitational acceleration, ft/sec^2
F_n = thrust at initial climb speed at the thrust (power) for takeoff = $(F_g \cos(\alpha + \iota) - D_r - D_p)$, lb
F_g = gross thrust, lb
D_r = ram drag, lb
D_p = propulsive drag (other than ram drag), lb
α = angle of attack
ι = thrust incidence angle
D = aerodynamic drag at initial climb speed and corresponding angle of attack, lb

Note: If thrust (power) is to be varied between liftoff and obstacle clearance speed, this equation can be so modified.

(1) 6 minutes at a thrust to weight ratio of 0.2 at sea level, standard day, plus takeoff and acceleration fuel.

(2) or ____ minutes at a thrust to weight ratio of ______ at _______ ft, _____ day, plus takeoff and acceleration fuel.

d. A specified quantity of fuel.

e. For aircraft with a short takeoff capability, fuel burned for a specified time at a specified power setting and altitude, at 0 Mach plus allowances for takeoff acceleration to obstacle clearance speed.

(1) 10 minutes at ground idle at sea level, standard day, plus 15 seconds at Intermediate thrust (power), plus 15 seconds at Takeoff (maximum) thrust (power).

(2) _____ minutes at _______ thrust (power) at _______ ft, ______ day, plus _____ seconds at _____ thrust (power), plus _____ seconds at _____ thrust (power)

f. For aircraft with a vertical takeoff capability, fuel burned for a specified time at a specified power setting and altitude, at 0 Mach plus an allowance for vertical liftoff and transition to forward flight.

(1) 2.5 minutes at Maximum Continuous (Intermediate for augmented engine powered aircraft) thrust (power) at sea level, standard day, plus 15 seconds at Takeoff (maximum) thrust (power).

(2) _____ minutes at _______ thrust (power) at _______ ft, ______ day, plus _____ seconds at _____ thrust (power).

g. Other criteria, or combinations of the above, which may be selected to more accurately portray the operational characteristics of a specific design or mission.

Note: Options a and f contain sufficient fuel to get to enroute climb speed. Options b, c, and e require the addition of an initial climb-out segment. Options d and g can be specified either way.

D.4.2.2 Climb. Climb after takeoff may be divided into two segments: initial climb out and enroute climb.

D.4.2.2.1 Initial Climb-Out. The time, distance, and fuel to climb and accelerate from obstacle clearance speed (Paragraph D.3.2.4) to the appropriate climb speed (Paragraph D.3.3.9) shall be calculated with the aircraft in the clean configuration, using the applicable thrust (power) setting. For calculation purposes, gear and flap retraction shall be assumed to take place instantaneously at the obstacle.

D.4.2.2.1.1 All Engines Operating (AEO). Initial climb-out with all engines operating shall be based on all engines operating from brake release to liftoff. Acceleration to climb-out speed and climb-out shall be based on the thrust (power) available with all available engines.

D.4.2.2.1.2 One Engine Inoperative (OEI). Initial climb-out with one engine inoperative shall be based on all engines operating from brake release to critical engine failure speed and with the critical engine inoperative from critical engine failure speed to liftoff. Acceleration to climb-out speed and climb-out shall be based upon the thrust (power) available with the remaining engines at Takeoff (Maximum) thrust (power) and the drag of the inoperative engine. If means of reducing drag of the inoperative engine is a design feature, such drag reduction shall be utilized with a time allowance for activation.

D.4.2.2.2 En route Climb. Except for point intercept missions, all climbs shall be en route with thrust (power) and speed schedules specified in Paragraph D.3.3.9. Point intercept missions shall be optimized to obtain minimum time to combat altitude, speed, and distance.

D.4.2.2.2.1 En route Climb Data. En route climb data (time, distance, and fuel) shall be based on the appropriate configuration, thrust (power) and weight. The aircraft shall have the landing gear and flaps retracted and have attained the airspeed for best climb for the specified mission.

D.4.2.2.2.2 En route Climb Power. Unless otherwise specified, Intermediate (Military) thrust shall be used for en route climb to cruise altitude for jet powered aircraft (turbojet, turbofan, ram jet, etc.). For propeller powered aircraft (internal combustion, turboprop) Maximum Continuous power shall be used.

D.4.2.3 Cruise. Unless otherwise specified, all cruise segments shall be performed in a cruise climb, maintaining optimum long range cruise speed (maximum range cruise speed for fighter and attack aircraft) and altitude for the specified weight and configuration. This altitude shall not exceed cruise ceiling. The changes in cruise speed, altitude, and specific range with weight during each cruise segment shall be taken into account. Constant altitude cruise, step climb, maximum range cruise speed, etc., shall be used if specified. For operationally realistic missions, the specified minimum terrain clearance shall be observed.

D.4.2.4 Penetration and Withdrawal. The penetration and withdrawal segments consist of entering and leaving a target area for a given distance at conditions of airspeed and altitude which maximize survivability. Time, distance, and fuel expended shall be included in the mission calculations.

D.4.2.5 Combat. Combat shall be considered by setting aside a quantity of fuel to account for the tasks to be performed during this segment. Fuel computation shall be based on the weight at the start of the combat period with benefit due to fuel weight reduction credited. Unless otherwise specified, combat fuel shall be calculated before ammunition and stores, both air-to-air and air-to-ground, are expended. Combat fuel shall consist of one of the following:

a. Fuel required to make a specified number of turns, at a specified load factor, Mach number, and thrust (power) setting, at a specified altitude. If more than one series of turns is to be made at different Mach numbers, the sequence of turns shall also be specified.

(1) One 540° turn at the maximum sustained load factor, at the specified Mach number and thrust (power) setting, at combat altitude, standard day.

(2) or _____ turns at ________ g's, _____ Mach number, _________ thrust (power), at _______ ft, ________ day.

b. Fuel required to perform an energy exchange at a specified Mach number, thrust (power) setting, weight, and altitude. Fuel used shall be determined from the following equation:

$$\text{Combat fuel} = \frac{\Delta E_s \dot{W}_f}{P_s}$$

Where:

ΔE_s = change in specific energy, feet
P_s = Specific excess power, ft/sec
$\dot{W}_f$ = Fuel flow, lb/sec

(1) 40,000 ft change in specific energy, at .9 Mach, 10,000 ft, standard day, at the specified thrust (power) setting.

(2) or _______ ft change in specific energy, at _____ Mach, ________ ft, ______ day, at ______ thrust (power).

c. Fuel required for a specified time, at a specified Mach number and thrust (power) setting, at a specified altitude.

(1) 5 minutes at Intermediate rated thrust (power) at the specified Mach number and altitude, standard day.

(2) or ______ minutes at _________ thrust (power), at ______ Mach, at _______ ft, ______ day.

d. A specified quantity of fuel.

e. Other criteria which may be selected to more accurately portray the operational characteristics of a specific design or mission.

D.4.2.6 Loiter. Unless otherwise specified, loiter segments shall consist of 1 g, level flight at maximum endurance speed and altitude away from the combat area, and at or slightly below corner speed in or near the combat area..

D.4.2.6.1 Mission Specific Tasks. Specialized tasks may be included which require maneuvering the aircraft as part of this mission requirement. These include maneuvers such as banked orbits, flat turns, search, patrol, etc. Fuel required to accomplish these specialized tasks shall be included with overall mission fuel.

D.4.2.7 Refueling. The refueling segment starts at the end of the previous segment and ends at the end of the refueling operation. If a climb or descent is required as part of this segment, it shall be conducted in accordance with Paragraph D.4.2.2 or D.4.2.8. Refueling shall take place within the refueling speed/altitude envelope common to both the tanker and receiver aircraft. The following time allowances shall be used for refueling:

a. 15 minutes for fighter and attack receiver aircraft.

b. 30 minutes for transports, strategic bombers and tanker receiver aircraft.

c. 60 minutes for tanker aircraft off-loading fuel.

d. _____ minutes. Time is dependent upon the specific refuel rates.

D.4.2.7.1 Rendezvous Refuel. For refueling operations involving a rendezvous between the tanker and receiver aircraft, rendezvous and refueling will commence with no less than _____ pounds of fuel onboard the receiver aircraft. _____ minutes shall be allowed for rendezvous and speed/altitude changes, if required. Distance covered during rendezvous and refueling will not be credited to the mission range or radius except for bombers and cargo/transports.

D.4.2.7.2 Buddy Refuel. When the tanker and receiver cruise together from shortly after takeoff to the refuel point, refueling will commence with no less than _____ pounds of fuel onboard the receiver aircraft. _____ minutes shall be allowed for speed/altitude changes, if required. Both distance and time for speed/altitude adjustments prior to refueling shall be credited to the mission range or radius. The distance flown during refueling shall also be credited.

D.4.2.8 Descent. For aircraft which start a descent at the end of a supersonic segment, time, distance, and fuel shall be credited for descent and deceleration to a specified altitude and speed. For aircraft which start a descent at the end of a subsonic segment, no time, distance, or fuel will normally be credited for descent. If realism is required for operational concerns, the descent shall be modeled at Flight Idle thrust (power) using one of the following speed schedules, and time, distance, and fuel shall be credited:

a. The speed for a descent starting at a point 2.5 nm/1000 ft of altitude change from the intended point of arrival.

b. Cruise speed or 250 KCAS, whichever is less

c. Speed for maximum lift/drag ratio

d. A specified speed schedule

e. Limit airspeed

f. Other.

D.4.2.9 Landing Reserves. A quantity of fuel shall be set aside at the end of each mission as a safety factor to allow for more than one landing pass, time in a holding pattern, or flight to an alternate field. It shall consist of one of the following:

D.4.2.9.1 Land Operations.

a. A specified percentage of total initial fuel plus fuel consumed for a specified time, at maximum endurance speed at a specified altitude, standard day. The following data contains the most commonly used examples.

% of total initial fuel	Time - min.	Altitude - ft
0	20	Sea Level
5	20	Sea Level
5	20	10,000
5	10	Sea Level
5	30	Sea Level
10	0	-----
--	--	-----

b. A quantity of fuel which would increase the mission time by 10 percent or 20 minutes, whichever is greater. Fuel consumption is calculated at maximum endurance airspeed at 10,000 ft for turbine powered aircraft, and at cruise altitude for reciprocating engine aircraft. (reference AFI 11-206)

c. A quantity of fuel to simulate a missed approach and flight to an alternate airfield a specified distance from the intended landing point. Reserves shall be equal to the sum of the fuel used in the segments shown in figure D-8 below. (reference National Business Aircraft Association Range Format) Descent shall follow the guidance in Paragraph D.4.2.8.

d. Other criteria to more accurately portray the operational characteristics of a specific design or mission.

Missed Approach	_____ min loiter at 5,000 ft
Min time climb	Climb to 5,000 ft
Hold	Loiter for _____ min at 5,000 ft
Min time climb	Climb to optimum cruise altitude
Optimum Cruise	Cruise at max range cruise speed
Descent	Descend to alternate field altitude
Final reserves	Final reserves equal 30 min loiter at 5,000 ft

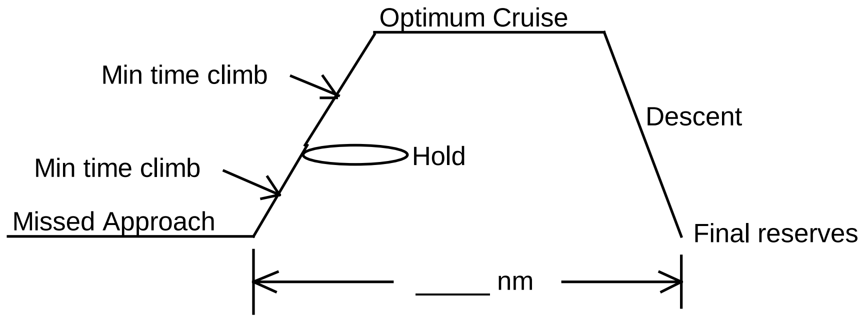

FIGURE D-8. Fuel for flight to an alternate field.

D.4.2.9.2. Carrier Operations. The following typical landing reserves are considered for carrier based missions (carrier operations landing reserves are to be calculated for an 89.8° F tropical day):

D.4.2.9.2.1 Visual Flight Rules (VFR). Landing reserve for a carrier based mission may consist of any number of VFR passes in the landing configuration (flaps and gear down). One VFR pass is defined as follows:

a. An Intermediate rated thrust (power) climb from 63 feet to 600 feet at a constant airspeed equivalent to 120 percent of V_{pa}.

b. One 180° turn (20° of bank) at 600 feet, at a constant airspeed equivalent to 120 percent of V_{pa}.

c. Cruise downwind 1 nautical mile at 600 feet at a constant airspeed equivalent to 120 percent of V_{pa}.

d. One 180° turn (20° of bank) at 600 feet at V_{pa}.

e. Final straight in approach, 1 nautical mile at 300 feet at V_{pa}.

D.4.2.9.2.2 Instrument Flight Rules (IFR). Landing reserve for a carrier based mission may consist of any number of IFR passes in the landing configuration (flaps and gear down). One IFR pass is defined as follows:

a. An Intermediate rated thrust (power) climb from 75 feet to 1200 feet at a constant airspeed equivalent to 120 percent of V_{pa}.

b. One 180° turn (20° of bank) at 1200 feet at a constant airspeed equivalent to 120 percent of V_{pa}.

c. Cruise downwind for 3 nautical miles at reduced power at 1200 feet at a constant airspeed equivalent to 120 percent of V_{pa}.

d. One 180° turn (20° of bank) at 1200 feet at a constant airspeed equivalent to V_{pa}.

e. Final straight in approach, 4 nautical miles at 600 feet at a constant airspeed equivalent to V_{pa}.

D.4.2.9.2.3 <u>100 Nautical Mile BINGO</u>. A 100 nautical mile BINGO landing reserve fuel allowance is defined as follows:

a. Intermediate rated thrust (power) acceleration from an airspeed equivalent to 120 percent of V_{pa} to best climb speed at sea level.

b. Intermediate rated thrust (power) climb from sea level at best climb speed to best cruise altitude.

c. Cruise at altitude(s) and speed(s) which maximize BINGO range.

d. Idle rated thrust (power) descent to 10,000 ft. at 250 KCAS .

e. Loiter for 10 minutes at 10,000 ft at maximum endurance speed.

Notes:

1. Total distance for segments a, b, c, and d only is credited towards 100 nautical mile BINGO.

2. BINGO is a term for a declared emergency, telling a landing aircraft to divert and land elsewhere.

3. BINGO fuel is the minimum fuel required to divert to an alternate landing site using an emergency flight profile.

D.4.2.9.2.4 <u>Other</u>. A specified quantity of fuel (typically 3000 or 4000 lb).

D.4.2.9.3 <u>Vertical Landing</u>. The following landing reserves are considered for aircraft (i.e., STOVL) which have a vertical landing capability:

a. Fuel required for 10 minutes of loiter at maximum endurance speed at Sea Level, standard day (89.8° F for carrier operations) plus 5 % of total fuel on board at takeoff.

b. Fuel required for ____ minutes of loiter at maximum endurance speed at ____ft, _____ day (89.8° F for carrier operations) plus ____ % of total fuel on board at takeoff.

c. Fuel required for ______ vertical landing passes at mission landing weight. A vertical landing pass is defined as follows:

(1) Transition from wing-borne flight (120 percent of power off aerodynamic stall speed) to a hover at 50 ft altitude above the landing position

(2) Initiate a 4 ft/sec vertical descent

(3) Arrest the vertical descent with zero descent velocity achieved at a wheel height of no less than 5 ft above the landing surface.

(4) Climb vertically to 50 ft, and accelerate into and complete transition to wingborne flight (120 percent of power off aerodynamic stall speed) at takeoff thrust. Horizontal acceleration shall be 0.13g or higher. Climb to 600 feet at an airspeed 120 percent of power off aerodynamic stall speed at Intermediate Thrust

(5) One 180 degree turn (20 degrees of bank) at 600 feet, at a constant airspeed equivalent to 120 percent of power off aerodynamic stall speed.

(6) Cruise downwind 1 nautical mile at 600 feet at constant airspeed equivalent to 120 percent of power off aerodynamic stall speed.

(7) One 180 degree turn (20 degrees of bank) at 600 feet at 120 percent of aerodynamic stall speed.

d. <u>100 Nautical BINGO</u>. A 100 nautical mile BINGO landing reserve fuel allowance for vertical landing aircraft is defined as follows:

(1) From hover at 50 feet altitude accelerate into and complete transition to wingborne flight.

(2) Intermediate rated thrust (power) climb from sea level at best climb speed to best cruise altitude.

(3) Cruise at altitude(s) and speed(s) which maximize BINGO range.

(4) Idle rated thrust (power) descent to 10,000 feet at 250 KCAS.

(5) Loiter for 10 minutes at 10,000 feet at maximum endurance speed.

Notes:

1. Total distance for segments 1, 2, 3, and 4 only is credited towards 100 nautical mile BINGO.

2. BINGO is a term for a declared emergency, telling a landing aircraft to divert and land elsewhere.

3. BINGO fuel is the minimum fuel required to divert to an alternate landing site using an emergency flight profile.

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TABLE D.1-I. Standard day amosphere.
ANNEX 1

PROFILES OF ATMOSPHERIC CHARACTERISTICS

This appendix to the draft military standard (Annex 1 to JSSG-2001 Appendix D) contains the profiles of atmospheric characteristics to be used in calculating aircraft performance, and the terms and constants used to relate these characteristics to the various performance definitions.

ATMOSPHERIC CHARACTERISTICS

1. STANDARD DAY. Over the years, as aircraft were being developed, it became obvious that since aircraft performance is dependent on the temperature, pressure, and density of the medium through which it flies, a description of those characteristics was necessary to define an aircraft's performance. It was further obvious that unless the same atmospheric description was used time after time, comparison of performance characteristics would be impossible. To fill this need, an arbitrary profile of atmospheric conditions versus altitude was developed which lay part way between the extremes of possible atmospheric variations and which meets the conditions of continuity exhibited by the atmosphere. This atmospheric model was titled "Standard Day" and has been used, basically unchanged since it was published in 1952 as the "Manual of the ICAO (International Civil Aviation Organization) Standard Atmosphere". Since then it has been published in many documents, and the altitude span covered by the profile has been greatly increased. Table D.1-I contains the standard day model for altitudes from minus 15,000 ft to 150,000 ft taken from the "U.S. Standard Atmosphere, 1976" prepared under the sponsorship of the National Aeronautics and Space Administration, United States Air Force, and United States Weather Bureau. The equations for standard day pressures and temperatures are presented in table D.1-II. They can be used to derive pressures and temperatures at intermediate altitudes. The tables were extended down to minus 15,000 ft geopotential altitude so density altitudes for conditions colder than standard day can be obtained.

2. POLAR AND TROPICAL DAYS. While the standard day is used as a common reference to which aircraft performance can be normalized, additional atmospheric models which describe realistic profiles of extremes of temperature and density are needed to calculate performance parameters under near worst case conditions. The atmospheres which have historically been used for this purpose are the Polar and Tropical atmospheres from MIL-STD-210A, "Climatic Extremes for Military Equipment", dated 2 August 1957. They are included here as Tables III (Polar Day) and IV (Tropical Day). These atmospheres extend to 100,000 ft geopotential altitude. If data is required for altitudes above 100,000 ft, atmospheres from the "U.S. Standard Atmosphere Supplements, 1966" which closely approximate the polar and tropical days at lower altitudes can be used. The 60° North, January (warm) can be substituted for the polar day, and the 15° North annual can be used instead of the tropical day. The conditions given in these tables are applicable to free air conditions. Temperatures close to the surface of the earth, even at high elevations, can be considerably higher than those for free air. Table D.1-V contains a model of hot day ground level atmospheric conditions to be used for takeoff and other ground operations at elevations up to 15,000 ft. It was

extracted from table VI, "Hot day atmosphere" of MIL-C-5011B, which in turn was taken from MIL-STD-210A.

3. TABLES OF ATMOSPHERIC CHARACTERISTICS. These tables contain 1) basic characteristics of the atmosphere (temperature, pressure, and density), 2) altitude to sea level ratios of these parameters, and 3) parameters derived from these values (speed of sound, coefficient of viscosity, and the ratio of dynamic pressure to Mach number squared). All tables show data as a function of both geometric and geopotential altitude. The data is shown for 1,000 ft increments (geopotential) below 100,000 ft and 5,000 ft increments above 100,000 ft. Temperature ratio, pressure ratio, and density ratio are referenced to standard day sea level values (T_o, P_o, and ρ_o) for all atmospheres.

WIND

The definitions in the main body of this specification were written for conditions of zero wind. When winds must be taken into account, the proper adjustments must be made to the value of "speed" being used. Wind is the difference between ground speed and the horizontal component of airspeed, and care must be taken to determine whether the speeds used in the definitions are ground speeds, airspeeds, or a mixture of both. Wind speed must be split into components of headwind and crosswind The effects of headwind are different for each segment of flight and the general effects are outlined below.

1. TAKEOFF AND LANDING. While the aircraft is on the ground, forces are being input by both the ground and the air. Where these forces are a function of speed, ground forces are a function of ground speed and aerodynamic forces are a function of airspeed. Care must be used to ensure that the effects of wind are properly taken into account for the other parameters included under the subject of takeoff (ground minimum control speed, critical field length, etc.). Crosswind limits must also be checked to ensure they are not being violated.

2. CLIMB AND DESCENT. While changing altitudes, the distance traveled, and the flight path angle will vary with wind speed. To optimize range, climb speed must be varied since optimum climb speed varies with wind speed.

3. CRUISE. The effect of a headwind is to change both the specific range and the optimum cruise speed of the aircraft. When tailwind components exist, specific range can be maximized by flying at a somewhat lower airspeed. For headwinds, the cruise airspeed must be increased to maximize specific range.

4. CEILING AND MANEUVERABILITY. No effect. All parameters are a function of airspeed only.

5. ENDURANCE. No effect. Position over the same portion of ground can be maintained by flying longer on the upwind leg than on the downwind leg

ANNEX 1

TERMS RELATED TO THE ATMOSPHERE

1. ALTITUDE. In general, altitude refers to the height above some reference surface. In order to define the altitude at which specific conditions occur, more specific definitions of both the height and the reference surface are required. The following is a list of commonly used altitudes:

GEOMETRIC ALTITUDE (Z): Geometric altitude is the tape line height of a point above sea level. This is the altitude which would be measured by an infinitely long ruler with equal divisions of physical length with one end placed at sea level. This is also the altitude which would be measured by an inertial sensor, or a radar set at sea level.

GEOPOTENTIAL ALTITUDE (H): Geopotential altitude is an altitude in which height is measured in equal divisions of potential energy. As distance from the surface of the earth (sea level) increases, gravity decreases, and the physical distance required to obtain the same quantity of potential energy as at a lower altitudes increases. Thus a difference in geopotential height of 1 ft at low altitude is physically shorter than a geopotential difference of 1 ft at high altitude. Since aircraft performance calculations are essentially a study of the energy state of the aircraft, geopotential is the proper altitude to use and the data in the atmospheric tables in Annex 1 are given at equal intervals of geopotential altitude. A secondary scale of geometric altitude is also given. The relationship between geometric and geopotential altitude is:

$$H = \frac{rZ}{r + Z}$$

Where: r = earth radius, ft
Z = geometric altitude, ft

The difference between geometric and geopotential altitude is small, and for most applications they are assumed to be equal. If extreme precision is needed, the proper definitions should be used. Also, since both gravity and the radius of the earth vary with latitude, the relationship between geometric and geopotential altitudes is affected by latitude variations. These variations are shown in table 4.20 of the "U.S. Standard Atmosphere Supplements, 1966".

PRESSURE ALTITUDE (H_p or Z_p): Pressure altitude is the altitude in a given atmosphere at which the pressure corresponds to the pressure in the standard day atmosphere. For a standard day (or any atmosphere for which the variation of pressure with altitude is the same as a standard day), equal increments of pressure altitude result in equal increments of height, and may be measured in either geometric or geopotential units. For atmospheres whose pressure /altitude profiles are different than standard day, equal increments of pressure altitude do not result in equal increments of height. Thus, for these days, pressure altitude cannot be used directly for climb calculations. Pressure altitude is also the altitude read from an altimeter set at 29.92 in Hg.

INDICATED ALTITUDE: Indicated altitude is the altitude read from the altimeter. It is equal to pressure altitude plus installation error plus instrument error.

DENSITY ALTITUDE (H_d or Z_d): Density altitude is the altitude in a given atmosphere at which the density corresponds to the density in the standard day atmosphere. For a standard day, pressure altitude and density altitude are equal. Although pressure altitude is the reference altitude at which the aircraft flies, density altitude is the altitude used for calculations on non-standard days since density is the parameter to which all aerodynamic coefficients are referred.

2. SPEED: Speed, in general, refers to the rate of change of distance of one object relative to another. More specific definitions are needed to describe both the object relative to which speed is measured and the method by which speed is calculated. The following is a list of commonly used speeds:

AIRSPEED: Air speed is the speed of an aircraft relative to the air mass through which it is flying.

WIND SPEED. Wind speed is the speed of the air mass relative to the ground.

GROUND SPEED: Ground speed is the horizontal component of the speed of the aircraft relative to the ground over which it is flying.

INDICATED AIRSPEED (V_{ias}): Indicated airspeed is the airspeed read from the cockpit airspeed indicator, corrected for instrument error.

CALIBRATED AIRSPEED ($V_{cas)}$: Calibrated airspeed is indicated airspeed corrected for airspeed instrumentation position error. The correction is unique for each model aircraft.

EQUIVALENT AIRSPEED (V_{eas}): Equivalent airspeed is calibrated airspeed corrected for compressibility effects. This correction is the same for all aircraft.

TRUE AIRSPEED (V_{tas}): True airspeed is equivalent airspeed corrected for change in atmospheric density. It is equal to equivalent airspeed divided by the square root of the density ratio. True airspeed is the actual speed of an aircraft relative to the mass through which it is flying.

CONSTANTS AND RELATIONSHIPS. The following is a list of constants commonly used in performance calculations:

Acceleration of gravity, sea level, 45° latitude	g_0 = 32.1741 ft/sec^2
Temperature, sea level, standard day	T_0 = 518.67 ^{0}R = 288.2 ^{0}K
Pressure, sea level, standard day, static	P_0 = 2116.22 lb/ft^2
Density, sea level, standard day	ρ_0 = .002377 slugs/ft^3
Equatorial earth radius	r_e = 20925646.0 ft
Feet per nautical mile	6076.14

Note: The values of equatorial earth radius and the conversion from feet to nautical miles were taken from the "World Geodetic System 1984", published by the Defense Mapping Agency, Department of Defense.

TABLE D.1-I. Standard day amosphere.

Geopotential Altitude	Geometric Altitude	Temperature				Temperature Ratio	Pressure		Pressure Ratio	Density	Density Ratio	Speed of Sound		Q/M2	Absolute Viscosity
H, ft	Z, ft	deg F	deg R	deg C	deg K	θ	in Hg	lb/ft2	δ	slugs/ft3	σ	ft/sec	Knots	lb/ft2	lb-sec/ft2
-15,000	-14,989	112.49	572.16	44.72	317.87	1.1031	50.1221	3544.95	1.675E+00	3.609E-03	1.519E+00	1172.6	694.7	2481.4	4.029E-07
-14,000	-13,991	108.93	568.60	42.74	315.89	1.0963	48.5018	3430.35	1.621E+00	3.515E-03	1.479E+00	1168.9	692.6	2401.2	4.010E-07
-13,000	-12,992	105.36	565.03	40.76	313.91	1.0894	46.9241	3318.77	1.568E+00	3.422E-03	1.440E+00	1165.3	690.4	2323.1	3.991E-07
-12,000	-11,993	101.79	561.46	38.77	311.92	1.0825	45.3883	3210.15	1.517E+00	3.331E-03	1.401E+00	1161.6	688.2	2247.1	3.972E-07
-11,000	-10,994	98.23	557.90	36.79	309.94	1.0756	43.8935	3104.42	1.467E+00	3.242E-03	1.364E+00	1157.9	686.0	2173.1	3.953E-07
-10,000	-9,995	94.66	554.33	34.81	307.96	1.0688	42.4387	3001.54	1.418E+00	3.154E-03	1.327E+00	1154.2	683.8	2101.1	3.934E-07
-9,000	-8,996	91.10	550.77	32.83	305.98	1.0619	41.0233	2901.43	1.371E+00	3.069E-03	1.291E+00	1150.5	681.6	2031.0	3.914E-07
-8,000	-7,997	87.53	547.20	30.85	304.00	1.0550	39.6463	2804.04	1.325E+00	2.985E-03	1.256E+00	1146.7	679.4	1962.8	3.895E-07
-7,000	-6,998	83.96	543.63	28.87	302.02	1.0481	38.3070	2709.31	1.280E+00	2.903E-03	1.221E+00	1143.0	677.2	1896.5	3.875E-07
-6,000	-5,998	80.40	540.07	26.89	300.04	1.0413	37.0045	2617.19	1.237E+00	2.823E-03	1.188E+00	1139.2	675.0	1832.0	3.856E-07
-5,000	-4,999	76.83	536.50	24.91	298.06	1.0344	35.7382	2527.63	1.194E+00	2.745E-03	1.155E+00	1135.5	672.7	1769.3	3.836E-07
-4,000	-3,999	73.26	532.93	22.92	296.07	1.0275	34.5071	2440.56	1.153E+00	2.668E-03	1.122E+00	1131.7	670.5	1708.4	3.816E-07
-3,000	-3,000	69.70	529.37	20.94	294.09	1.0206	33.3107	2355.94	1.113E+00	2.593E-03	1.091E+00	1127.9	668.3	1649.1	3.797E-07
-2,000	-2,000	66.13	525.80	18.96	292.11	1.0138	32.1480	2273.71	1.074E+00	2.519E-03	1.060E+00	1124.1	666.0	1591.6	3.777E-07
-1,000	-1,000	62.57	522.24	16.98	290.13	1.0069	31.0184	2193.82	1.037E+00	2.447E-03	1.030E+00	1120.3	663.7	1535.7	3.757E-07
0	0	59.00	518.67	15.00	288.15	1.0000	29.9212	2116.22	1.000E+00	2.377E-03	1.000E+00	1116.4	661.5	1481.3	3.737E-07
1,000	1,000	55.43	515.10	13.02	286.17	0.9931	28.8557	2040.86	9.644E-01	2.308E-03	9.711E-01	1112.6	659.2	1428.6	3.717E-07
2,000	2,000	51.87	511.54	11.04	284.19	0.9862	27.8210	1967.68	9.298E-01	2.241E-03	9.428E-01	1108.7	656.9	1377.4	3.697E-07
3,000	3,000	48.30	507.97	9.06	282.21	0.9794	26.8166	1896.64	8.962E-01	2.175E-03	9.151E-01	1104.9	654.6	1327.6	3.677E-07
4,000	4,001	44.74	504.41	7.08	280.23	0.9725	25.8418	1827.70	8.637E-01	2.111E-03	8.881E-01	1101.0	652.3	1279.4	3.657E-07
5,000	5,001	41.17	500.84	5.09	278.24	0.9656	24.8959	1760.80	8.320E-01	2.048E-03	8.617E-01	1097.1	650.0	1232.5	3.636E-07
6,000	6,002	37.60	497.27	3.11	276.26	0.9587	23.9782	1695.89	8.014E-01	1.987E-03	8.359E-01	1093.2	647.7	1187.1	3.616E-07
7,000	7,002	34.04	493.71	1.13	274.28	0.9519	23.0881	1632.94	7.716E-01	1.927E-03	8.106E-01	1089.2	645.4	1143.0	3.596E-07
8,000	8,003	30.47	490.14	-0.85	272.30	0.9450	22.2249	1571.89	7.428E-01	1.868E-03	7.860E-01	1085.3	643.0	1100.3	3.575E-07
9,000	9,004	26.90	486.57	-2.83	270.32	0.9381	21.3881	1512.70	7.148E-01	1.811E-03	7.620E-01	1081.3	640.7	1058.9	3.555E-07
10,000	10,005	23.34	483.01	-4.81	268.34	0.9312	20.5769	1455.33	6.877E-01	1.755E-03	7.385E-01	1077.4	638.3	1018.7	3.534E-07
11,000	11,006	19.77	479.44	-6.79	266.36	0.9244	19.7909	1399.74	6.614E-01	1.701E-03	7.156E-01	1073.4	636.0	979.8	3.513E-07
12,000	12,007	16.21	475.88	-8.77	264.38	0.9175	19.0293	1345.87	6.360E-01	1.648E-03	6.932E-01	1069.4	633.6	942.1	3.492E-07
13,000	13,008	12.64	472.31	-10.76	262.39	0.9106	18.2917	1293.70	6.113E-01	1.596E-03	6.713E-01	1065.4	631.2	905.6	3.472E-07

TABLE D.1-I. Standard day atmosphere (continued).

Geopotential Altitude	Geometric Altitude	Temperature				Temperature Ratio	Pressure		Pressure Ratio	Density	Density Ratio	Speed of Sound		Q/M2	Absolute Viscosity
H, ft	Z, ft	deg F	deg R	deg C	deg K	θ	in Hg	lb/ft2	δ	slugs/ft3	σ	ft/sec	Knots	lb/ft2	lb-sec/ft2
14,000	14,009	9.07	468.74	-12.74	260.41	0.9037	17.5773	1243.18	5.875E-01	1.545E-03	6.500E-01	1061.4	628.8	870.2	3.451E-07
15,000	15,011	5.51	465.18	-14.72	258.43	0.8969	16.8858	1194.27	5.643E-01	1.496E-03	6.292E-01	1057.3	626.4	836.0	3.430E-07
16,000	16,012	1.94	461.61	-16.70	256.45	0.8900	16.2164	1146.93	5.420E-01	1.447E-03	6.090E-01	1053.2	624.0	802.8	3.409E-07
17,000	17,014	-1.62	458.05	-18.68	254.47	0.8831	15.5687	1101.12	5.203E-01	1.400E-03	5.892E-01	1049.2	621.6	770.8	3.387E-07
18,000	18,016	-5.19	454.48	-20.66	252.49	0.8762	14.9421	1056.80	4.994E-01	1.355E-03	5.699E-01	1045.1	619.2	739.8	3.366E-07
19,000	19,017	-8.76	450.91	-22.64	250.51	0.8694	14.3360	1013.94	4.791E-01	1.310E-03	5.511E-01	1041.0	616.8	709.7	3.345E-07
20,000	20,019	-12.32	447.35	-24.62	248.53	0.8625	13.7501	972.49	4.595E-01	1.266E-03	5.328E-01	1036.8	614.3	680.7	3.324E-07
21,000	21,021	-15.89	443.78	-26.61	246.54	0.8556	13.1836	932.43	4.406E-01	1.224E-03	5.150E-01	1032.7	611.9	652.7	3.302E-07
22,000	22,023	-19.46	440.21	-28.59	244.56	0.8487	12.6362	893.72	4.223E-01	1.183E-03	4.976E-01	1028.5	609.4	625.6	3.281E-07
23,000	23,025	-23.02	436.65	-30.57	242.58	0.8419	12.1074	856.31	4.046E-01	1.142E-03	4.807E-01	1024.4	606.9	599.4	3.259E-07
24,000	24,028	-26.59	433.08	-32.55	240.60	0.8350	11.5967	820.19	3.876E-01	1.103E-03	4.642E-01	1020.2	604.4	574.1	3.237E-07
25,000	25,030	-30.15	429.52	-34.53	238.62	0.8281	11.1035	785.31	3.711E-01	1.065E-03	4.481E-01	1016.0	601.9	549.7	3.216E-07
26,000	26,032	-33.72	425.95	-36.51	236.64	0.8212	10.6274	751.64	3.552E-01	1.028E-03	4.325E-01	1011.7	599.4	526.1	3.194E-07
27,000	27,035	-37.29	422.38	-38.49	234.66	0.8144	10.1680	719.15	3.398E-01	9.919E-04	4.173E-01	1007.5	596.9	503.4	3.172E-07
28,000	28,038	-40.85	418.82	-40.47	232.68	0.8075	9.7249	687.80	3.250E-01	9.567E-04	4.025E-01	1003.2	594.4	481.5	3.150E-07
29,000	29,040	-44.42	415.25	-42.45	230.70	0.8006	9.2974	657.57	3.107E-01	9.225E-04	3.881E-01	999.0	591.9	460.3	3.128E-07
30,000	30,043	-47.98	411.69	-44.44	228.71	0.7937	8.8854	628.43	2.970E-01	8.893E-04	3.741E-01	994.7	589.3	439.9	3.106E-07
31,000	31,046	-51.55	408.12	-46.42	226.73	0.7869	8.4882	600.34	2.837E-01	8.569E-04	3.605E-01	990.3	586.8	420.2	3.083E-07
32,000	32,049	-55.12	404.55	-48.40	224.75	0.7800	8.1056	573.28	2.709E-01	8.255E-04	3.473E-01	986.0	584.2	401.3	3.061E-07
33,000	33,052	-58.68	400.99	-50.38	222.77	0.7731	7.7370	547.21	2.586E-01	7.950E-04	3.345E-01	981.6	581.6	383.0	3.039E-07
34,000	34,055	-62.25	397.42	-52.36	220.79	0.7662	7.3821	522.11	2.467E-01	7.653E-04	3.220E-01	977.3	579.0	365.5	3.016E-07
35,000	35,059	-65.82	393.85	-54.34	218.81	0.7594	7.0406	497.95	2.353E-01	7.365E-04	3.099E-01	972.9	576.4	348.6	2.993E-07
36,000	36,062	-69.38	390.29	-56.32	216.83	0.7525	6.7119	474.71	2.243E-01	7.086E-04	2.981E-01	968.5	573.8	332.3	2.971E-07
36,089	36,151	-69.70	389.97	-56.50	216.65	0.7519	6.6833	472.68	2.234E-01	7.061E-04	2.971E-01	968.1	573.6	330.9	2.969E-07
37,000	37,066	-69.70	389.97	-56.50	216.65	0.7519	6.3970	452.43	2.138E-01	6.759E-04	2.844E-01	968.1	573.6	316.7	2.969E-07
38,000	38,069	-69.70	389.97	-56.50	216.65	0.7519	6.0968	431.20	2.038E-01	6.442E-04	2.710E-01	968.1	573.6	301.8	2.969E-07
39,000	39,073	-69.70	389.97	-56.50	216.65	0.7519	5.8107	410.97	1.942E-01	6.139E-04	2.583E-01	968.1	573.6	287.7	2.969E-07
40,000	40,077	-69.70	389.97	-56.50	216.65	0.7519	5.5380	391.68	1.851E-01	5.851E-04	2.462E-01	968.1	573.6	274.2	2.969E-07
41,000	41,081	-69.70	389.97	-56.50	216.65	0.7519	5.2781	373.30	1.764E-01	5.577E-04	2.346E-01	968.1	573.6	261.3	2.969E-07
42,000	42,085	-69.70	389.97	-56.50	216.65	0.7519	5.0304	355.78	1.681E-01	5.315E-04	2.236E-01	968.1	573.6	249.0	2.969E-07
43,000	43,089	-69.70	389.97	-56.50	216.65	0.7519	4.7944	339.09	1.602E-01	5.066E-04	2.131E-01	968.1	573.6	237.4	2.969E-07

TABLE D.1-I. Standard day atmosphere (continued).

Geopo-tential Altitude	Geo-metric Altitude	Temperature				Temper-ature Ratio	Pressure		Pressure Ratio	Density	Density Ratio	Speed of Sound		Q/M2	Absolute Viscosity
H, ft	Z, ft	deg F	deg R	deg C	deg K	θ	in Hg	lb/ft2	δ	slugs/ft3	σ	ft/sec	Knots	lb/ft2	lb-sec/ft2
44,000	44,093	-69.70	389.97	-56.50	216.65	0.7519	4.5694	323.18	1.527E-01	4.828E-04	2.031E-01	968.1	573.6	226.2	2.969E-07
45,000	45,097	-69.70	389.97	-56.50	216.65	0.7519	4.3550	308.01	1.455E-01	4.601E-04	1.936E-01	968.1	573.6	215.6	2.969E-07
46,000	46,102	-69.70	389.97	-56.50	216.65	0.7519	4.1506	293.56	1.387E-01	4.385E-04	1.845E-01	968.1	573.6	205.5	2.969E-07
47,000	47,106	-69.70	389.97	-56.50	216.65	0.7519	3.9558	279.78	1.322E-01	4.180E-04	1.758E-01	968.1	573.6	195.8	2.969E-07
48,000	48,111	-69.70	389.97	-56.50	216.65	0.7519	3.7702	266.65	1.260E-01	3.983E-04	1.676E-01	968.1	573.6	186.7	2.969E-07
49,000	49,115	-69.70	389.97	-56.50	216.65	0.7519	3.5933	254.14	1.201E-01	3.796E-04	1.597E-01	968.1	573.6	177.9	2.969E-07
50,000	50,120	-69.70	389.97	-56.50	216.65	0.7519	3.4246	242.21	1.145E-01	3.618E-04	1.522E-01	968.1	573.6	169.5	2.969E-07
51,000	51,125	-69.70	389.97	-56.50	216.65	0.7519	3.2639	230.85	1.091E-01	3.449E-04	1.451E-01	968.1	573.6	161.6	2.969E-07
52,000	52,130	-69.70	389.97	-56.50	216.65	0.7519	3.1108	220.01	1.040E-01	3.287E-04	1.383E-01	968.1	573.6	154.0	2.969E-07
53,000	53,135	-69.70	389.97	-56.50	216.65	0.7519	2.9648	209.69	9.909E-02	3.132E-04	1.318E-01	968.1	573.6	146.8	2.969E-07
54,000	54,140	-69.70	389.97	-56.50	216.65	0.7519	2.8257	199.85	9.444E-02	2.985E-04	1.256E-01	968.1	573.6	139.9	2.969E-07
55,000	55,145	-69.70	389.97	-56.50	216.65	0.7519	2.6931	190.47	9.000E-02	2.845E-04	1.197E-01	968.1	573.6	133.3	2.969E-07
56,000	56,151	-69.70	389.97	-56.50	216.65	0.7519	2.5667	181.53	8.578E-02	2.712E-04	1.141E-01	968.1	573.6	127.1	2.969E-07
57,000	57,156	-69.70	389.97	-56.50	216.65	0.7519	2.4462	173.01	8.176E-02	2.585E-04	1.087E-01	968.1	573.6	121.1	2.969E-07
58,000	58,161	-69.70	389.97	-56.50	216.65	0.7519	2.3314	164.89	7.792E-02	2.463E-04	1.036E-01	968.1	573.6	115.4	2.969E-07
59,000	59,167	-69.70	389.97	-56.50	216.65	0.7519	2.2220	157.16	7.426E-02	2.348E-04	9.877E-02	968.1	573.6	110.0	2.969E-07
60,000	60,173	-69.70	389.97	-56.50	216.65	0.7519	2.1178	149.78	7.078E-02	2.238E-04	9.414E-02	968.1	573.6	104.8	2.969E-07
61,000	61,179	-69.70	389.97	-56.50	216.65	0.7519	2.0184	142.75	6.746E-02	2.133E-04	8.972E-02	968.1	573.6	99.9	2.969E-07
62,000	62,185	-69.70	389.97	-56.50	216.65	0.7519	1.9237	136.05	6.429E-02	2.032E-04	8.551E-02	968.1	573.6	95.2	2.969E-07
63,000	63,191	-69.70	389.97	-56.50	216.65	0.7519	1.8334	129.67	6.127E-02	1.937E-04	8.150E-02	968.1	573.6	90.8	2.969E-07
64,000	64,197	-69.70	389.97	-56.50	216.65	0.7519	1.7474	123.58	5.840E-02	1.846E-04	7.767E-02	968.1	573.6	86.5	2.969E-07
65,000	65,203	-69.70	389.97	-56.50	216.65	0.7519	1.6654	117.78	5.566E-02	1.760E-04	7.403E-02	968.1	573.6	82.4	2.969E-07
65,617	65,824	-69.70	389.97	-56.50	216.65	0.7519	1.6167	114.34	5.403E-02	1.708E-04	7.186E-02	968.1	573.6	80.0	2.969E-07
66,000	66,209	-69.49	390.18	-56.38	216.77	0.7523	1.5872	112.26	5.305E-02	1.676E-04	7.051E-02	968.3	573.7	78.6	2.970E-07
67,000	67,216	-68.94	390.73	-56.08	217.07	0.7533	1.5128	107.00	5.056E-02	1.595E-04	6.712E-02	969.0	574.1	74.9	2.974E-07
68,000	68,222	-68.39	391.28	-55.77	217.38	0.7544	1.4420	101.99	4.819E-02	1.518E-04	6.388E-02	969.7	574.5	71.4	2.977E-07
69,000	69,229	-67.84	391.83	-55.47	217.68	0.7554	1.3746	97.22	4.594E-02	1.445E-04	6.081E-02	970.4	574.9	68.1	2.981E-07
70,000	70,235	-67.30	392.37	-55.16	217.99	0.7565	1.3104	92.68	4.380E-02	1.376E-04	5.789E-02	971.0	575.3	64.9	2.984E-07
71,000	71,242	-66.75	392.92	-54.86	218.29	0.7576	1.2494	88.36	4.175E-02	1.310E-04	5.512E-02	971.7	575.7	61.9	2.987E-07
72,000	72,249	-66.20	393.47	-54.55	218.60	0.7586	1.1912	84.25	3.981E-02	1.247E-04	5.248E-02	972.4	576.1	59.0	2.991E-07
73,000	73,256	-65.65	394.02	-54.25	218.90	0.7597	1.1358	80.33	3.796E-02	1.188E-04	4.997E-02	973.1	576.5	56.2	2.994E-07

TABLE D.1-I. Standard day atmosphere (continued).

Geopotential Altitude	Geometric Altitude	Temperature				Temperature Ratio	Pressure		Pressure Ratio	Density	Density Ratio	Speed of Sound		Q/M2	Absolute Viscosity
H, ft	Z, ft	deg F	deg R	deg C	deg K	θ	in Hg	lb/ft2	δ	slugs/ft3	σ	ft/sec	Knots	lb/ft2	lb-sec/ft2
74,000	74,263	-65.10	394.57	-53.94	219.21	0.7607	1.0831	76.60	3.620E-02	1.131E-04	4.758E-02	973.8	576.9	53.6	2.998E-07
75,000	75,270	-64.55	395.12	-53.64	219.51	0.7618	1.0329	73.05	3.452E-02	1.077E-04	4.531E-02	974.4	577.3	51.1	3.001E-07
76,000	76,277	-64.00	395.67	-53.34	219.81	0.7628	0.9851	69.67	3.292E-02	1.026E-04	4.316E-02	975.1	577.7	48.8	3.005E-07
77,000	77,285	-63.45	396.22	-53.03	220.12	0.7639	0.9395	66.45	3.140E-02	9.770E-05	4.110E-02	975.8	578.1	46.5	3.008E-07
78,000	78,292	-62.91	396.76	-52.73	220.42	0.7650	0.8961	63.38	2.995E-02	9.306E-05	3.915E-02	976.5	578.5	44.4	3.012E-07
79,000	79,300	-62.36	397.31	-52.42	220.73	0.7660	0.8548	60.46	2.857E-02	8.865E-05	3.729E-02	977.1	578.9	42.3	3.015E-07
80,000	80,308	-61.81	397.86	-52.12	221.03	0.7671	0.8154	57.67	2.725E-02	8.445E-05	3.553E-02	977.8	579.3	40.4	3.019E-07
81,000	81,315	-61.26	398.41	-51.81	221.34	0.7681	0.7779	55.02	2.600E-02	8.045E-05	3.385E-02	978.5	579.7	38.5	3.022E-07
82,000	82,323	-60.71	398.96	-51.51	221.64	0.7692	0.7422	52.49	2.481E-02	7.665E-05	3.225E-02	979.2	580.1	36.7	3.026E-07
83,000	83,331	-60.16	399.51	-51.20	221.95	0.7703	0.7082	50.09	2.367E-02	7.304E-05	3.073E-02	979.8	580.5	35.1	3.029E-07
84,000	84,339	-59.61	400.06	-50.90	222.25	0.7713	0.6757	47.79	2.258E-02	6.960E-05	2.928E-02	980.5	580.9	33.5	3.033E-07
85,000	85,347	-59.07	400.60	-50.59	222.56	0.7724	0.6448	45.61	2.155E-02	6.632E-05	2.790E-02	981.2	581.3	31.9	3.036E-07
86,000	86,356	-58.52	401.15	-50.29	222.86	0.7734	0.6154	43.52	2.057E-02	6.321E-05	2.659E-02	981.9	581.7	30.5	3.040E-07
87,000	87,364	-57.97	401.70	-49.98	223.17	0.7745	0.5873	41.54	1.963E-02	6.024E-05	2.534E-02	982.5	582.1	29.1	3.043E-07
88,000	88,372	-57.42	402.25	-49.68	223.47	0.7755	0.5606	39.65	1.873E-02	5.742E-05	2.416E-02	983.2	582.5	27.8	3.046E-07
89,000	89,381	-56.87	402.80	-49.37	223.78	0.7766	0.5350	37.84	1.788E-02	5.473E-05	2.303E-02	983.9	582.9	26.5	3.050E-07
90,000	90,389	-56.32	403.35	-49.07	224.08	0.7777	0.5107	36.12	1.707E-02	5.217E-05	2.195E-02	984.5	583.3	25.3	3.053E-07
91,000	91,398	-55.77	403.90	-48.76	224.39	0.7787	0.4876	34.48	1.629E-02	4.974E-05	2.093E-02	985.2	583.7	24.1	3.057E-07
92,000	92,407	-55.23	404.44	-48.46	224.69	0.7798	0.4655	32.92	1.556E-02	4.742E-05	1.995E-02	985.9	584.1	23.0	3.060E-07
93,000	93,416	-54.68	404.99	-48.15	225.00	0.7808	0.4444	31.43	1.485E-02	4.521E-05	1.902E-02	986.5	584.5	22.0	3.064E-07
94,000	94,425	-54.13	405.54	-47.85	225.30	0.7819	0.4243	30.01	1.418E-02	4.311E-05	1.814E-02	987.2	584.9	21.0	3.067E-07
95,000	95,434	-53.58	406.09	-47.54	225.61	0.7829	0.4052	28.66	1.354E-02	4.111E-05	1.729E-02	987.9	585.3	20.1	3.071E-07
96,000	96,443	-53.03	406.64	-47.24	225.91	0.7840	0.3869	27.36	1.293E-02	3.920E-05	1.649E-02	988.5	585.7	19.2	3.074E-07
97,000	97,452	-52.48	407.19	-46.93	226.22	0.7851	0.3695	26.13	1.235E-02	3.739E-05	1.573E-02	989.2	586.1	18.3	3.077E-07
98,000	98,462	-51.93	407.74	-46.63	226.52	0.7861	0.3529	24.96	1.179E-02	3.566E-05	1.500E-02	989.9	586.5	17.5	3.081E-07
99,000	99,471	-51.38	408.29	-46.32	226.83	0.7872	0.3370	23.84	1.126E-02	3.401E-05	1.431E-02	990.5	586.9	16.7	3.084E-07
100,000	100,481	-50.84	408.83	-46.02	227.13	0.7882	0.3219	22.77	1.076E-02	3.244E-05	1.365E-02	991.2	587.3	15.9	3.088E-07
105,000	105,530	-48.08	411.59	-44.49	228.66	0.7935	0.2562	18.12	8.561E-03	2.564E-05	1.079E-02	994.5	589.2	12.7	3.105E-07
110,000	110,582	-40.40	419.27	-40.22	232.93	0.8084	0.2044	14.46	6.832E-03	2.009E-05	8.452E-03	1003.8	594.7	10.1	3.153E-07
115,000	115,637	-32.72	426.95	-35.95	237.20	0.8232	0.1638	11.59	5.475E-03	1.581E-05	6.651E-03	1012.9	600.1	8.1	3.200E-07
120,000	120,693	-25.04	434.63	-31.69	241.46	0.8380	0.1318	9.32	4.404E-03	1.249E-05	5.256E-03	1022.0	605.5	6.5	3.247E-07

TABLE D.1-I. Standard day atmosphere (continued).

Geopotential Altitude	Geometric Altitude	Temperature				Temperature Ratio	Pressure		Pressure Ratio	Density	Density Ratio	Speed of Sound		Q/M2	Absolute Viscosity
H, ft	Z, ft	deg F	deg R	deg C	deg K	θ	in Hg	lb/ft2	δ	slugs/ft3	σ	ft/sec	Knots	lb/ft2	lb-sec/ft2
125,000	125,752	-17.36	442.31	-27.42	245.73	0.8528	0.1064	7.53	3.557E-03	9.914E-06	4.171E-03	1031.0	610.8	5.3	3.293E-07
130,000	130,814	-9.68	449.99	-23.15	250.00	0.8676	0.0863	6.10	2.883E-03	7.898E-06	3.323E-03	1039.9	616.1	4.3	3.339E-07
135,000	135,878	-1.99	457.68	-18.89	254.26	0.8824	0.0702	4.96	2.345E-03	6.317E-06	2.658E-03	1048.7	621.4	3.5	3.385E-07
140,000	140,945	5.69	465.36	-14.62	258.53	0.8972	0.0573	4.05	1.914E-03	5.071E-06	2.133E-03	1057.5	626.6	2.8	3.431E-07
145,000	146,013	13.37	473.04	-10.35	262.80	0.9120	0.0469	3.32	1.568E-03	4.085E-06	1.719E-03	1066.2	631.7	2.3	3.476E-07
150,000	151,085	21.05	480.72	-6.08	267.07	0.9268	0.0385	2.73	1.288E-03	3.303E-06	1.390E-03	1074.8	636.8	1.9	3.521E-07

TABLE D.1-II. Standard day temperature and pressure equations.

Geopotential Altitude Bands H - ft	Temperature Deg - K	Pressure lb/ft2
-15000 to 36089	288.15*(1-6.87558E-6*H)	2116.22*(1-6.87558E-6*H)^5.25591
36089 to 65617	216.65	2116.22*0.22336* EXP(-4.80637E-5*(H-36089.24))
65617 to 104987	216.65*(1+1.40688E-6*(H-65616.8))	2116.22*0.0540322* (1+1.40688E-6* (H-65616.8))^-34.1634
104987 to 150000	228.65*(1+3.73252E-6* (H-104986.88))	2116.22*0.00856649*(1+3.73252E-6* (H-104986.88))^-12.2012

TABLE D.1-III. Polar day amosphere.

Pres-sure Altitude	Temperature				Temper-ature Ratio	Pressure		Pressure Ratio	Density	Density Ratio	Speed of Sound		Q/M2	Absolute Viscosity	Geopo-tential Altitude	Geo-metric Altitude
H, ft	deg F	deg R	deg C	deg K	θ	in Hg	lb/ft2	δ	slugs/ft3	σ	ft/sec	Knots	lb/ft2	lb-sec/ft2	H, ft	Z, ft
0	-15.70	443.97	-26.5	246.65	0.8560	29.9212	2116.22	1.000E+00	2.777E-03	1.168E+00	1032.9	612.0	1481.3	3.296E-07	272	272
1,000	-13	447	-24.8	248	1	28.8557	2040.86	9.644E-01	2.660E-03	1.119E+00	1036.5	614.1	1428.6	3.315E-07	1,133	1,133
2,000	-10	450	-23.1	250.05	0.8678	27.8210	1967.68	9.298E-01	2.547E-03	1.071E+00	1040.0	616.2	1377.4	3.333E-07	2,006	2,006
3,000	-7	453	-21.4	251.75	0.8737	26.8166	1896.64	8.962E-01	2.438E-03	1.026E+00	1043.5	618.3	1327.6	3.352E-07	2,890	2,890
3,243	-6	454	-21.0	252.15	0.8751	26.5771	1879.70	8.882E-01	2.413E-03	1.015E+00	1044.4	618.8	1315.8	3.357E-07	3,112	3,112
4,000	-6.16	453.51	-21.2	251.95	0.8744	25.8418	1827.70	8.637E-01	2.348E-03	9.878E-01	1044.0	618.5	1279.4	3.354E-07	3,790	3,791
5,000	-6.70	452.97	-21.5	251.65	0.8733	24.8959	1760.80	8.320E-01	2.265E-03	9.527E-01	1043.3	618.2	1232.5	3.351E-07	4,691	4,692
6,000	-7.24	452.43	-21.8	251.35	0.8723	23.9782	1695.89	8.014E-01	2.184E-03	9.187E-01	1042.7	617.8	1187.1	3.348E-07	5,597	5,598
7,000	-7.78	451.89	-22.1	251.05	0.8712	23.0881	1632.94	7.716E-01	2.105E-03	8.857E-01	1042.1	617.4	1143.0	3.344E-07	6,509	6,511
8,000	-8.32	451.35	-22.4	250.75	0.8702	22.2249	1571.89	7.428E-01	2.029E-03	8.536E-01	1041.5	617.1	1100.3	3.341E-07	7,426	7,429
9,000	-8.86	450.81	-22.7	250.45	0.8692	21.3881	1512.70	7.148E-01	1.955E-03	8.224E-01	1040.8	616.7	1058.9	3.338E-07	8,349	8,352
9,882	-9.40	450.27	-23.0	250.15	0.8681	20.6712	1462.00	6.909E-01	1.892E-03	7.958E-01	1040.2	616.3	1023.4	3.335E-07	9,173	9,177
10,000	-9.76	449.91	-23.2	249.95	0.8674	20.5769	1455.33	6.877E-01	1.884E-03	7.928E-01	1039.8	616.1	1018.7	3.332E-07	9,282	9,286
11,000	-12.46	447.21	-24.7	248.45	0.8622	19.7909	1399.74	6.614E-01	1.823E-03	7.671E-01	1036.7	614.2	979.8	3.316E-07	10,213	10,218
12,000	-15.34	444.33	-26.3	246.85	0.8567	19.0293	1345.87	6.360E-01	1.765E-03	7.424E-01	1033.3	612.2	942.1	3.298E-07	11,145	11,151
13,000	-18.22	441.45	-27.9	245.25	0.8511	18.2917	1293.70	6.113E-01	1.707E-03	7.183E-01	1030.0	610.2	905.6	3.281E-07	12,079	12,086
14,000	-21.10	438.57	-29.5	243.65	0.8456	17.5773	1243.18	5.875E-01	1.651E-03	6.947E-01	1026.6	608.3	870.2	3.263E-07	13,013	13,021
15,000	-23.80	435.87	-31.0	242.15	0.8404	16.8858	1194.27	5.643E-01	1.596E-03	6.715E-01	1023.5	606.4	836.0	3.246E-07	13,949	13,958
16,000	-26.68	432.99	-32.6	240.55	0.8348	16.2164	1146.93	5.420E-01	1.543E-03	6.492E-01	1020.1	604.4	802.8	3.228E-07	14,885	14,896
17,000	-29.56	430.11	-34.2	238.95	0.8293	15.5687	1101.12	5.203E-01	1.491E-03	6.275E-01	1016.7	602.4	770.8	3.210E-07	15,823	15,835
18,000	-32.26	427.41	-35.7	237.45	0.8240	14.9421	1056.80	4.994E-01	1.440E-03	6.060E-01	1013.5	600.5	739.8	3.193E-07	16,762	16,775
19,000	-35.14	424.53	-37.3	235.85	0.8185	14.3360	1013.94	4.791E-01	1.391E-03	5.854E-01	1010.1	598.4	709.7	3.175E-07	17,702	17,717
20,000	-38.02	421.65	-38.9	234.25	0.8129	13.7501	972.49	4.595E-01	1.344E-03	5.653E-01	1006.6	596.4	680.7	3.157E-07	18,643	18,660
21,000	-40.90	418.77	-40.5	232.65	0.8074	13.1836	932.43	4.406E-01	1.297E-03	5.457E-01	1003.2	594.4	652.7	3.139E-07	19,585	19,603
22,000	-43.78	415.89	-42.1	231.05	0.8018	12.6362	893.72	4.223E-01	1.252E-03	5.267E-01	999.7	592.3	625.6	3.121E-07	20,529	20,549
23,000	-46.66	413.01	-43.7	229.45	0.7963	12.1074	856.31	4.046E-01	1.208E-03	5.082E-01	996.3	590.3	599.4	3.103E-07	21,473	21,495
24,000	-49.36	410.31	-45.2	227.95	0.7911	11.5967	820.19	3.876E-01	1.165E-03	4.899E-01	993.0	588.3	574.1	3.086E-07	22,419	22,443
25,000	-52.24	407.43	-46.8	226.35	0.7855	11.1035	785.31	3.711E-01	1.123E-03	4.724E-01	989.5	586.3	549.7	3.067E-07	23,366	23,392

TABLE D.1-III. Polar day amosphere (continued).

Pres-sure Altitude	Temperature				Temper-ature Ratio	Pressure		Pressure Ratio	Density	Density Ratio	Speed of Sound		Q/M2	Absolute Viscosity	Geopo-tential Altitude	Geo-metric Altitude
H, ft	deg F	deg R	deg C	deg K	θ	in Hg	lb/ft2	δ	slugs/ft3	σ	ft/sec	Knots	lb/ft2	lb-sec/ft2	H, ft	Z, ft
26,000	-55.12	404.55	-48.4	224.75	0.7800	10.6274	751.64	3.552E-01	1.082E-03	4.554E-01	986.0	584.2	526.1	3.049E-07	24,314	24,342
27,000	-58.00	401.67	-50.0	223.15	0.7744	10.1680	719.15	3.398E-01	1.043E-03	4.388E-01	982.5	582.1	503.4	3.031E-07	25,263	25,294
28,000	-60.88	398.79	-51.6	221.55	0.7689	9.7249	687.80	3.250E-01	1.005E-03	4.227E-01	979.0	580.0	481.5	3.012E-07	26,214	26,247
29,000	-63.76	395.91	-53.2	219.95	0.7633	9.2974	657.57	3.107E-01	9.676E-04	4.071E-01	975.4	577.9	460.3	2.994E-07	27,166	27,201
30,000	-66.64	393.03	-54.8	218.35	0.7578	8.8854	628.43	2.970E-01	9.315E-04	3.919E-01	971.9	575.8	439.9	2.975E-07	28,119	28,157
30,065	-67.00	392.67	-55.0	218.15	0.7571	8.8595	626.60	2.961E-01	9.296E-04	3.911E-01	971.4	575.5	438.6	2.973E-07	28,225	28,263
31,000	-67.18	392.49	-55.1	218.05	0.7567	8.4882	600.34	2.837E-01	8.911E-04	3.749E-01	971.2	575.4	420.2	2.971E-07	29,119	29,160
32,000	-67.54	392.13	-55.3	217.85	0.7560	8.1056	573.28	2.709E-01	8.517E-04	3.583E-01	970.7	575.1	401.3	2.969E-07	30,084	30,127
33,000	-67.72	391.95	-55.4	217.75	0.7557	7.7370	547.21	2.586E-01	8.133E-04	3.422E-01	970.5	575.0	383.0	2.968E-07	31,056	31,102
34,000	-68.08	391.59	-55.6	217.55	0.7550	7.3821	522.11	2.467E-01	7.767E-04	3.268E-01	970.1	574.8	365.5	2.966E-07	32,037	32,086
35,000	-68.26	391.41	-55.7	217.45	0.7546	7.0406	497.95	2.353E-01	7.411E-04	3.118E-01	969.9	574.6	348.6	2.964E-07	33,025	33,077
36,000	-68.44	391.23	-55.8	217.35	0.7543	6.7119	474.71	2.243E-01	7.069E-04	2.974E-01	969.6	574.5	332.3	2.963E-07	34,023	34,079
37,000	-68.80	390.87	-56.0	217.15	0.7536	6.3970	452.43	2.138E-01	6.743E-04	2.837E-01	969.2	574.2	316.7	2.961E-07	35,024	35,083
38,000	-68.98	390.69	-56.1	217.05	0.7533	6.0968	431.20	2.038E-01	6.430E-04	2.705E-01	969.0	574.1	301.8	2.960E-07	36,025	36,087
39,000	-69.34	390.33	-56.3	216.85	0.7526	5.8107	410.97	1.942E-01	6.134E-04	2.581E-01	968.5	573.8	287.7	2.957E-07	37,026	37,092
40,000	-69.52	390.15	-56.4	216.75	0.7522	5.5380	391.68	1.851E-01	5.848E-04	2.461E-01	968.3	573.7	274.2	2.956E-07	38,026	38,095
41,000	-69.88	389.79	-56.6	216.55	0.7515	5.2781	373.30	1.764E-01	5.579E-04	2.347E-01	967.8	573.4	261.3	2.954E-07	39,025	39,098
42,000	-70.06	389.61	-56.7	216.45	0.7512	5.0304	355.78	1.681E-01	5.320E-04	2.238E-01	967.6	573.3	249.0	2.953E-07	40,023	40,100
43,000	-70.42	389.25	-56.9	216.25	0.7505	4.7944	339.09	1.602E-01	5.075E-04	2.135E-01	967.2	573.0	237.4	2.950E-07	41,021	41,102
44,000	-70.60	389.07	-57.0	216.15	0.7501	4.5694	323.18	1.527E-01	4.839E-04	2.036E-01	967.0	572.9	226.2	2.949E-07	42,018	42,103
45,000	-70.78	388.89	-57.1	216.05	0.7498	4.3550	308.01	1.455E-01	4.614E-04	1.941E-01	966.7	572.8	215.6	2.948E-07	43,015	43,104
46,000	-71.14	388.53	-57.3	215.85	0.7491	4.1506	293.56	1.387E-01	4.402E-04	1.852E-01	966.3	572.5	205.5	2.946E-07	44,010	44,103
47,000	-71.32	388.35	-57.4	215.75	0.7487	3.9558	279.78	1.322E-01	4.197E-04	1.766E-01	966.1	572.4	195.8	2.945E-07	45,005	45,102
48,000	-71.68	387.99	-57.6	215.55	0.7480	3.7702	266.65	1.260E-01	4.004E-04	1.684E-01	965.6	572.1	186.7	2.942E-07	46,000	46,102
49,000	-71.86	387.81	-57.7	215.45	0.7477	3.5933	254.14	1.201E-01	3.818E-04	1.606E-01	965.4	572.0	177.9	2.941E-07	46,994	47,100
50,000	-72.22	387.45	-57.9	215.25	0.7470	3.4246	242.21	1.145E-01	3.642E-04	1.532E-01	964.9	571.7	169.5	2.939E-07	47,987	48,097
51,000	-72.40	387.27	-58.0	215.15	0.7467	3.2639	230.85	1.091E-01	3.473E-04	1.461E-01	964.7	571.6	161.6	2.938E-07	48,979	49,094
52,000	-72.76	386.91	-58.2	214.95	0.7460	3.1108	220.01	1.040E-01	3.313E-04	1.394E-01	964.3	571.3	154.0	2.935E-07	49,971	50,091
53,000	-72.94	386.73	-58.3	214.85	0.7456	2.9648	209.69	9.909E-02	3.159E-04	1.329E-01	964.0	571.2	146.8	2.934E-07	50,962	51,087
54,000	-73.12	386.55	-58.4	214.75	0.7453	2.8257	199.85	9.630E-02	3.012E-04	1.267E-01	963.8	571.0	139.9	2.933E-07	51,953	52,083

TABLE D.1-III. Polar day amosphere (continued).

Pres-sure Altitude	Temperature				Temper-ature Ratio	Pressure		Pressure Ratio	Density	Density Ratio	Speed of Sound		Q/M2	Absolute Viscosity	Geopo-tential Altitude	Geo-metric Altitude
H, ft	deg F	deg R	deg C	deg K	θ	in Hg	lb/ft2	δ	slugs/ft3	σ	ft/sec	Knots	lb/ft2	lb-sec/ft2	H, ft	Z, ft
55,000	-73.48	386.19	-58.6	214.55	0.7446	2.6931	190.47	9.444E-02	2.873E-04	1.209E-01	963.4	570.8	133.3	2.931E-07	52,942	53,077
56,000	-73.66	386.01	-58.7	214.45	0.7442	2.5667	181.53	8.578E-02	2.740E-04	1.153E-01	963.1	570.6	127.1	2.929E-07	53,932	54,072
57,000	-74.02	385.65	-58.9	214.25	0.7435	2.4462	173.01	8.176E-02	2.614E-04	1.100E-01	962.7	570.4	121.1	2.927E-07	54,920	55,065
58,000	-74.20	385.47	-59.0	214.15	0.7432	2.3314	164.89	7.792E-02	2.492E-04	1.048E-01	962.5	570.2	115.4	2.926E-07	55,908	56,058
59,000	-74.56	385.11	-59.2	213.95	0.7425	2.2220	157.16	7.426E-02	2.377E-04	1.000E-01	962.0	570.0	110.0	2.924E-07	56,895	57,050
60,000	-74.74	384.93	-59.3	213.85	0.7421	2.1178	149.78	7.078E-02	2.267E-04	9.537E-02	961.8	569.8	104.8	2.922E-07	57,882	58,043
61,000	-74.92	384.75	-59.4	213.75	0.7418	2.0184	142.75	6.746E-02	2.161E-04	9.094E-02	961.6	569.7	99.9	2.921E-07	58,868	59,034
62,000	-75.28	384.39	-59.6	213.55	0.7411	1.9237	136.05	6.429E-02	2.062E-04	8.675E-02	961.1	569.4	95.2	2.919E-07	59,852	60,024
63,000	-75.46	384.21	-59.7	213.45	0.7408	1.8334	129.67	6.127E-02	1.966E-04	8.272E-02	960.9	569.3	90.8	2.918E-07	60,837	61,015
64,000	-75.82	383.85	-59.9	213.25	0.7401	1.7474	123.58	5.840E-02	1.876E-04	7.891E-02	960.4	569.0	86.5	2.915E-07	61,821	62,004
65,000	-76.00	383.67	-60.0	213.15	0.7397	1.6654	117.78	5.566E-02	1.788E-04	7.524E-02	960.2	568.9	82.4	2.914E-07	62,804	62,993
66,000	-76.36	383.31	-60.2	212.95	0.7390	1.5872	112.26	5.305E-02	1.706E-04	7.178E-02	959.8	568.6	78.6	2.912E-07	63,787	63,982
67,000	-76.54	383.13	-60.3	212.85	0.7387	1.5128	107.00	5.056E-02	1.627E-04	6.845E-02	959.5	568.5	74.9	2.911E-07	64,768	64,969
68,000	-76.72	382.95	-60.4	212.75	0.7383	1.4420	101.99	4.819E-02	1.551E-04	6.527E-02	959.3	568.4	71.4	2.909E-07	65,750	65,958
69,000	-77.08	382.59	-60.6	212.55	0.7376	1.3746	97.22	4.594E-02	1.480E-04	6.228E-02	958.9	568.1	68.1	2.907E-07	66,730	66,944
70,000	-77.26	382.41	-60.7	212.45	0.7373	1.3104	92.68	4.380E-02	1.412E-04	5.940E-02	958.6	568.0	64.9	2.906E-07	67,710	67,930
71,000	-77.62	382.05	-60.9	212.25	0.7366	1.2494	88.36	4.175E-02	1.347E-04	5.669E-02	958.2	567.7	61.9	2.904E-07	68,690	68,917
72,000	-77.80	381.87	-61.0	212.15	0.7362	1.1912	84.25	3.981E-02	1.285E-04	5.407E-02	958.0	567.6	59.0	2.902E-07	69,668	69,901
73,000	-78.16	381.51	-61.2	211.95	0.7356	1.1358	80.33	3.796E-02	1.227E-04	5.161E-02	957.5	567.3	56.2	2.900E-07	70,646	70,886
74,000	-78.34	381.33	-61.3	211.85	0.7352	1.0831	76.60	3.620E-02	1.170E-04	4.924E-02	957.3	567.2	53.6	2.899E-07	71,623	71,869
75,000	-78.52	381.15	-61.4	211.75	0.7349	1.0329	73.05	3.452E-02	1.117E-04	4.697E-02	957.1	567.0	51.1	2.898E-07	72,600	72,853
76,000	-78.88	380.79	-61.6	211.55	0.7342	0.9851	69.67	3.292E-02	1.066E-04	4.484E-02	956.6	566.8	48.8	2.895E-07	73,576	73,836
77,000	-79.06	380.61	-61.7	211.45	0.7338	0.9395	66.45	3.140E-02	1.017E-04	4.279E-02	956.4	566.6	46.5	2.894E-07	74,551	74,818
78,000	-79.42	380.25	-61.9	211.25	0.7331	0.8961	63.38	2.995E-02	9.710E-05	4.085E-02	955.9	566.4	44.4	2.892E-07	75,525	75,799
79,000	-79.60	380.07	-62.0	211.15	0.7328	0.8548	60.46	2.857E-02	9.267E-05	3.899E-02	955.7	566.2	42.3	2.891E-07	76,500	76,781
80,000	-79.78	379.89	-62.1	211.05	0.7324	0.8154	57.67	2.725E-02	8.844E-05	3.721E-02	955.5	566.1	40.4	2.889E-07	77,473	77,761
81,000	-80.14	379.53	-62.3	210.85	0.7317	0.7779	55.02	2.600E-02	8.446E-05	3.553E-02	955.0	565.8	38.5	2.887E-07	78,446	78,742
82,000	-80.32	379.35	-62.4	210.75	0.7314	0.7422	52.49	2.481E-02	8.062E-05	3.392E-02	954.8	565.7	36.7	2.886E-07	79,419	79,722
83,000	-80.68	378.99	-62.6	210.55	0.7307	0.7082	50.09	2.367E-02	7.699E-05	3.239E-02	954.3	565.4	35.1	2.883E-07	80,388	80,699
84,000	-80.86	378.81	-62.7	210.45	0.7303	0.6757	47.79	2.258E-02	7.350E-05	3.092E-02	954.1	565.3	33.5	2.882E-07	81,353	81,671

TABLE D.1-III. Polar day amosphere (continued).

Pres-sure Altitude	Temperature				Temper-ature Ratio	Pressure		Pressure Ratio	Density	Density Ratio	Speed of Sound		Q/M2	Absolute Viscosity	Geopo-tential Altitude	Geo-metric Altitude
H, ft	deg F	deg R	deg C	deg K	θ	in Hg	lb/ft2	δ	slugs/ft3	σ	ft/sec	Knots	lb/ft2	lb-sec/ft2	H, ft	Z, ft
85,000	-81.04	378.63	-62.8	210.35	0.7300	0.6448	45.61	2.155E-02	7.017E-05	2.952E-02	953.9	565.2	31.9	2.881E-07	82,312	82,638
86,000	-81.40	378.27	-63.0	210.15	0.7293	0.6154	43.52	2.057E-02	6.703E-05	2.820E-02	953.4	564.9	30.5	2.879E-07	83,268	83,601
86,092	-81.40	378.27	-63.0	210.15	0.7293	0.6051	42.80	######	6.591E-05	2.773E-02	953.4	564.9	30.0	2.879E-07	83,363	83,697
87,000	-81.40	378.27	-63.0	210.15	0.7293	0.5873	41.54	1.963E-02	6.397E-05	2.691E-02	953.4	564.9	29.1	2.879E-07	84,229	84,570
88,000	-81.40	378.27	-63.0	210.15	0.7293	0.5606	39.65	1.873E-02	6.106E-05	2.569E-02	953.4	564.9	27.8	2.879E-07	85,177	85,526
89,000	-81.40	378.27	-63.0	210.15	0.7293	0.5350	37.84	1.788E-02	5.828E-05	2.452E-02	953.4	564.9	26.5	2.879E-07	86,120	86,476
90,000	-81.40	378.27	-63.0	210.15	0.7293	0.5107	36.12	1.707E-02	5.563E-05	2.340E-02	953.4	564.9	25.3	2.879E-07	87,059	87,423
91,000	-81.40	378.27	-63.0	210.15	0.7293	0.4876	34.48	1.629E-02	5.311E-05	2.234E-02	953.4	564.9	24.1	2.879E-07	87,995	88,367
92,000	-81.40	378.27	-63.0	210.15	0.7293	0.4655	32.92	1.556E-02	5.070E-05	2.133E-02	953.4	564.9	23.0	2.879E-07	88,927	89,307
93,000	-81.40	378.27	-63.0	210.15	0.7293	0.4444	31.43	1.485E-02	4.841E-05	2.037E-02	953.4	564.9	22.0	2.879E-07	89,855	90,243
94,000	-81.40	378.27	-63.0	210.15	0.7293	0.4243	30.01	1.418E-02	4.622E-05	1.944E-02	953.4	564.9	21.0	2.879E-07	90,779	91,175
95,000	-81.40	378.27	-63.0	210.15	0.7293	0.4052	28.66	1.354E-02	4.413E-05	1.857E-02	953.4	564.9	20.1	2.879E-07	91,699	92,103
96,000	-81.40	378.27	-63.0	210.15	0.7293	0.3869	27.36	1.293E-02	4.214E-05	1.773E-02	953.4	564.9	19.2	2.879E-07	92,616	93,028
97,000	-81.40	378.27	-63.0	210.15	0.7293	0.3695	26.13	1.235E-02	4.025E-05	1.693E-02	953.4	564.9	18.3	2.879E-07	93,530	93,951
98,000	-81.40	378.27	-63.0	210.15	0.7293	0.3529	24.96	1.179E-02	3.844E-05	1.617E-02	953.4	564.9	17.5	2.879E-07	94,440	94,869
99,000	-81.40	378.27	-63.0	210.15	0.7293	0.3370	23.84	1.126E-02	3.671E-05	1.544E-02	953.4	564.9	16.7	2.879E-07	95,345	95,782
100,000	-81.40	378.27	-63.0	210.15	0.7293	0.3219	22.77	1.076E-02	3.506E-05	1.475E-02	953.4	564.9	15.9	2.879E-07	96,249	96,695

TABLE D.1-IV. Tropical day amosphere.

Pres-sure Altitude	Temperature				Temper-ature Ratio	Pressure		Pressure Ratio	Density	Density Ratio	Speed of Sound		Q/M2	Absolute Viscosity	Geopo-tential Altitude	Geo-metric Altitude
H, ft	deg F	deg R	deg C	deg K	θ	in Hg	lb/ft2	δ	slugs/ft3	σ	ft/sec	Knots	lb/ft2	lb-sec/ft2	H, ft	Z, ft
0	89.78	549.45	32.1	305.25	1.0593	29.9212	2116.22	1.000E+00	2.244E-03	9.440E-01	1149.1	680.8	1481.3	3.919E-07	0	0
1,000	85.82	545.49	29.9	303.05	1.0517	28.8557	2040.86	9.644E-01	2.180E-03	9.170E-01	1144.9	678.4	1428.6	3.897E-07	1,058	1,058
2,000	82.04	541.71	27.8	300.95	1.0444	27.8210	1967.68	9.298E-01	2.116E-03	8.903E-01	1141.0	676.0	1377.4	3.876E-07	2,116	2,116
3,000	78.08	537.75	25.6	298.75	1.0368	26.8166	1896.64	8.962E-01	2.055E-03	8.644E-01	1136.8	673.5	1327.6	3.853E-07	3,174	3,174
4,000	74.30	533.97	23.5	296.65	1.0295	25.8418	1827.70	8.637E-01	1.994E-03	8.389E-01	1132.8	671.2	1279.4	3.832E-07	4,232	4,233
5,000	70.34	530.01	21.3	294.45	1.0219	24.8959	1760.80	8.320E-01	1.935E-03	8.142E-01	1128.6	668.7	1232.5	3.810E-07	5,289	5,290
6,000	66.56	526.23	19.2	292.35	1.0146	23.9782	1695.89	8.014E-01	1.877E-03	7.899E-01	1124.6	666.3	1187.1	3.788E-07	6,347	6,349
7,000	62.60	522.27	17.0	290.15	1.0069	23.0881	1632.94	7.716E-01	1.821E-03	7.663E-01	1120.3	663.8	1143.0	3.766E-07	7,404	7,407
8,000	58.82	518.49	14.9	288.05	0.9997	22.2249	1571.89	7.428E-01	1.766E-03	7.430E-01	1116.2	661.4	1100.3	3.744E-07	8,460	8,463
9,000	54.86	514.53	12.7	285.85	0.9920	21.3881	1512.70	7.148E-01	1.713E-03	7.206E-01	1112.0	658.8	1058.9	3.721E-07	9,517	9,521
10,000	50.90	510.57	10.5	283.65	0.9844	20.5769	1455.33	6.877E-01	1.661E-03	6.986E-01	1107.7	656.3	1018.7	3.698E-07	10,573	10,578
11,000	47.12	506.79	8.4	281.55	0.9771	19.7909	1399.74	6.614E-01	1.609E-03	6.769E-01	1103.6	653.9	979.8	3.676E-07	11,630	11,636
12,000	43.16	502.83	6.2	279.35	0.9695	19.0293	1345.87	6.360E-01	1.559E-03	6.560E-01	1099.3	651.3	942.1	3.653E-07	12,685	12,693
13,000	39.38	499.05	4.1	277.25	0.9622	18.2917	1293.70	6.113E-01	1.510E-03	6.354E-01	1095.1	648.8	905.6	3.631E-07	13,741	13,750
14,000	35.42	495.09	1.9	275.05	0.9545	17.5773	1243.18	5.875E-01	1.463E-03	6.154E-01	1090.8	646.3	870.2	3.608E-07	14,797	14,807
15,000	31.64	491.31	-0.2	272.95	0.9472	16.8858	1194.27	5.643E-01	1.416E-03	5.958E-01	1086.6	643.8	836.0	3.586E-07	15,852	15,864
16,000	27.68	487.35	-2.4	270.75	0.9396	16.2164	1146.93	5.420E-01	1.371E-03	5.768E-01	1082.2	641.2	802.8	3.563E-07	16,907	16,921
17,000	23.90	483.57	-4.5	268.65	0.9323	15.5687	1101.12	5.203E-01	1.327E-03	5.581E-01	1078.0	638.7	770.8	3.540E-07	17,962	17,977
18,000	19.94	479.61	-6.7	266.45	0.9247	14.9421	1056.80	4.994E-01	1.284E-03	5.400E-01	1073.6	636.1	739.8	3.517E-07	19,016	19,033
19,000	16.16	475.83	-8.8	264.35	0.9174	14.3360	1013.94	4.791E-01	1.241E-03	5.223E-01	1069.3	633.6	709.7	3.494E-07	20,071	20,090
20,000	12.20	471.87	-11.0	262.15	0.9098	13.7501	972.49	4.595E-01	1.201E-03	5.051E-01	1064.9	630.9	680.7	3.471E-07	21,125	21,146
21,000	8.42	468.09	-13.1	260.05	0.9025	13.1836	932.43	4.406E-01	1.160E-03	4.882E-01	1060.6	628.4	652.7	3.448E-07	22,179	22,203
22,000	4.46	464.13	-15.3	257.85	0.8948	12.6362	893.72	4.223E-01	1.122E-03	4.719E-01	1056.1	625.7	625.6	3.424E-07	23,233	23,259
23,000	0.68	460.35	-17.4	255.75	0.8876	12.1074	856.31	4.046E-01	1.084E-03	4.559E-01	1051.8	623.2	599.4	3.401E-07	24,286	24,314
24,000	-3.10	456.57	-19.5	253.65	0.8803	11.5967	820.19	3.876E-01	1.047E-03	4.403E-01	1047.5	620.6	574.1	3.378E-07	25,339	25,370
25,000	-7.06	452.61	-21.7	251.45	0.8726	11.1035	785.31	3.711E-01	1.011E-03	4.253E-01	1042.9	617.9	549.7	3.354E-07	26,392	26,425
26,000	-10.84	448.83	-23.8	249.35	0.8653	10.6274	751.64	3.552E-01	9.756E-04	4.104E-01	1038.6	615.3	526.1	3.331E-07	27,445	27,481
27,000	-14.80	444.87	-26.0	247.15	0.8577	10.1680	719.15	3.398E-01	9.417E-04	3.962E-01	1034.0	612.6	503.4	3.307E-07	28,497	28,536
28,000	-18.58	441.09	-28.1	245.05	0.8504	9.7249	687.80	3.250E-01	9.084E-04	3.822E-01	1029.6	610.0	481.5	3.284E-07	29,550	29,592
29,000	-22.54	437.13	-30.3	242.85	0.8428	9.2974	657.57	3.107E-01	8.763E-04	3.687E-01	1024.9	607.3	460.3	3.259E-07	30,062	30,105

TABLE D.1-IV. Tropical day amosphere (continued).

Pres-sure Altitude	Temperature				Temper-ature Ratio	Pressure		Pressure Ratio	Density	Density Ratio	Speed of Sound		Q/M2	Absolute Viscosity	Geopo-tential Altitude	Geo-metric Altitude
H, ft	deg F	deg R	deg C	deg K	θ	in Hg	lb/ft2	δ	slugs/ft3	σ	ft/sec	Knots	lb/ft2	lb-sec/ft2	H, ft	Z, ft
30,000	-26.32	433.35	-32.4	240.75	0.8355	8.8854	628.43	2.970E-01	8.448E-04	3.554E-01	1020.5	604.6	439.9	3.236E-07	31,653	31,701
31,000	-30.28	429.39	-34.6	238.55	0.8279	8.4882	600.34	2.837E-01	8.145E-04	3.427E-01	1015.8	601.9	420.2	3.211E-07	32,705	32,756
32,000	-34.06	425.61	-36.7	236.45	0.8206	8.1056	573.28	2.709E-01	7.847E-04	3.301E-01	1011.3	599.2	401.3	3.187E-07	33,756	33,811
33,000	-37.84	421.83	-38.8	234.35	0.8133	7.7370	547.21	2.586E-01	7.557E-04	3.179E-01	1006.8	596.5	383.0	3.164E-07	34,807	34,865
34,000	-41.80	417.87	-41.0	232.15	0.8057	7.3821	522.11	2.467E-01	7.279E-04	3.062E-01	1002.1	593.7	365.5	3.139E-07	35,858	35,920
35,000	-45.58	414.09	-43.1	230.05	0.7984	7.0406	497.95	2.353E-01	7.005E-04	2.947E-01	997.6	591.0	348.6	3.115E-07	36,908	36,973
36,000	-49.54	410.13	-45.3	227.85	0.7907	6.7119	474.71	2.243E-01	6.743E-04	2.837E-01	992.8	588.2	332.3	3.090E-07	37,958	38,027
37,000	-53.32	406.35	-47.4	225.75	0.7834	6.3970	452.43	2.138E-01	6.486E-04	2.729E-01	988.2	585.5	316.7	3.066E-07	39,004	39,077
38,000	-57.10	402.57	-49.5	223.65	0.7762	6.0968	431.20	2.038E-01	6.240E-04	2.625E-01	983.6	582.8	301.8	3.041E-07	40,040	40,117
39,000	-60.88	398.79	-51.6	221.55	0.7689	5.8107	410.97	1.942E-01	6.004E-04	2.526E-01	979.0	580.0	287.7	3.017E-07	41,067	41,148
40,000	-64.66	395.01	-53.7	219.45	0.7616	5.5380	391.68	1.851E-01	5.777E-04	2.430E-01	974.3	577.3	274.2	2.993E-07	42,084	42,169
41,000	-68.26	391.41	-55.7	217.45	0.7546	5.2781	373.30	1.764E-01	5.556E-04	2.338E-01	969.9	574.6	261.3	2.969E-07	43,091	43,180
42,000	-72.04	387.63	-57.8	215.35	0.7474	5.0304	355.78	1.681E-01	5.347E-04	2.250E-01	965.2	571.8	249.0	2.945E-07	44,089	44,182
43,000	-75.64	384.03	-59.8	213.35	0.7404	4.7944	339.09	1.602E-01	5.144E-04	2.164E-01	960.7	569.2	237.4	2.921E-07	45,078	45,175
44,000	-79.24	380.43	-61.8	211.35	0.7335	4.5694	323.18	1.527E-01	4.949E-04	2.082E-01	956.2	566.5	226.2	2.898E-07	46,057	46,159
45,000	-82.84	376.83	-63.8	209.35	0.7265	4.3550	308.01	1.455E-01	4.762E-04	2.003E-01	951.6	563.8	215.6	2.874E-07	47,027	47,133
46,000	-86.26	373.41	-65.7	207.45	0.7199	4.1506	293.56	1.387E-01	4.580E-04	1.927E-01	947.3	561.3	205.5	2.851E-07	47,988	48,098
47,000	-89.68	369.99	-67.6	205.55	0.7133	3.9558	279.78	1.322E-01	4.405E-04	1.853E-01	942.9	558.7	195.8	2.829E-07	48,940	49,055
48,000	-93.28	366.39	-69.6	203.55	0.7064	3.7702	266.65	1.260E-01	4.240E-04	1.784E-01	938.3	556.0	186.7	2.805E-07	49,884	50,003
49,000	-96.70	362.97	-71.5	201.65	0.6998	3.5933	254.14	1.201E-01	4.079E-04	1.716E-01	934.0	553.4	177.9	2.782E-07	50,818	50,942
50,000	-100.12	359.55	-73.4	199.75	0.6932	3.4246	242.21	1.145E-01	3.924E-04	1.651E-01	929.5	550.7	169.5	2.759E-07	51,744	51,872
51,000	-103.36	356.31	-75.2	197.95	0.6870	3.2639	230.85	1.091E-01	3.774E-04	1.588E-01	925.3	548.3	161.6	2.737E-07	52,661	52,794
52,000	-106.78	352.89	-77.1	196.05	0.6804	3.1108	220.01	1.040E-01	3.632E-04	1.528E-01	920.9	545.6	154.0	2.714E-07	53,569	53,707
53,000	-110.02	349.65	-78.9	194.25	0.6741	2.9648	209.69	9.909E-02	3.494E-04	1.470E-01	916.7	543.1	146.8	2.692E-07	54,469	54,611
53,595	-112.00	347.67	-80.0	193.15	0.6703	2.8815	203.80	9.630E-02	3.415E-04	1.437E-01	914.1	541.6	142.7	2.679E-07	55,000	55,145
54,000	-111.10	348.57	-79.5	193.65	0.6720	2.8257	199.85	9.444E-02	3.340E-04	1.405E-01	915.2	542.3	139.9	2.685E-07	55,362	55,509
55,000	-108.94	350.73	-78.3	194.85	0.6762	2.6931	190.47	9.000E-02	3.164E-04	1.331E-01	918.1	543.9	133.3	2.699E-07	56,258	56,410
56,000	-106.78	352.89	-77.1	196.05	0.6804	2.5667	181.53	8.578E-02	2.997E-04	1.261E-01	920.9	545.6	127.1	2.714E-07	57,159	57,316
57,000	-104.62	355.05	-75.9	197.25	0.6845	2.4462	173.01	8.176E-02	2.839E-04	1.194E-01	923.7	547.3	121.1	2.729E-07	58,066	58,228
58,000	-102.46	357.21	-74.7	198.45	0.6887	2.3314	164.89	7.792E-02	2.689E-04	1.131E-01	926.5	548.9	115.4	2.743E-07	58,979	59,146
59,000	-100.30	359.37	-73.5	199.65	0.6929	2.2220	157.16	7.426E-02	2.548E-04	1.072E-01	929.3	550.6	110.0	2.758E-07	59,896	60,068

TABLE D.1-IV. Tropical day amosphere (continued).

Pres-sure Altitude	Temperature				Temper-ature Ratio	Pressure		Pressure Ratio	Density	Density Ratio	Speed of Sound		Q/M2	Absolute Viscosity	Geopo-tential Altitude	Geo-metric Altitude
H, ft	deg F	deg R	deg C	deg K	θ	in Hg	lb/ft2	δ	slugs/ft3	σ	ft/sec	Knots	lb/ft2	lb-sec/ft2	H, ft	Z, ft
60,000	-97.96	361.71	-72.2	200.95	0.6974	2.1178	149.78	7.078E-02	2.412E-04	1.015E-01	932.3	552.4	104.8	2.774E-07	60,820	60,998
61,000	-95.80	363.87	-71.0	202.15	0.7015	2.0184	142.75	6.746E-02	2.285E-04	9.615E-02	935.1	554.0	99.9	2.788E-07	61,750	61,933
62,000	-93.64	366.03	-69.8	203.35	0.7057	1.9237	136.05	6.429E-02	2.165E-04	9.110E-02	937.9	555.7	95.2	2.802E-07	62,685	62,874
63,000	-91.30	368.37	-68.5	204.65	0.7102	1.8334	129.67	6.127E-02	2.051E-04	8.627E-02	940.9	557.5	90.8	2.818E-07	63,626	63,820
64,000	-88.96	370.71	-67.2	205.95	0.7147	1.7474	123.58	5.840E-02	1.942E-04	8.171E-02	943.9	559.2	86.5	2.834E-07	64,572	64,772
65,000	-86.80	372.87	-66.0	207.15	0.7189	1.6654	117.78	5.566E-02	1.840E-04	7.742E-02	946.6	560.8	82.4	2.848E-07	65,525	65,731
66,000	-84.46	375.21	-64.7	208.45	0.7234	1.5872	112.26	5.305E-02	1.743E-04	7.333E-02	949.6	562.6	78.6	2.863E-07	66,483	66,695
67,000	-82.12	377.55	-63.4	209.75	0.7279	1.5128	107.00	5.056E-02	1.651E-04	6.946E-02	952.5	564.4	74.9	2.879E-07	67,447	67,665
68,000	-79.78	379.89	-62.1	211.05	0.7324	1.4420	101.99	4.819E-02	1.564E-04	6.580E-02	955.5	566.1	71.4	2.894E-07	68,418	68,643
69,000	-77.44	382.23	-60.8	212.35	0.7369	1.3746	97.22	4.594E-02	1.482E-04	6.234E-02	958.4	567.8	68.1	2.910E-07	69,394	69,625
69,620	-76.00	383.67	-60.0	213.15	0.7397	1.3333	94.30	4.456E-02	1.432E-04	6.024E-02	960.2	568.9	66.0	2.919E-07	70,000	70,235
70,000	-75.46	384.21	-59.7	213.45	0.7408	1.3104	92.68	4.380E-02	1.405E-04	5.912E-02	960.9	569.3	64.9	2.922E-07	70,392	70,630
71,000	-74.20	385.47	-59.0	214.15	0.7432	1.2494	88.36	4.175E-02	1.335E-04	5.618E-02	962.5	570.2	61.9	2.931E-07	71,423	71,668
72,000	-72.76	386.91	-58.2	214.95	0.7460	1.1912	84.25	3.981E-02	1.269E-04	5.337E-02	964.3	571.3	59.0	2.940E-07	72,457	72,709
73,000	-71.32	388.35	-57.4	215.75	0.7487	1.1358	80.33	3.796E-02	1.205E-04	5.070E-02	966.1	572.4	56.2	2.949E-07	73,496	73,755
74,000	-70.06	389.61	-56.7	216.45	0.7512	1.0831	76.60	3.620E-02	1.145E-04	4.819E-02	967.6	573.3	53.6	2.958E-07	74,538	74,805
75,000	-68.62	391.05	-55.9	217.25	0.7539	1.0329	73.05	3.452E-02	1.088E-04	4.579E-02	969.4	574.4	51.1	2.967E-07	75,583	75,857
76,000	-67.18	392.49	-55.1	218.05	0.7567	0.9851	69.67	3.292E-02	1.034E-04	4.351E-02	971.2	575.4	48.8	2.976E-07	76,633	76,915
77,000	-65.92	393.75	-54.4	218.75	0.7592	0.9395	66.45	3.140E-02	9.831E-05	4.136E-02	972.8	576.3	46.5	2.985E-07	77,685	77,975
78,000	-64.48	395.19	-53.6	219.55	0.7619	0.8961	63.38	2.995E-02	9.343E-05	3.931E-02	974.5	577.4	44.4	2.994E-07	78,742	79,040
79,000	-63.04	396.63	-52.8	220.35	0.7647	0.8548	60.46	2.857E-02	8.880E-05	3.736E-02	976.3	578.4	42.3	3.003E-07	79,803	80,109
80,000	-61.60	398.07	-52.0	221.15	0.7675	0.8154	57.67	2.725E-02	8.440E-05	3.551E-02	978.1	579.5	40.4	3.012E-07	80,867	81,181
81,000	-60.16	399.51	-51.2	221.95	0.7703	0.7779	55.02	2.600E-02	8.023E-05	3.375E-02	979.8	580.5	38.5	3.022E-07	81,935	82,258
82,000	-58.90	400.77	-50.5	222.65	0.7727	0.7422	52.49	2.481E-02	7.631E-05	3.210E-02	981.4	581.5	36.7	3.030E-07	83,008	83,339
83,000	-57.46	402.21	-49.7	223.45	0.7755	0.7082	50.09	2.367E-02	7.255E-05	3.052E-02	983.1	582.5	35.1	3.039E-07	84,081	84,421
84,000	-56.02	403.65	-48.9	224.25	0.7782	0.6757	47.79	2.258E-02	6.898E-05	2.902E-02	984.9	583.5	33.5	3.048E-07	85,153	85,502
85,000	-54.58	405.09	-48.1	225.05	0.7810	0.6448	45.61	2.155E-02	6.559E-05	2.759E-02	986.7	584.6	31.9	3.058E-07	86,225	86,582
86,000	-53.14	406.53	-47.3	225.85	0.7838	0.6154	43.52	2.057E-02	6.237E-05	2.624E-02	988.4	585.6	30.5	3.067E-07	87,296	87,662
87,000	-51.70	407.97	-46.5	226.65	0.7866	0.5873	41.54	1.963E-02	5.931E-05	2.495E-02	990.2	586.7	29.1	3.076E-07	88,367	88,742
88,000	-50.26	409.41	-45.7	227.45	0.7893	0.5606	39.65	1.873E-02	5.641E-05	2.373E-02	991.9	587.7	27.8	3.085E-07	89,437	89,822
89,000	-49.00	410.67	-45.0	228.15	0.7918	0.5350	37.84	1.788E-02	5.368E-05	2.258E-02	993.4	588.6	26.5	3.093E-07	90,506	90,900

TABLE D.1-IV. Tropical day amosphere (continued).

Pres-sure Altitude	Temperature				Temper-ature Ratio	Pressure		Pressure Ratio	Density	Density Ratio	Speed of Sound		Q/M2	Absolute Viscosity	Geopo-tential Altitude	Geo-metric Altitude
H, ft	deg F	deg R	deg C	deg K	θ	in Hg	lb/ft2	δ	slugs/ft3	σ	ft/sec	Knots	lb/ft2	lb-sec/ft2	H, ft	Z, ft
90,000	-47.56	412.11	-44.2	228.95	0.7946	0.5107	36.12	1.707E-02	5.106E-05	2.148E-02	995.2	589.6	25.3	3.102E-07	91,574	91,977
91,000	-46.12	413.55	-43.4	229.75	0.7973	0.4876	34.48	1.629E-02	4.858E-05	2.044E-02	996.9	590.6	24.1	3.111E-07	92,642	93,055
92,000	-44.68	414.99	-42.6	230.55	0.8001	0.4655	32.92	1.556E-02	4.621E-05	1.944E-02	998.6	591.7	23.0	3.121E-07	93,708	94,130
93,000	-43.24	416.43	-41.8	231.35	0.8029	0.4444	31.43	1.485E-02	4.397E-05	1.850E-02	1000.4	592.7	22.0	3.130E-07	94,775	95,207
94,000	-41.98	417.69	-41.1	232.05	0.8053	0.4243	30.01	1.418E-02	4.186E-05	1.761E-02	1001.9	593.6	21.0	3.138E-07	95,841	96,283
95,000	-40.54	419.13	-40.3	232.85	0.8081	0.4052	28.66	1.354E-02	3.983E-05	1.676E-02	1003.6	594.6	20.1	3.147E-07	96,905	97,357
96,000	-39.10	420.57	-39.5	233.65	0.8109	0.3869	27.36	1.293E-02	3.790E-05	1.595E-02	1005.3	595.6	19.2	3.156E-07	97,970	98,432
97,000	-37.66	422.01	-38.7	234.45	0.8136	0.3695	26.13	1.235E-02	3.607E-05	1.518E-02	1007.1	596.7	18.3	3.165E-07	99,033	99,505
98,000	-36.22	423.45	-37.9	235.25	0.8164	0.3529	24.96	1.179E-02	3.433E-05	1.445E-02	1008.8	597.7	17.5	3.174E-07	100,096	100,578
99,000	-34.78	424.89	-37.1	236.05	0.8192	0.3370	23.84	1.126E-02	3.268E-05	1.375E-02	1010.5	598.7	16.7	3.183E-07	101,159	101,651
100,000	-33.52	426.15	-36.4	236.75	0.8216	0.3219	22.77	1.076E-02	3.112E-05	1.309E-02	1012.0	599.6	15.9	3.191E-07	102,219	102,722

TABLE D.1-V. Ground level hot day atmosphere.

Pressure Altitude	Temperature				Temperature Ratio	Pressure		Pressure Ratio	Density	Density Ratio	Speed of Sound		Q/M2	Absolute Viscosity	Geopotential Altitude	Geometric Altitude
H, ft	deg F	deg R	deg C	deg K	θ	in Hg	lb/ft2	δ	slugs/ft3	σ	ft/sec	Knots	lb/ft2	lb-sec/ft2	H, ft	Z, ft
0	102.92	562.59	39.40	312.55	1.0847	29.9212	2116.22	1.0000	2.191E-03	0.9219	1162.8	688.9	1481.3	3.992E-07	0	0
1,000	99.14	558.81	37.30	310.45	1.0774	28.8557	2040.86	0.9644	2.128E-03	0.8951	1158.8	686.6	1428.6	3.971E-07	1,000	1,000
2,000	95.36	555.03	35.20	308.35	1.0701	27.8210	1967.68	0.9298	2.065E-03	0.8689	1154.9	684.3	1377.4	3.950E-07	2,100	2,100
3,000	91.58	551.25	33.10	306.25	1.0628	26.8166	1896.64	0.8962	2.004E-03	0.8433	1151.0	681.9	1327.6	3.929E-07	3,100	3,100
4,000	87.62	547.29	30.90	304.05	1.0552	25.8418	1827.70	0.8637	1.945E-03	0.8185	1146.8	679.5	1279.4	3.907E-07	4,200	4,201
5,000	83.66	543.33	28.70	301.85	1.0475	24.8959	1760.80	0.8320	1.888E-03	0.7943	1142.7	677.0	1232.5	3.885E-07	5,200	5,201
6,000	79.70	539.37	26.50	299.65	1.0399	23.9782	1695.89	0.8014	1.832E-03	0.7706	1138.5	674.5	1187.1	3.863E-07	6,300	6,302
7,000	75.74	535.41	24.30	297.45	1.0323	23.0881	1632.94	0.7716	1.777E-03	0.7475	1134.3	672.1	1143.0	3.840E-07	7,400	7,403
8,000	71.78	531.45	22.10	295.25	1.0246	22.2249	1571.89	0.7428	1.723E-03	0.7249	1130.1	669.6	1100.3	3.818E-07	8,400	8,403
9,000	67.82	527.49	19.90	293.05	1.0170	21.3881	1512.70	0.7148	1.671E-03	0.7029	1125.9	667.1	1058.9	3.795E-07	9,500	9,504
10,000	63.86	523.53	17.70	290.85	1.0094	20.5769	1455.33	0.6877	1.619E-03	0.6813	1121.7	664.6	1018.7	3.773E-07	10,600	10,605
11,000	60.26	519.93	15.70	288.85	1.0024	19.7909	1399.74	0.6614	1.568E-03	0.6598	1117.8	662.3	979.8	3.752E-07	11,600	11,606
12,000	56.48	516.15	13.60	286.75	0.9951	19.0293	1345.87	0.6360	1.519E-03	0.6391	1113.7	659.9	942.1	3.731E-07	12,600	12,608
13,000	52.52	512.19	11.40	284.55	0.9875	18.2917	1293.70	0.6113	1.471E-03	0.6191	1109.4	657.3	905.6	3.708E-07	13,600	13,609
14,000	48.74	508.41	9.30	282.45	0.9802	17.5773	1243.18	0.5875	1.424E-03	0.5993	1105.3	654.9	870.2	3.686E-07	14,700	14,710
15,000	44.96	504.63	7.20	280.35	0.9729	16.8858	1194.27	0.5643	1.379E-03	0.5800	1101.2	652.5	836.0	3.664E-07	15,700	15,712

ANNEX 2

MISSION PROFILES

This Annex to JSSG-2001 Appendix D contains mission profiles to be used to compute the mission capability of military aircraft. Profiles are presented for a variety of missions for each aircraft type. A list of these missions, by aircraft type, is included. The primary use of these profiles is to provide the framework for the comparison of the capabilities of different aircraft performing the same mission. All times and distances have been specified except for the segment (or segments) which provides the variability needed to maximize the parameter of interest (radius, range, loiter time, etc). The variable parameter/segment for each of these profiles has been shaded ( ) to make it easy to recognize. Wherever the distance for a cruise leg has been specified, it includes the climb distance for any preceding or following climbs.

MISSION PROFILES SPECIFIC TO AIRCRAFT TYPE

Table D.2-I contains a list of aircraft types, the missions normally performed by them, and the profile appropriate to each mission. Also included is a list of comments describing unique features of the profiles.

MISSION PROFILES. Figures 1 through 40 contain profiles to be used for each mission for the various aircraft types. Some mission profiles are further identified by the altitudes at which the different segments (cruise, penetration/egress, combat) are flown: three segment names being outbound cruise-combat-return cruise, and four segment names being outbound cruise-penetration-egress-return cruise. The term combat is used in these mission profiles to define the task, at the mid-point of the mission, which is the reason for the mission to be performed. Combat is defined for each aircraft type in table D.2-I if more information is needed than is provided in Paragraph D.4.2.5.

Parameters for climb and cruise segments of these profiles are defined to produce the maximum range/radius. Even though missions may not normally be flown at these optimum conditions, missions calculated with these ground rules provide the maximum that can be expected of an aircraft, and provide an achievable estimate of maximum capability early in a development program before operational constraints are defined. All descents are modeled with the cruise segment continued to the range which would be the end of the descent segment, with descent becoming a non-segment consisting of zero time, distance and fuel. The mission profiles can be tailored to more operationally realistic conditions by redefining the appropriate parameters. Minimum time climb speed schedules can be replaced with operational schedules, cruise may be flown at constant altitude or as a step climb, descents may be modeled with operationally realistic parameters, etc. All radius missions are modeled as equal length outbound and return legs with takeoff and landing at the same point. Operational missions may sometimes require unequal length legs with different takeoff and landing locations. *The takeoff fuel allowance and landing fuel reserves shown on these example profiles are for land based operations*. For calculating carrier based mission performance, takeoff power setting should comply with launch requirements. For landing reserves refer to paragraph D.4.2.9.2. In addition, the acceleration to climb speed after launch from a carrier should start at Mach 0.3 instead of obstacle speed.

For each profile, all independent variables except one are defined. Warm-up and takeoff fuel, reserves, penetration and egress speeds and altitudes, etc. have been quantified for each specific mission application. The undefined variable for most missions is cruise distance, but for some missions it is loiter time, combat time, or penetration/withdrawal distance. All values for the parameters in the mission profiles are for guidance only and other values may be used when appropriate. The important point is that when comparing the capability of two or more aircraft to perform the same mission, care must be taken to ensure the comparison is made to identical mission rules. Also, if the comparison includes different kinds of aircraft (VTOL vs. STOL vs. conventional, carrier vs. land based, etc.), the mission rules appropriate to each kind of aircraft should be used.

TABLE D.2-I. Mission profiles specific to air vehicle type.

AIRCRAFT TYPE	MISSION	PROFILE	VARIATIONS/COMMENTS
ATTACK			
	CLOSE AIR SUPPORT (CAS)	FIG. 1 - LONG RANGE	Combat consists of dropping/launching onboard weapons.
	CLOSE AIR SUPPORT (CAS)	FIG. 2 - SHORT RANGE	Combat consists of dropping/launching onboard weapons.
	INTERDICTION	FIG. 3 - (LO-LO-LO-LO)	Combat consists of dropping/launching onboard weapons.
	INTERDICTION	FIG. 4 - (LO-LO-LO-HI)	Combat consists of dropping/launching onboard weapons.
	INTERDICTION	FIG. 5 - (HI-LO-LO-HI)	Combat consists of dropping/launching onboard weapons.
	INTERDICTION	FIG. 6 - (HI-MED-MED-HI)	Combat consists of dropping/launching onboard weapons.
	INTERDICTION	FIG. 7 - (HI-HI-HI-HI)	Combat consists of dropping/launching onboard weapons.
	MULTI-ROLE SELF ESCORT INTERDICTION (HI-MED-MED-HI)	FIG. 8	Combat consists of dropping/launching onboard weapons.
	SURFACE COMBAT AIR PATROL (SUCAP)	FIG. 9	Same mission profile as the combat air patrol mission for fighters. Weapons loading consists of air-to-ground weapons instead of air-to-air for the fighters.
	SUPPRESSION OF ENEMY AIR DEFENSES (SEAD)	FIG. 10	Same mission profile as the interdiction mission (FIG. 6), but weapons will be tailored to a different target set.

ANNEX 2

TABLE D.2-I. Mission profiles specific to air vehicle type (continued).

AIRCRAFT TYPE	MISSION	PROFILE	VARIATIONS/COMMENTS
BOMBER			
	HIGH LEVEL	FIG.11 - (HI-HI-HI)	Combat consists of dropping/launching onboard weapons.
	LOW LEVEL PENETRATION	FIG. 12 - (HI-LO-LO-HI)	Combat consists of dropping/launching onboard weapons.
	MEDIUM LEVEL PENETRATION	FIG. 13 - (HI-MED-MED-HI)	Combat consists of dropping/launching onboard weapons.
	HIGH LEVEL PENETRATION	FIG. 14 - (HI-HI-HI-HI)	Combat consists of dropping/launching onboard weapons.
CARGO/ TRANSPORT			
	AIR DROP/ASSAULT TRANSPORT	FIG. 15 - (HI-LO-LO-HI)	
	SUPPLY - RADIUS	FIG. 16 - (HI-LO-HI)	
	SUPPLY - RANGE	FIG. 17	
ELECTRONIC WARFARE			
	AIRBORNE WARNING AND CONTROL (AWACS)	FIG. 18	
	SPECIAL ELECTRONICS MISSIONS		
	- CORPS	FIG. 19	
	- DIVISION	FIG. 20	

ANNEX 2

TABLE D.2-I. Mission profiles specific to air vehicle type (continued).

AIRCRAFT TYPE	MISSION	PROFILE	VARIATIONS/COMMENTS
FIGHTER			
	COMBAT AIR PATROL (CAP)	FIG. 21	Combat consists of air-to-air fighting
	INTERCEPT	FIG. 22 - SUBSONIC INTERCEPT	Combat consists of air-to-air fighting
	INTERCEPT	FIG. 23 - SUPERSONIC INTERCEPT	Combat consists of air-to-air fighting
	MEDIUM ALTITUDE FIGHTER SWEEP	FIG. 24 - (HI-MED-HI)	Combat consists of air-to-air fighting
	HIGH ALTITUDE FIGHTER SWEEP	FIG. 25 - (HI-HI-HI-HI)	Combat consists of air-to-air fighting
RECONNAIS-SANCE			
	LOW LEVEL PENETRATION	FIG. 26 - (HI-LO-LO-HI)	
	HIGH LEVEL PENETRATION	FIG. 27 - (HI-HI-HI-HI)	
TANKER			
	BUDDY REFUEL	FIG. 28	
	RENDEZVOUS REFUEL	FIG. 29	
	RENDEZVOUS REFUEL - NAVY	FIG. 30	

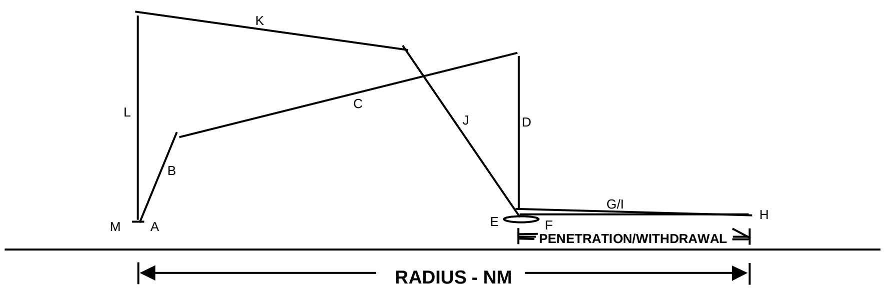
ANNEX 2

TABLE D.2-I. Mission profiles specific to air vehicle type (continued).

AIRCRAFT TYPE	MISSION	PROFILE	VARIATIONS/COMMENTS
TRAINER			
	BASIC - FAMILIARIZATION	FIG. 31	
	BASIC - TASK FAMILIARIZATION	FIG. 32	
	BASIC - LOW LEVEL NAVIGATION	FIG. 33	
	BASIC - HIGH LEVEL NAVIGATION	FIG. 34	
	ADVANCED - WEAPONS DELIVERY	FIG. 35	
	ADVANCED - AIR COMBAT MANEUVERING	FIG. 36	
MISCELLA-NEOUS			
	FORWARD AIR CONTROL (FAC)	FIG. 37	Combat consists of two segments: loiter for a specified period, and weapon drop/launch
	PATROL/ANTI-SUBMARINE WARFARE (ASW)	FIG. 38	Combat consists of a variable number or loiter segments, each flown at a lower altitude than the previous
	MINELAYING	FIG. 39	Combat consists of jettisoning mines
	FERRY	FIG. 40	

ANNEX 2

CLOSE AIR SUPPORT (CAS) - LONG RANGE

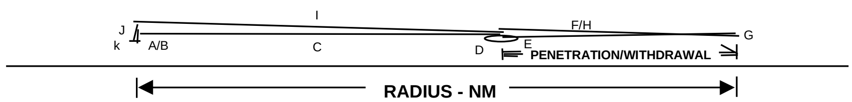


	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING (1)
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (4)	TAKEOFF TO OPTIMUM CRUISE	INTERMEDIATE
C	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
D	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LOITER	
E	LOITER (PARA. 4.2.6) (5)		10 MINUTES	NO CREDIT	INSTANTANEOUS CORNER SPEED	2000 FEET PRESS. ALT.	
F	ACCELERATE				LOITER TO PENETRATION	2000 FEET PRESS. ALT.	MAXIMUM/INTERMEDIATE
G	PENETRATION (PARA. 4.2.4)			30 NM INCLUDING ACCEL	0.8 MACH OR Virt WHICHEVER IS LOWER	2000 FEET PRESS. ALT.	
H	COMBAT (2), (3)	ONE 2000 FT ENERGY EXCHANGE PLUS ONE 180 DEG TURN @ (Virt - 50 KTAS) WITH MAX SUSTAINED G's @ MAXIMUM/MAXIMUM A/B. (1) EXPEND HALF OF AIR-TO-GROUND STORES. NO DISTANCE CREDIT.					
I	WITHDRAWAL (PARA. 4.2.4)			30 NM	0.8 MACH OR Virt WHICHEVER IS LOWER	2000 FEET PRESS. ALT.	
J	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (4)	2000 FEET PRESS ALT. TO OPTIMUM CRUISE	INTERMEDIATE
K	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
L	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
M	RESERVES	20 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	

NOTES:
(1) THRUST SETTINGS ARE NON-AUGMENTED/AUGMENTED (SEE PARA. 3.11.3.2)
(2) SEE PARA 4.1.5, 4.1.7
(3) INCLUDE ACCELERATION FUEL IF COMBAT SPEED IS GREATER THAN PENETRATION SPEED
(4) CLIMB SCHEDULE ENDS AT OPTIMUM CRUISE SPEED/ALTITUDE
(5) REPEAT SEGMENTS E-I ONCE. SECOND LOITER IS 5 MINUTES

FIGURE D.2-1. Close air support (CAS) - long range.

CLOSE AIR SUPPORT (CAS) - SHORT RANGE



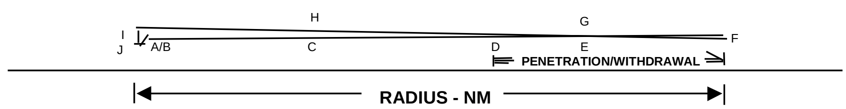
	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING (1)
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB				MINIMUM TIME CLIMB SCHEDULE	TAKEOFF TO 2000 FEET PRESS ALT.	MAX CONTINUOUS/ INTERMEDIATE
C	CRUISE (PARA. 4.2.3)				MAXIMUM RANGE CRUISE	2000 FEET PRESS ALT.	
D	LOITER (PARA. 4.2.6) (4)		10 MINUTES	NO CREDIT	INSTANTANEOUS CORNER SPEED	2000 FEET PRESS ALT.	
E	ACCELERATE				LOITER TO PENETRATION	2000 FEET PRESS ALT.	MAXIMUM/INTERMEDIATE
F	PENETRATION (PARA. 4.2.4)			30 NM INCLUDING ACCEL	0.8 MACH OR Virt WHICHEVER IS LOWER	2000 FEET PRESS ALT.	
G	COMBAT (2), (3)	ONE 2000 FT ENERGY EXCHANGE PLUS ONE 180 DEG TURN @ (Virt - 50 KTAS) WITH MAX SUSTAINED G's @ MAXIMUM/MAXIMUM A/B. (1) EXPEND HALF OF AIR-TO-GROUND STORES. NO DISTANCE CREDIT.					
H	WITHDRAWAL (PARA. 4.2.4)			30 NM INCLUDING ACCEL	0.8 MACH OR Virt WHICHEVER IS LOWER	2000 FEET PRESS ALT.	
I	CRUISE (PARA. 4.2.3)				MAXIMUM RANGE CRUISE	2000 FEET PRESS ALT.	
J	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		2000 FEET PRESS ALT. TO LANDING	
K	RESERVES	20 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
L							

NOTES: (1) THRUST SETTINGS ARE NON-AUGMENTED/AUGMENTED (SEE PARA. 3.11.3.2)
(2) SEE PARA 4.1.5, 4.1.7
(3) INCLUDE ACCELERATION FUEL IF COMBAT SPEED IS GREATER THAN PENETRATION SPEED
(4) REPEAT SEGMENTS D-H ONCE. SECOND LOITER IS 5 MINUTES

FIGURE D.2-2. Close air support (CAS) - short range.

ANNEX 2

INTERDICTION (LO-LO-LO-LO)



	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING (1)
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE	TAKEOFF TO 2000 FEET PRESS ALT.	INTERMEDIATE
C	CRUISE (PARA..4.2.3)				MAXIMUM RANGE CRUISE	2000 FEET PRESS ALT.	
D	ACCELERATE				CRUISE TO PENETRATION	2000 FEET PRESS ALT.	MAXIMUM/INTERMEDIATE
E	PENETRATION (PARA. 4.2.4)			50 NM INCLUDING ACCEL	0.8 MACH OR Virt WHICHEVER IS LOWER	2000 FEET PRESS ALT.	
F	COMBAT (2), (3)	ONE 2000 FT ENERGY EXCHANGE PLUS ONE 180 DEG TURN @ (Virt - 50 KTAS) WITH MAX SUSTAINED G's @ MAXIMUM/MAXIMUM A/B. (1) EXPEND AIR-TO-GROUND STORES. NO DISTANCE CREDIT.					
G	WITHDRAWAL (PARA. 4.2.4)			50 NM INCLUDING ACCEL	0.8 MACH OR Virt WHICHEVER IS LOWER	2000 FEET PRESS ALT.	
H	CRUISE (PARA. 4.2.3)				MAXIMUM RANGE CRUISE	2000 FEET PRESS ALT.	
I	DESCENT (PARA.4.2.8)	NONE	NONE	NO CREDIT		2000 FEET PRESS ALT. TO LANDING	
J	RESERVES (PARA. 4.2.9)	20 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
K							
L							

NOTES: (1) THRUST SETTINGS ARE NON-AUGMENTED/AUGMENTED (SEE PARA.3.11.3.2)

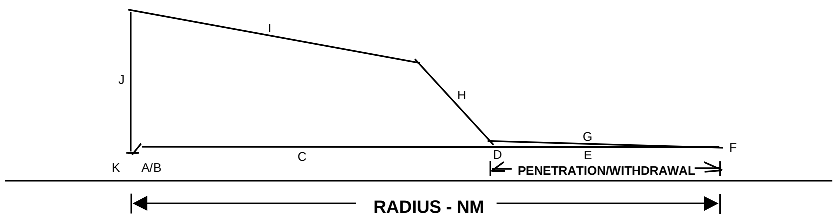
(2) SEE PARA 4.1.5, 4.1.7

(3) INCLUDE ACCELERATION FUEL IF COMBAT SPEED IS GREATER THAN PENETRATION SPEED

FIGURE D.2-3. Interdiction (LO-LO-LO-LO).

ANNEX 2

INTERDICTION (LO-LO-LO-HI)



	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING (1)
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE	TAKEOFF TO 2000 FEET PRESS ALT.	INTERMEDIATE
C	CRUISE (PARA. 4.2.3)				MAXIMUM RANGE CRUISE	2000 FEET PRESS ALT.	
D	ACCELERATE				CRUISE TO PENETRATION	2000 FEET PRESS ALT.	MAXIMUM/ INTERMEDIATE
E	PENETRATION (PARA. 4.2.4)			50 NM INCLUDING ACCEL	0.8 MACH OR Virt WHICHEVER IS LOWER	2000 FEET PRESS ALT.	
F	COMBAT (2), (3)	ONE 2000 FT ENERGY EXCHANGE PLUS ONE 180 DEG TURN @ (Virt - 50 KTAS) WITH MAX SUSTAINED G's @ MAXIMUM/MAXIMUM A/B. (1) EXPEND AIR-TO-GROUND STORES. NO DISTANCE CREDIT.					
G	WITHDRAWAL (PARA. 4.2.4)			50 NM INCLUDING ACCEL	0.8 MACH OR Virt WHICHEVER IS LOWER	2000 FEET PRESS ALT.	
H	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (4)	2000 FEET PRESS ALT. TO OPTIMUM CRUISE	INTERMEDIATE
I	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
J	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
K	RESERVES	20 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
L							

NOTES: (1) THRUST SETTINGS ARE NON-AUGMENTED/AUGMENTED (SEE PARA.3.11.3.2)

(2) SEE PARA 4.1.5, 4.1.7

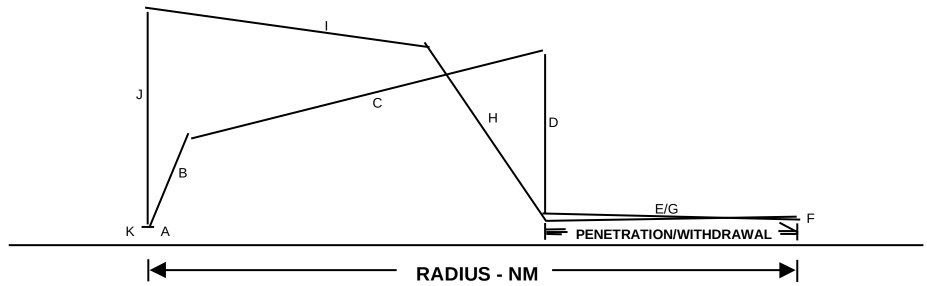
(3) INCLUDE ACCELERATION FUEL IF COMBAT SPEED IS GREATER THAN PENETRATION SPEED

(4) CLIMB SCHEDULE ENDS AT OPTIMUM CRUISE SPEED/ALTITUDE

FIGURE D.2-4. Interdiction (LO-LO-LO-HI).

ANNEX 2

INTERDICTION (HI-LO-LO-HI)

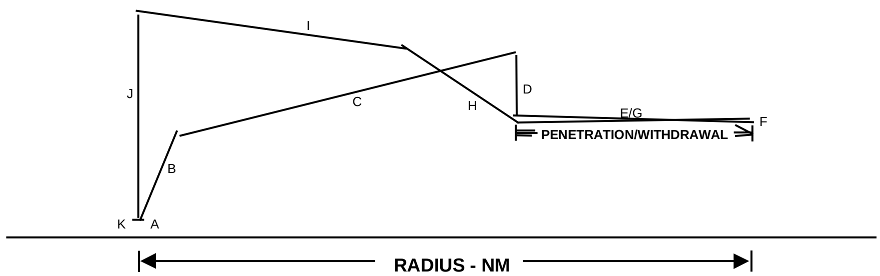


	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (3)	TAKEOFF TO OPTIMUM CRUISE	INTERMEDIATE
C	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
D	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO 2000 FEET PRESS ALT.	
E	PENETRATION (PARA. 4.2.4)			50 NM	0.8 MACH OR Virt WHICHEVER IS LOWER	2000 FEET PRESS ALT.	
F	COMBAT (1), (2)	ONE 2000 FT ENERGY EXCHANGE PLUS ONE 180 DEG TURN @ (Virt - 50 KTAS) WITH MAX SUSTAINED G's @ MAXIMUM/MAXIMUM A/B. (4) EXPEND AIR-TO-GROUND STORES. NO DISTANCE CREDIT.					
G	WITHDRAWAL (PARA. 4.2.4)			50 NM INCLUDING ACCEL	0.8 MACH OR Virt WHICHEVER IS LOWER	2000 FEET PRESS ALT.	
H	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (3)	2000 FEET PRESS ALT. TO OPTIMUM CRUISE	INTERMEDIATE
I	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
J	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
K	RESERVES	20 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
L							

NOTES: (1) SEE PARA 4.1.5, 4.1.7
(2) INCLUDE ACCELERATION FUEL IF COMBAT SPEED IS GREATER THAN PENETRATION SPEED
(3) CLIMB SCHEDULE ENDS AT OPTIMUM CRUISE SPEED/ALTITUDE
(4) THRUST SETTINGS ARE NON-AUGMENTED/AUGMENTED (SEE PARA.3.11.3.2)

FIGURE D.2-5. Interdiction (HI-LO-LO-HI).

INTERDICTION (HI-MED-MED-HI)



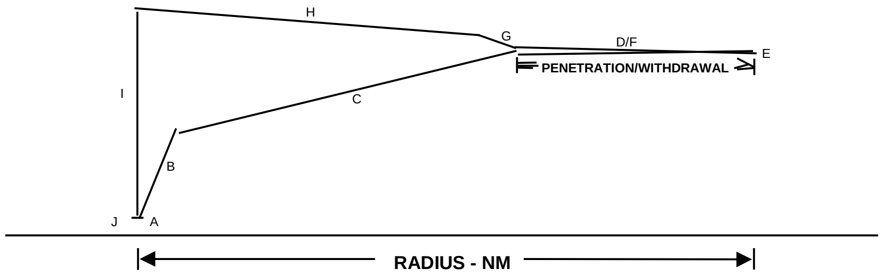
	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (3)	TAKEOFF TO OPTIMUM CRUISE	INTERMEDIATE
C	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
D	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO 20,000 FEET PRESS ALT.	
E	PENETRATION (PARA. 4.2.4)			50 NM	540 KTAS OR Virt WHICHEVER IS LOWER	20,000 FEET PRESS ALT.	
F	COMBAT (1), (2)	ONE 180 DEG TURN @ (Virt - 50 KTAS) WITH MAX SUSTAINED G's @ MAXIMUM/MAXIMUM A/B. (4) EXPEND AIR-TO-GROUND STORES. NO DISTANCE CREDIT.					
G	WITHDRAWAL (PARA. 4.2.4)			50 NM INCLUDING ACCEL	540 KTAS OR Virt WHICHEVER IS LOWER	20,000 FEET PRESS ALT.	
H	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (3)	20,000 FEET PRESS ALT. TO OPTIMUM CRUISE	INTERMEDIATE
I	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
J	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
K	RESERVES	20 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
L							

NOTES: (1) SEE PARA 4.1.5, 4.1.7
(2) INCLUDE ACCELERATION FUEL IF COMBAT SPEED IS GREATER THAN PENETRATION SPEED
(3) CLIMB SCHEDULE ENDS AT OPTIMUM CRUISE SPEED/ALTITUDE
(4) THRUST SETTINGS ARE NON-AUGMENTED/AUGMENTED (SEE PARA.3.11.3.2)

FIGURE D.2-6. Interdiction (HI-MED-MED-HI).

ANNEX 2

INTERDICTION (HI-HI-HI-HI)



	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING (1)
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (4)	TAKEOFF TO OPTIMUM CRUISE	INTERMEDIATE
C	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
D	ACCELERATE				CRUISE TO PENETRATION	END CRUISE ALT.	MAXIMUM/ INTERMEDIATE
E	PENETRATION (PARA. 4.2.4)			50 NM	540 KTAS OR Virt WHICHEVER IS LOWER	END CRUISE ALT.	
F	COMBAT (2), (3)	ONE 180 DEG TURN @ (Virt - 50 KTAS) WITH MAX SUSTAINED G's @ MAXIMUM/MAXIMUM A/B. (1) EXPEND AIR-TO-GROUND STORES. NO DISTANCE CREDIT.					
G	WITHDRAWAL (PARA. 4.2.4)			50 NM INCLUDING ACCEL	540 KTAS OR Virt WHICHEVER IS LOWER	END CRUISE ALT.	
H	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (4)	WITHDRAWAL ALT.TO OPTIMUM CRUISE	INTERMEDIATE
I	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
J	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
K	RESERVES	20 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
L							

NOTES: (1) THRUST SETTNGS ARE NON-AUGMENTED/AUGMENTED. (SEE PARA. 3.11.3.2)

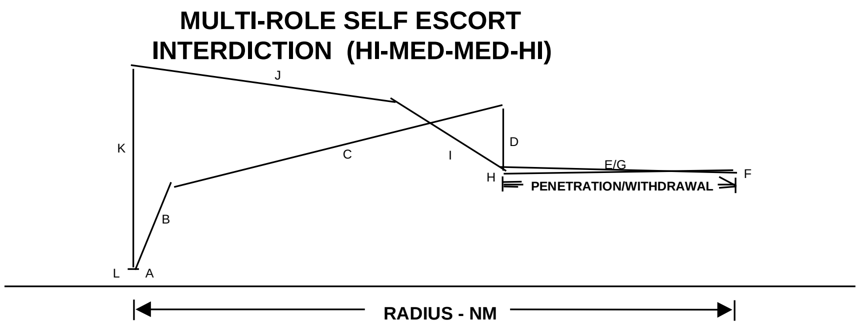
(2) SEE PARA 4.1.5, 4.1.7

(3) INCLUDE ACCELERATION FUEL IF COMBAT SPEED IS GREATER THAN PENETRATION SPEED

(4) CLIMB SCHEDULE ENDS AT OPTIMUM CRUISE SPEED/ALTITUDE

FIGURE D.2-7. Interdiction (HI-HI-HI-HI).

ANNEX 2



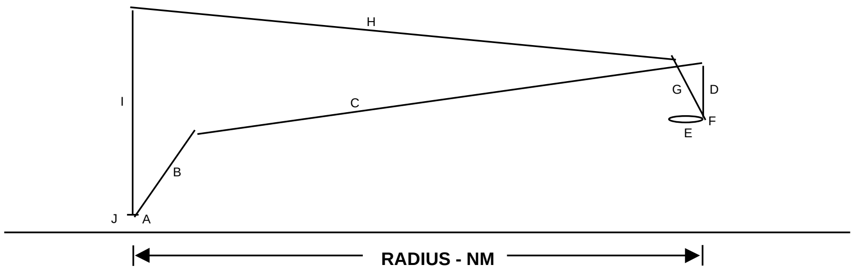
	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (3)	TAKEOFF TO OPTIMUM CRUISE	INTERMEDIATE
C	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
D	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO 20,000 FEET PRESS ALT.	
E	PENETRATION (PARA. 4.2.4)			50 NM	540 KTAS OR Virt WHICHEVER IS LOWER	20,000 FEET PRESS ALT.	
F	COMBAT (1), (2)	ONE 180 DEG TURN @ (Virt - 50 KTAS) WITH MAX SUSTAINED G's @ MAXIMUM/MAXIMUM A/B. (4) EXPEND AIR-TO-GROUND STORES. NO DISTANCE CREDIT.					
G	WITHDRAWAL (PARA. 4.2.4)			50 NM INCLUDING ACCEL	540 KTAS OR Virt WHICHEVER IS LOWER	20,000 FEET PRESS ALT.	
H	COMBAT (1)	ONE 360 DEG TURN @ 540 KTAS WITH MAX SUSTAINED G's @ MAXIMUM/MAXIMUM A/B. (4) LAUNCH AIR-TO-AIR MISSILES. NO DISTANCE CREDIT.					
I	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (3)	20,000 FEET PRESS ALT. TO OPTIMUM CRUISE	INTERMEDIATE
J	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
K	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
L	RESERVES	20 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	

NOTES: (1) SEE PARA 4.1.5, 4.1.7
(2) INCLUDE ACCELERATION FUEL IF COMBAT SPEED IS GREATER THAN PENETRATION SPEED
(3) CLIMB SCHEDULE ENDS AT OPTIMUM CRUISE SPEED/ALTITUDE
(4) THRUST SETTINGS ARE NON-AUGMENTED/AUGMENTED (SEE PARA. 3.11.3.2)

FIGURE D.2-8. Multi-role self escort interdiction (HI-MED-MED-HI).

ANNEX 2

SURFACE COMBAT AIR PATROL (SUCAP)



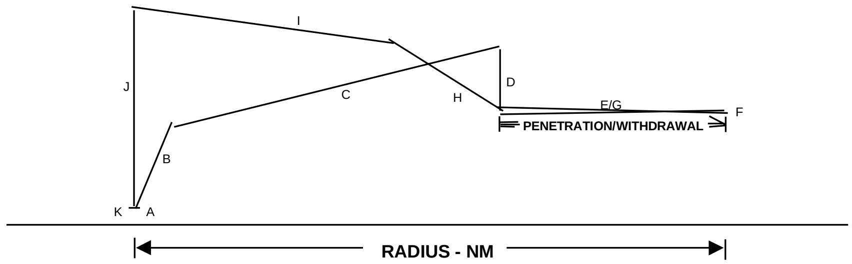
	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (2)	TAKEOFF TO OPTIMUM CRUISE	INTERMEDIATE
C	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
D	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO 20,000 FT PRESS. ALT.	
E	LOITER (PARA. 4.2.6)			NO CREDIT	COMBAT LOITER	20,000 FT PRESS. ALT.	
F	COMBAT (1)	EXPEND AIR-TO-GROUND STORES. NO DISTANCE CREDIT.					
G	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (2)	20,000 FT PRESS. ALT. TO OPTIMUM CRUISE	INTERMEDIATE
H	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
I	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
J	RESERVES	20 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
K							
L							

NOTES: (1) SEE PARA 4.1.5,4.1.7

(2) CLIMB SCHEDULE ENDS AT OPTIMUM CRUISE SPEED ALTITUDE

FIGURE D.2-9. Surface Combat Air Patrol (SUCAP).

SUPPRESSION OF ENEMY AIR DEFENSES (SEAD)

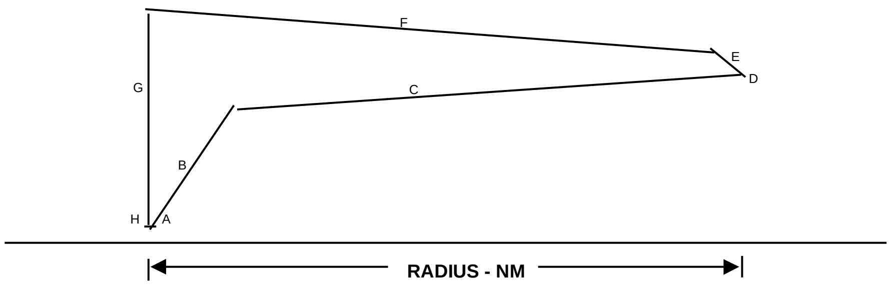


	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (3)	TAKEOFF TO OPTIMUM CRUISE	INTERMEDIATE
C	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
D	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO 20,000 FEET PRESS ALT.	
E	PENETRATION (PARA. 4.2.4)			50 NM	540 KTAS OR Virt WHICHEVER IS LOWER	20,000 FEET PRESS ALT.	
F	COMBAT (1), (2)	ONE 180 DEG TURN @ (Virt - 50 KTAS) WITH MAX SUSTAINED G's @ MAXIMUM/MAXIMUM A/B. (4) EXPEND AIR-TO-GROUND STORES. NO DISTANCE CREDIT.					
G	WITHDRAWAL (PARA. 4.2.4)			50 NM INCLUDING ACCEL	540 KTAS OR Virt WHICHEVER IS LOWER	20,000 FEET PRESS ALT.	
H	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (3)	20,000 FEET PRESS ALT. TO OPTIMUM CRUISE	INTERMEDIATE
I	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
J	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
K	RESERVES	20 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
L							

NOTES: (1) SEE PARA 4.1.5, 4.1.7
(2) INCLUDE ACCELERATION FUEL IF COMBAT SPEED IS GREATER THAN PENETRATION SPEED
(3) CLIMB SCHEDULE ENDS AT OPTIMUM CRUISE SPEED/ALTITUDE
(4) THRUST SETTINGS ARE NON-AUGMENTED/AUGMENTED (SEE PARA. 3.11.3.2)

FIGURE D.2-10. Suppression of enemy air defenses (SEAD).

BOMBER - HIGH LEVEL



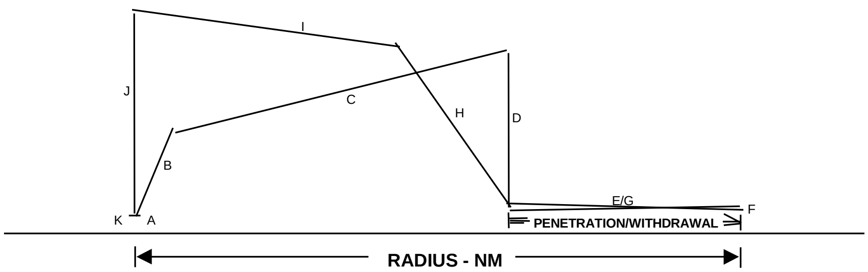
	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING (1)
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT. (4)					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (3)	TAKEOFF TO OPTIMUM CRUISE	MAX CONTINUOUS/ INTERMEDIATE
C	CRUISE (PARA. 4.2.3)				LONG RANGE CRUISE	OPTIMUM CRUISE	
D	COMBAT (2)	EXPEND AIR-TO-GROUND STORES.					
E	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (3)	COMBAT TO OPTIMUM CRUISE	MAX CONTINUOUS/ INTERMEDIATE
F	CRUISE (PARA. 4.2.3)				LONG RANGE CRUISE	OPTIMUM CRUISE	
G	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
H	RESERVES	30 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
I							
J							
K							
L							

NOTES: (1) THRUST SETTINGS ARE NON-AUGMENTED/AUGMENTED (SEE PARA. 3.11.3.2)
(2) SEE PARA 4.1.5, 4.1.7
(3) CLIMB SCHEDULE ENDS AT LONG RANGE CRUISE SPEED/OPTIMUM CRUISE ALTITUDE
(4) LONGER WARM-UP TIMES MAY BE REQUIRED BY ELECTRONIC EQUIPMENT

FIGURE D.2-11. Bomber - high level.

ANNEX 2

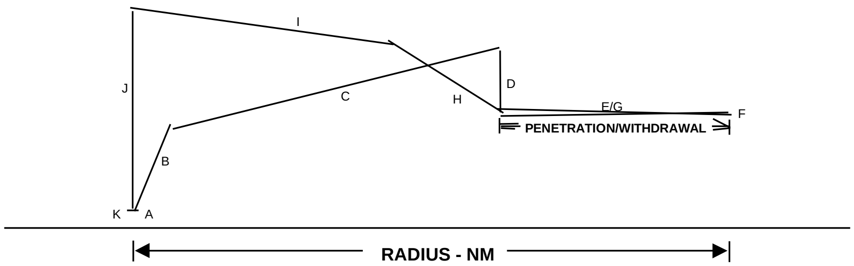
BOMBER - LOW LEVEL PENETRATION



	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING (1)
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT. (4)					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (5)	TAKEOFF TO OPTIMUM CRUISE	MAX CONTINUOUS/ INTERMEDIATE
C	CRUISE (PARA. 4.2.3)				LONG RANGE CRUISE	OPTIMUM CRUISE	
D	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO 2000 FEET PRESS ALT.	
E	PENETRATION (PARA. 4.2.4)			500 NM	.55/.85 MACH (3)	2000 FEET PRESS ALT.	
F	COMBAT (2)	2 MINUTES @ MAX CONT ($V_{MAX\ CONT}$) / MAX A/B ($V_{MAX\ A/B}$). (1) EXPEND AIR-TO-GROUND STORES. NO DISTANCE CREDIT. (6)					
G	WITHDRAWAL (PARA. 4.2.4)			500 NM	.55/.85 MACH (3)	2000 FEET PRESS ALT.	
H	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (5)	2000 FEET PRESS ALT. TO OPTIMUM CRUISE	MAX CONTINUOUS/ INTERMEDIATE
I	CRUISE (PARA. 4.2.3)				LONG RANGE CRUISE	OPTIMUM CRUISE	
J	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
K	RESERVES	30 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
L							

NOTES:
(1) THRUST SETTINGS ARE NON-AUGMENTED/AUGMENTED (SEE PARA. 3.11.3.2)
(2) SEE PARA 4.1.5, 4.1.7
(3) SUBSONIC/SUPERSONIC AIRCRAFT
(4) LONGER WARM-UP TIMES MAY BE REQUIRED BY ELECTRONIC EQUIPMENT
(5) CLIMB SCHEDULE ENDS AT LONG RANGE CRUISE SPEED/OPTIMUM CRUISE ALTITUDE
(6) INCLUDE ACCELERATION FUEL FROM PENETRATION TO COMBAT SPEED

FIGURE D.2-12. Bomber - low-level penetration.

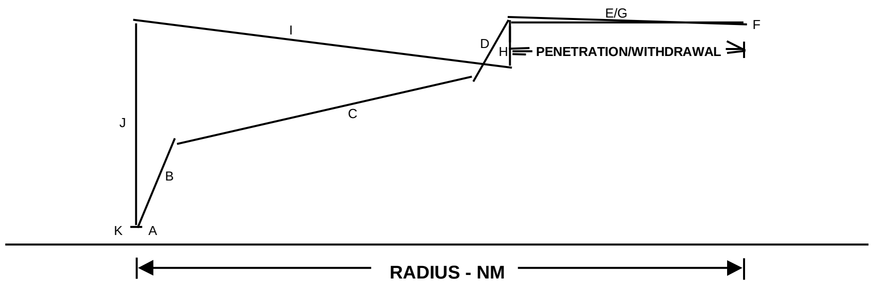


	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING (1)
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT. (4)					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (3)	TAKEOFF TO OPTIMUM CRUISE	MAX CONTINUOUS/ INTERMEDIATE
C	CRUISE (PARA. 4.2.3)				LONG RANGE CRUISE	OPTIMUM CRUISE	
D	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO 20,000 FEET PRESS ALT.	
E	PENETRATION (PARA. 4.2.4)		15 MINUTES		$V_{MAX\ CONT}$ / $V_{MAX\ A/B}$ (1)	20,000 FEET PRESS ALT.	
F	COMBAT (2)	2 MINUTES @ MAX CONT ($V_{MAX\ CONT}$) / MAX A/B ($V_{MAX\ A/B}$). (1) EXPEND AIR-TO-GROUND STORES. NO DISTANCE CREDIT.					
G	WITHDRAWAL (PARA. 4.2.4)		15 MINUTES		$V_{MAX\ CONT}$ / $V_{MAX\ A/B}$ (1)	20,000 FEET PRESS ALT.	
H	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (3)	20,000 FEET PRESS ALT. TO OPTIMUM CRUISE	MAX CONTINUOUS/ INTERMEDIATE
I	CRUISE (PARA. 4.2.3)				LONG RANGE CRUISE	OPTIMUM CRUISE	
J	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
K	RESERVES	30 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
L							

NOTES: (1) THRUST SETTINGS ARE NON-AUGMENTED/AUGMENTED (SEE PARA. 3.11.3.2)
(2) SEE PARA 4.1.5, 4.1.7
(3) CLIMB SCHEDULE ENDS AT LONG RANGE CRUISE SPEED/OPTIMUM CRUISE ALTITUDE
(4) LONGER WARM-UP TIMES MAY BE REQUIRED BY ELECTRONICS EQUPMENT

FIGURE D.2-13. Bomber - medium-level penetration.

BOMBER - HIGH LEVEL PENETRATION



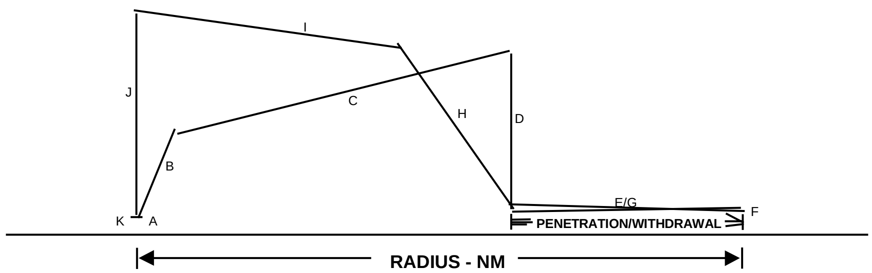
	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING (1)
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT. (3)					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (4)	TAKEOFF TO OPTIMUM CRUISE	MAX CONTINUOUS/ INTERMEDIATE
C	CRUISE (PARA. 4.2.3)				LONG RANGE CRUISE	OPTIMUM CRUISE	
D	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (5)	END CRUISE TO COMBAT CEILING	INTERMEDIATE/MAXIMUM A/B
E	PENETRATION (PARA. 4.2.4)		15 MINUTES		$V_{MAX\ CONT}$ / $V_{MAX\ A/B}$ (1)	COMBAT CEILING	MAX CONTINUOUS/ MAXIMUM A/B
F	COMBAT (2)	2 MIN @ MAX CONT ($V_{MAX\ CONT}$) / MAX A/B ($V_{MAX\ A/B}$). (1) EXPEND AIR-TO-GROUND STORES. NO DISTANCE CREDIT.					
G	WITHDRAWAL (PARA. 4.2.4)		15 MINUTES		$V_{MAX\ CONT}$ / $V_{MAX\ A/B}$ (1)	COMBAT CEILING	MAX CONTINUOUS/ MAXIMUM A/B
H	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		COMBAT CEILING TO OPTIMUM CRUISE	
I	CRUISE (PARA. 4.2.3)				LONG RANGE CRUISE	OPTIMUM CRUISE	
J	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
K	RESERVES	30 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
L							

NOTES: (1) THRUST SETTINGS ARE NON-AUGMENTED/AUGMENTED (SEE PARA. 3.11.3.2)
(2) SEE PARA 4.1.5, 4.1.7
(3) LONGER WARM-UP TIMES MAY BE REQUIRED BY ELECTRONICS EQUIPMENT
(4) CLIMB SCHEDULE ENDS AT LONG RANGE CRUISE SPEED/OPTIMUM CRUISE ALTITUDE
(5) CLIMB SCHEDULE ENDS AT PENETRATION SPEED/ALTITUDE

FIGURE D.2-14. Bomber - high-level penetration.

ANNEX 2

AIR DROP/AIR ASSAULT



	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (1)	TAKEOFF TO OPTIMUM CRUISE	MAX CONTINUOUS
C	CRUISE (PARA. 4.2.3)				LONG RANGE CRUISE	OPTIMUM CRUISE	
D	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO 2000 FEET PRESS ALT.	
E	PENETRATION (PARA. 4.2.4)			200 NM	360 KTAS OR $V_{MAX\ CONT}$ WHICHEVER IS LOWER	2000 FEET PRESS ALT.	
F	AIR DROP/AIR ASSAULT	(2)	15 MINUTES	NO CREDIT	DROP SPEED	2000 FEET PRESS ALT.	
G	WITHDRAWAL (PARA. 4.2.4) (3)			200 NM	360 KTAS OR $V_{MAX\ CONT}$ WHICHEVER IS LOWER	2000 FEET PRESS ALT.	
H	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (1)	2000 FEET PRESS ALT. TO OPTIMUM CRUISE	MAX CONTINUOUS
I	CRUISE (PARA. 4.2.3)				LONG RANGE CRUISE	OPTIMUM CRUISE	
J	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
K	RESERVES	30 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
L							

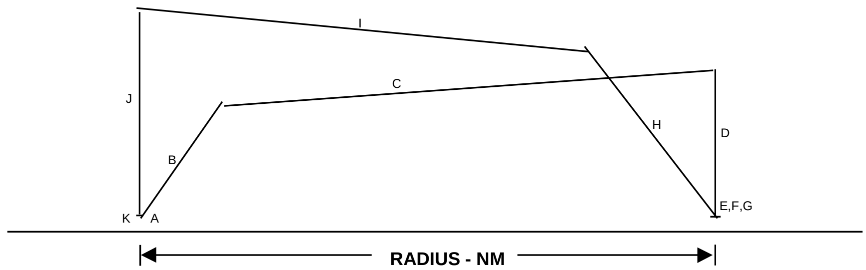
NOTES: (1) CLIMB SCHEDULE ENDS AT LONG RANGE CRUISE SPEED/OPTIMUM CRUISE ALTITUDE

(2) FUEL BURNED IS FOR IG THRUST REQUIRED IN THE AIR DROP CONFIGURATION

(3) INCLUDE FUEL TO ACCELERATE FROM DROP SPEED TO 360 KTAS

FIGURE D.2-15. Air drop/air assault.

CARGO/TRANSPORT SUPPLY - RADIUS

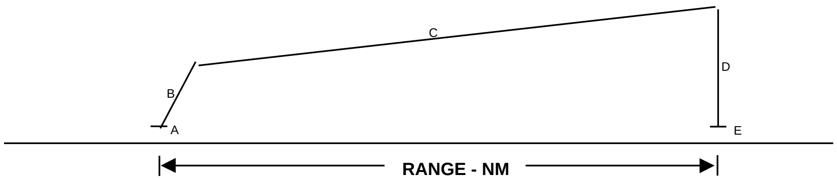


	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (1)	TAKEOFF TO OPTIMUM CRUISE	MAX CONTINUOUS
C	CRUISE (PARA. 4.2.3)				LONG RANGE CRUISE	OPTIMUM CRUISE	
D	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
E	LAND	NONE	NONE	NO CREDIT			
F	LOAD/UNLOAD CARGO/PASSENGERS	NONE	NONE	NONE			
G	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
H	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (1)	LANDING TO OPTIMUM CRUISE	MAX CONTINUOUS
I	CRUISE (PARA. 4.2.3)				LONG RANGE CRUISE	OPTIMUM CRUISE	
J	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
K	RESERVES	30 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
L							

NOTES: (1) CLIMB SCHEDULE ENDS AT LONG RANGE CRUISE SPEED/OPTIMUM CRUISE ALTITUDE

FIGURE D.2-16. Cargo/transport supply - radius.

CARGO/TRANSPORT SUPPLY - RANGE

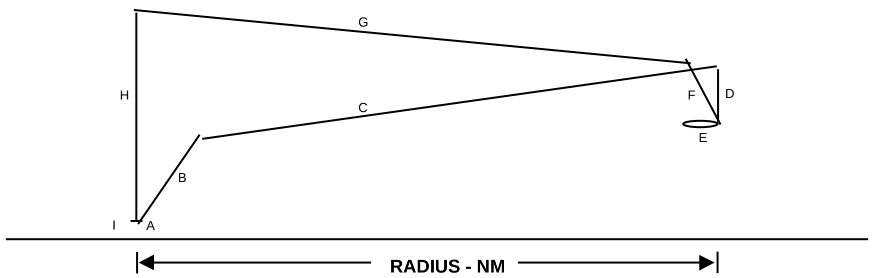


	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (1)	TAKEOFF TO OPTIMUM CRUISE	MAX CONTINUOUS
C	CRUISE (PARA. 4.2.3)				LONG RANGE CRUISE	OPTIMUM CRUISE	
D	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
E	RESERVES	30 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
F							
G							
H							
I							
J							
K							
L							

NOTES: (1) CLIMB SCHEDULE ENDS AT LONG RANGE CRUISE SPEED/OPTIMUM CRUISE ALTITUDE

FIGURE D.2-17. Cargo/transport supply - range.

AIRBORNE WARNING AND CONTROL (AWACS)



	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)			(2)	MINIMUM TIME CLIMB SCHEDULE (1)	TAKEOFF TO OPTIMUM CRUISE	MAX CONTINUOUS
C	CRUISE (PARA. 4.2.3)			600 NM/200 NM (2)	LONG RANGE CRUISE	OPTIMUM CRUISE	
D	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO MISSION ALTITUDE	
E	LOITER (PARA. 4.2.6)			NO CREDIT	MAXIMUM ENDURANCE	MISSION ALTITUDE (3)	
F	CLIMB (PARA. 4.2.2)			(2)	MINIMUM TIME CLIMB SCHEDULE (1)	MISSION ALTITUDE TO OPTIMUM CRUISE	MAX CONTINUOUS
G	CRUISE (PARA. 4.2.3)			600 NM/200NM (2)	LONG RANGE CRUISE	OPTIMUM CRUISE	
H	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
I	RESERVES	30 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
J							
K							
L							

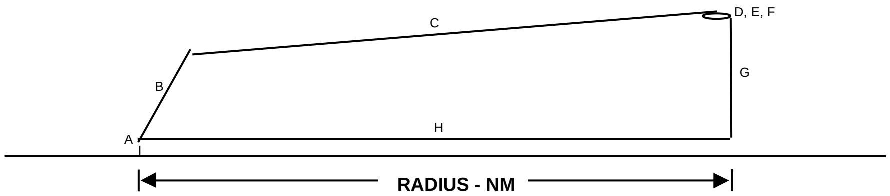
NOTES: (1) CLIMB SCHEDULE ENDS AT LONG RANGE CRUISE SPEED/OPTIMUM CRUISE ALTITUDE

(2) CRUISE DISTANCES ARE LAND BASED/CARRIER BASED AND INCLUDE CLIMB DISTANCES

(3) MISSION ALTITUDE IS THE RADAR OPTIMUM ALTITUDE AS LIMITED BY THE AIRCRAFT

FIGURE D.2-18. Airborne warning and control (AWACS).

CORPS SPECIAL ELECTRONICS MISSION



	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)			(2)	MINIMUM TIME CLIMB SCHEDULE (1)	TAKEOFF TO OPTIMUM CRUISE	INTERMEDIATE
C	CRUISE (PARA. 4.2.3)			110 NM (2)	MAXIMUM CRUISE	OPTIMUM CRUISE	MAX CONTINUOUS
D	LOITER (PARA. 4.2.6)			NO CREDIT	MAXIMUM ENDURANCE	END CRUISE	
E	COMBAT		5 MINUTES	NO CREDIT	MAXIMUM ENDURANCE	END CRUISE	INTERMEDIATE
F	LOITER (PARA. 4.2.6)		1 HOUR	NO CREDIT	MAXIMUM ENDURANCE	END CRUISE	
G	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
H	CRUISE (PARA. 4.2.3)			110 NM	MAXIMUM CRUISE	LANDING	MAX CONTINUOUS
I	RESERVES	30 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
J							
K							
L							

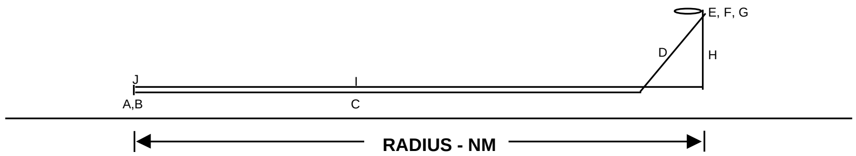
NOTES: (1) CLIMB SCHEDULE ENDS AT OPTIMUM CRUISE SPEED/ALTITUDE

(2) DISTANCE INCLUDES CLIMB FROM TAKEOFF

FIGURE D.2-19. Corps special electronics mission.

ANNEX 2

DIVISION SPECIAL
ELECTRONICS MISSION



	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB			(3)	MINIMUM TIME CLIMB SCHEDULE (1)	TAKEOFF TO 4000 FEET PRESS ALT.	INTERMEDIATE
C	CRUISE (PARA. 4.2.3)			60 NM (3)	MAX RANGE CRUISE	4000 FEET PRESS ALT.	
D	CLIMB (PARA. 4.2.2)			(3)	MINIMUM TIME CLIMB SCHEDULE (2)	4000 FEET PRESS ALT. TO 7000 FEET PRESS ALT.	INTERMEDIATE
E	LOITER (PARA. 4.2.6)			NO CREDIT	MAXIMUM ENDURANCE	7000 FEET PRESS ALT.	
F	COMBAT	SIX 3000 FT ENERGY EXCHANGES @ MAX ENDURANCE SPEED @ IRT. NO DISTANCE CREDIT.					
G	LOITER (PARA. 4.2.6)		1 HOUR	NO CREDIT	MAXIMUM ENDURANCE	7000 FEET PRESS ALT.	
H	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		7000 FEET PRESS ALT. TO 4000 FEET PRESS ALT.	
I	CRUISE (PARA. 4.2.3)			60 NM	MAX RANGE CRUISE	LANDING	
J	RESERVES	30 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	4000 FEET PRESS ALT.	
K							
L							

NOTES: (1) CLIMB SCHEDULE ENDS AT MAXIMUM RANGE CRUISE SPEED AT 2000 FEET PRESSURE ALTITUDE

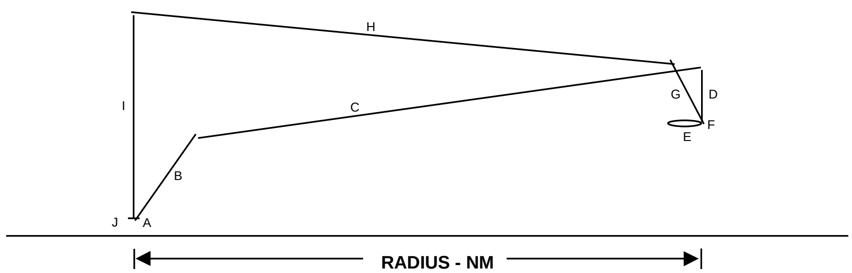
(2) CLIMB SCHEDULE ENDS AT MAXIMUM ENDURANCE SPEED AT LOITER ALTITUDE

(3) INCLUDES CLIMB DISTANCE FROM BOTH ENDS OF CRUISE

FIGURE D.2-20. Division special electronics mission.

ANNEX 2

COMBAT AIR PATROL (CAP)



	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (3)	TAKEOFF TO OPTIMUM CRUISE	INTERMEDIATE
C	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
D	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO 35,000 FEET PRESS ALT.	
E	LOITER (PARA. 4.2.6)		1 HOUR	NO CREDIT	MAXIMUM ENDURANCE	35,000 FEET PRESS ALT.	
F	COMBAT (1), (2)	ONE 360 DEG TURN @ MACH 1.2 (MAX A/B) + TW0 360 DEG TURNS @ MACH 0.9 (MAX A/B). EXPEND HALF OF AMMO AND MISSILES. NO DISTANCE CREDIT.					
G	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (3)	35,000 FEET PRESS ALT. TO OPTIMUM CRUISE	INTERMEDIATE
H	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
I	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
J	RESERVES	20 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
K							
L							

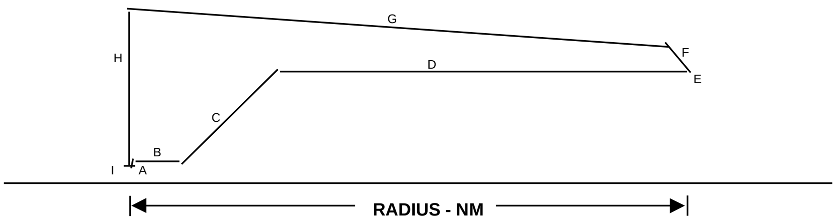
NOTES: (1) SEE PARA 4.1.5, 4.1.7

(2) INCLUDE FUEL TO ACCELERATE TO MACH 1.2

(3) CLIMB SCHEDULE ENDS AT OPTIMUM CRUISE SPEED/ALTITUDE

FIGURE D.2-21. Combat air patrol (CAP).

SUBSONIC INTERCEPT



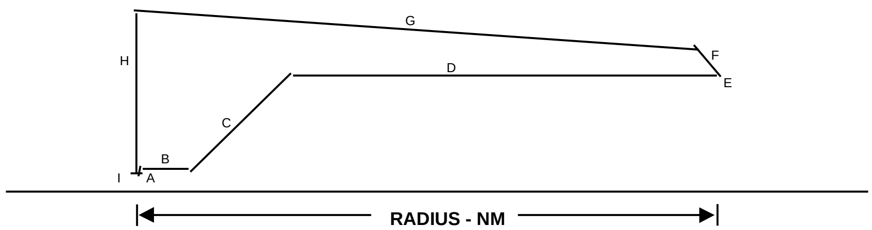
	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING (1)
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED). NO DISTANCE CREDIT.					
B	ACCELERATE				OBSTACLE CLEARANCE TO 0.9 MACH	TAKEOFF	MAXIMUM/MAXIMUM A/B
C	CLIMB (PARA. 4.2.2)				0.9 MACH	TAKEOFF TO 40,000 FEET PRESS ALT.	INTERMEDIATE
D	CRUISE (5)				0.95 MACH OR Virt WHICHEVER IS LOWER	40,000 FEET PRESS ALT.	
E	COMBAT (2), (3)	ONE 180 DEG TURN @ .95 MACH WITH MAX SUSTAINED G's @ MAXIMUM/MAXIMUM A/B. (1) EXPEND HALF OF AMMO AND MISSILES. NO DISTANCE CREDIT.					
F	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (4)	40,000 FEET PRESS ALT. TO OPTIMUM CRUISE	INTERMEDIATE
G	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
H	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
I	RESERVES	20 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
J							
K							
L							

NOTES: (1) THRUST SETTINGS ARE NON-AUGMENTED/AUGMENTED (SEE PARA. 3.11.3.2)
(2) SEE PARA 4.1.5, 4.1.7
(3) INCLUDE ACCELERATION FUEL IF COMBAT SPEED IS GREATER THAN CRUISE SPEED
(4) CLIMB SCHEDULE ENDS AT OPTIMUM CRUISE SPEED/ALTITUDE
(5) INCLUDE ACCELERATION FUEL FROM 0.9 TO 0.95 MACH

FIGURE D.2-22. Subsonic intercept.

ANNEX 2

SUPERSONIC INTERCEPT

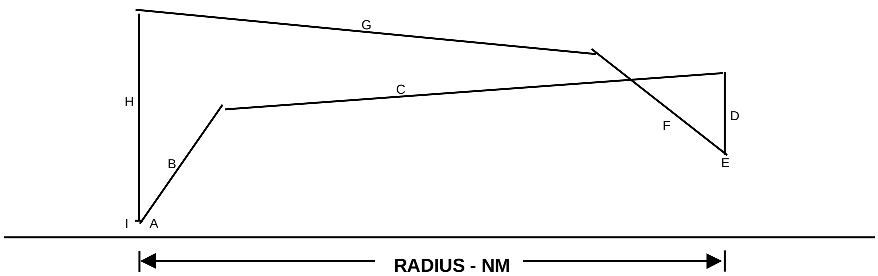


	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING (1)
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED). NO DISTANCE CREDIT.					
B	ACCELERATE				OBSTACLE CLEARANCE TO 0.9 MACH	TAKEOFF	MAXIMUM/MAXIMUM A/B
C	CLIMB (PARA. 4.2.2)				0.9 MACH	TAKEOFF TO 40,000 FEET PRESS ALT.	MAXIMUM/MAXIMUM A/B
D	CRUISE				1.4 MACH OR $V_{MAX/MAX\ A/B}$ WHICHEVER IS LOWER (3)	40,000 FEET PRESS ALT.	
E	COMBAT (2)	ONE 180 DEG TURN @ 1.2 MACH WITH MAX SUSTAINED G's @ MAXIMUM A/B. EXPEND HALF OF AMMO AND MISSILES. NO DISTANCE CREDIT.					
F	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (4)	40,000 FEET PRESS ALT. TO OPTIMUM CRUISE	INTERMEDIATE
G	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
H	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
I	RESERVES	20 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
J							
K							
L							

NOTES: (1) THRUST SETTINGS ARE NON-AUGMENTED/AUGMENTED (SEE PARA. 3.11.3.2)
(2) SEE PARA 4.1.5, 4.1.7
(3) INCLUDE ACCELERATION FUEL TO THE PROPER SPEED
(4) CLIMB SCHEDULE ENDS AT OPTIMUM CRUISE SPEED/ALTITUDE

FIGURE D.2-23. Supersonic intercept.

MEDIUM ALTITUDE FIGHTER SWEEP



	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (3)	TAKEOFF TO OPTIMUM CRUISE	INTERMEDIATE
C	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
D	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO 15,000 FEET PRESS ALT.	
E	COMBAT (1), (2)	ONE 360 DEG TURN @ MACH 1.2 (MAX A/B) + TW0 360 DEG TURNS @ MACH 0.9 (MAX A/B). EXPEND HALF OF AMMO AND MISSILES. NO DISTANCE CREDIT.					
F	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (3)	15,000 FEET PRESS ALT. TO OPTIMUM CRUISE	INTERMEDIATE
G	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
H	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
I	RESERVES	20 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
J							
K							
L							

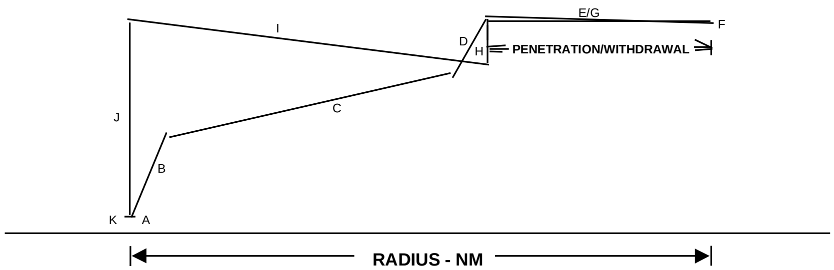
NOTES: (1) SEE PARA 4.1.5, 4.1.7

(2) INCLUDE ACCELERATION FUEL IF THE ENERGY LEVEL AT THE START OF COMBAT IS GREATER THAN THE ENERGY LEVEL AT THE END OF CRUISE.

(3) CLIMB SCHEDULE ENDS AT OPTIMUM CRUISE SPEED/ALTITUDE

FIGURE D.2-24. Medium altitude fighter sweep.

HIGH ALTITUDE FIGHTER SWEEP



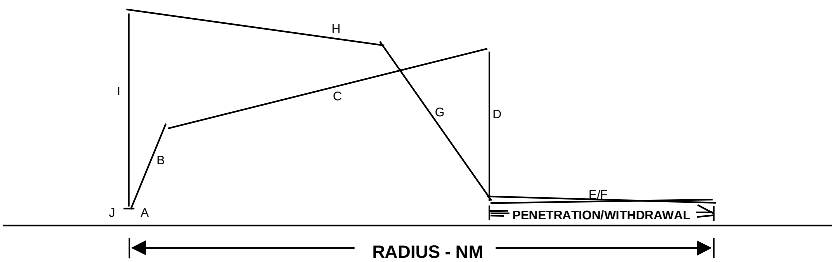
	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (2)	TAKEOFF TO OPTIMUM CRUISE	INTERMEDIATE
C	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
D	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (3)	END CRUISE TO 40,000 FEET PRESS ALT.	INTERMEDIATE
E	PENETRATION (PARA. 4.2.4)			50 NM	Virt	40,000 FEET PRESS ALT.	INTERMEDIATE
F	COMBAT (1)	ONE 180 DEG TURN @END PENETRATION MACH NR WITH MAX SUSTAINED G's @ MAXIMUM/MAXIMUM A/B. (4) EXPEND HALF OF AMMO AND MISSILES. NO DISTANCE CREDIT.					
G	WITHDRAWAL (PARA. 4.2.4)			50 NM	Virt	40,000 FEET PRESS ALT.	INTERMEDIATE
H	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		40,000 FEET PRESS ALT. TO OPTIMUM CRUISE	
I	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
J	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
K	RESERVES	20 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
L							

NOTES: (1) SEE PARA 4.1.5, 4.1.7
(2) CLIMB SCHEDULE ENDS AT OPTIMUM CRUISE SPEED/ALTITUDE
(3) CLIMB SCHEDULE ENDS AT Virt/ 40,000 FEET PRESSURE ALTITUDE
(4) THRUST SETTINGS ARE NON-AUGMENTED/AUGMENTED (SEE PARA. 3.11.3.2)

FIGURE D.2-25. High altitude fighter sweep.

ANNEX 2

RECONNAISSANCE - LOW LEVEL PENETRATION



	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING (1)
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (2)	TAKEOFF TO OPTIMUM CRUISE	MAX CONTINUOUS/ INTERMEDIATE
C	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
D	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO 2000 FEET PRESS ALT.	
E	PENETRATION (PARA. 4.2.4)			50 NM	Virt	2000 FEET PRESS ALT.	INTERMEDIATE
F	WITHDRAWAL (PARA. 4.2.4)			50 NM	Virt	2000 FEET PRESS ALT.	INTERMEDIATE
G	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (2)	2000 FEET PRESS ALT. TO OPTIMUM CRUISE	MAX CONTINUOUS/ INTERMEDIATE
H	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
I	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
J	RESERVES	20 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
K							
L							

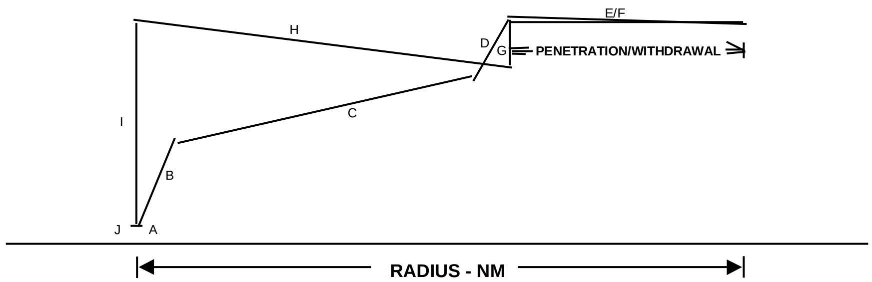
NOTES: (1) THRUST SETTINGS ARE NON-AUGMENTED/AUGMENTED (SEE PARA. 3.11.3.2)

(2) CLIMB SCHEDULE ENDS AT OPTIMUM CRUISE SPEED/ALTITUDE

FIGURE D.2-26. Reconnaissance - low-level penetration.

ANNEX 2

RECONNAISSANCE - HIGH LEVEL PENETRATION



	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING (1)
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (2)	TAKEOFF TO OPTIMUM CRUISE	MAX CONTINUOUS/ INTERMEDIATE
C	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
D	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (3)	END CRUISE TO 40,000 FEET PRESS ALT.	INTERMEDIATE
E	PENETRATION (PARA. 4.2.4)			50 NM	Virt	40,000 FEET PRESS ALT.	INTERMEDIATE
F	WITHDRAWAL (PARA. 4.2.4)			50 NM	Virt	40,000 FEET PRESS ALT.	INTERMEDIATE
G	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		40,000 FEET PRESS ALT. TO OPTIMUM CRUISE	
H	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
I	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
J	RESERVES	20 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
K							
L							

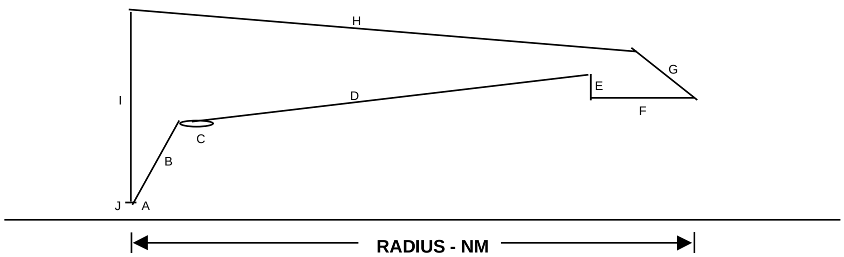
NOTES: (1) THRUST SETTINGS ARE NON-AUGMENTED/AUGMENTED (SEE PARA. 3.11.3.2)

(2) CLIMB SCHEDULE ENDS AT OPTIMUM CRUISE SPEED/ALTITUDE

(3) CLIMB SCHEDULE ENDS AT Virt/ 40,000 FEET PRESSURE ALTITUDE

FIGURE D.2-27. Reconnaissance - high-level penetration.

TANKER - BUDDY REFUEL MISSION



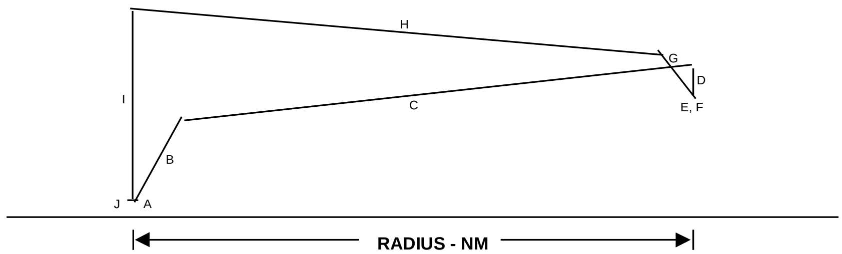
	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (1)	TAKEOFF TO OPTIMUM CRUISE	MAX CONTINUOUS
C	RENDEZVOUS WITH RECEIVER		10 MINUTES	NO CREDIT	MAXIMUM ENDURANCE	OPTIMUM CRUISE	
D	CRUISE (PARA. 4.2.3)				LONG RANGE CRUISE	OPTIMUM CRUISE	
E	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO REFUEL	
F	HOOKUP AND TRANSFER FUEL		(2)		(2)	(2)	
G	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (1)	REFUEL TO OPTIMUM CRUISE	MAX CONTINUOUS
H	CRUISE (PARA. 4.2.3)				LONG RANGE CRUISE	OPTIMUM CRUISE	
I	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
J	RESERVES	30 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
K							
L							

NOTES: (1) CLIMB SCHEDULE ENDS AT LONG RANGECRUISE SPEED/OPTIMUM CRUISE ALTITUDE

(2) REFUELING SPEED, TIME, AND ALTITUDE ARE DEPENDENT ON THE AIRCRAFT BEING REFUELED. THESE CHARACTERISTICS MUST BE KNOWN TO CALCULATE TANKER MISSION PERFORMANCE. DISTANCE FLOWN DURING REFUELING IS CREDITED TO THE OUTBOUND LEG.

FIGURE D.2-28. Tanker - buddy refuel mission.

TANKER - RENDEZVOUS
REFUEL MISSION



	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (1)	TAKEOFF TO OPTIMUM CRUISE	MAX CONTINUOUS
C	CRUISE (PARA. 4.2.3)				LONG RANGECRUISE	OPTIMUM CRUISE	
D	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO REFUEL	
E	LOITER (PARA. 4.2.6)		1 HOUR	NO CREDIT	MAXIMUM ENDURANCE	REFUELING	
F	HOOKUP AND TRANSFER FUEL (PARA. 4.2.7)		(2)	NO CREDIT (3)	(2)	(2)	
G	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (1)	REFUEL TO OPTIMUM CRUISE	MAX CONTINUOUS
H	CRUISE (PARA. 4.2.3)				LONG RANGE CRUISE	OPTIMUM CRUISE	
I	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
J	RESERVES	30 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
K							
L							

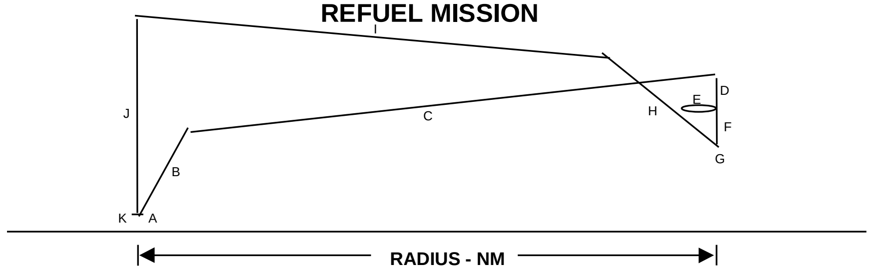
NOTES: (1) CLIMB SCHEDULE ENDS AT LONG RANGE CRUISE SPEED/OPTIMUM CRUISE ALTITUDE

(2) REFUELING SPEED, TIME, AND ALTITUDE ARE DEPENDENT ON THE AIRCRAFT BEING REFUELED. THESE CHARACTERISTICS MUST BE KNOWN TO CALCULATE TANKER MISSION PERFORMANCE.

(3) CREDIT DISTANCE FOR REFUELING BOMBERS AND CARGO/ TRANSPORTS

FIGURE D.2-29. Tanker - rendezvous refuel mission.

NAVY TANKER - RENDEZVOUS
REFUEL MISSION



	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (1)	TAKEOFF TO OPTIMUM CRUISE	INTERMEDIATE
C	CRUISE (PARA. 4.2.3)				LONG RANGECRUISE	OPTIMUM CRUISE	
D	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO MAXIMUM ENDURANCE	
E	LOITER (PARA. 4.2.6)		1 HOUR	NO CREDIT	MAXIMUM ENDURANCE	MAXIMUM ENDURANCE	
F	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		MAXIMUM ENDURANCE TO 5000 PRESS ALT.	
G	HOOKUP AND TRANSFER FUEL (PARA. 4.2.7)		(2)	NO CREDIT	(2)	(2)	
H	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (1)	5000 FEET PRESS ALT. TO OPTIMUM CRUISE	INTERMEDIATE
I	CRUISE (PARA. 4.2.3)				LONG RANGE CRUISE	OPTIMUM CRUISE	
J	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
K	RESERVES	20 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
L							

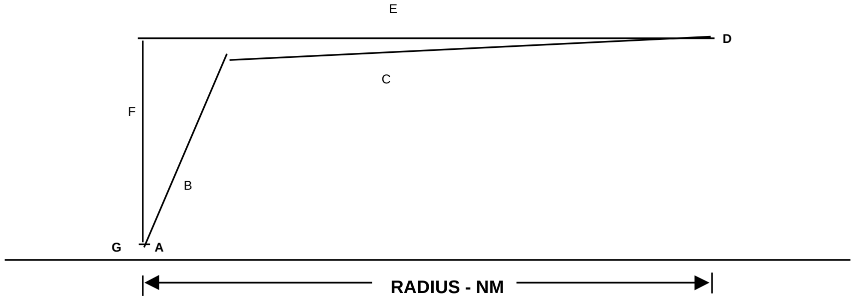
NOTES: (1) CLIMB SCHEDULE ENDS AT LONG RANGE CRUISE SPEED/OPTIMUM CRUISE ALTITUDE

(2) REFUELING SPEED, TIME, AND ALTITUDE ARE DEPENDENT ON THE AIRCRAFT BEING REFUELED. THESE CHARACTERISTICS MUST BE KNOWN TO CALCULATE TANKER MISSION PERFORMANCE.

FIGURE D.2-30. Navy tanker - rendezvous refuel mission.

ANNEX 2

BASIC TRAINER - FAMILIARIZATION



	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)			(2)	MINIMUM TIME CLIMB SCHEDULE (1)	TAKEOFF TO 20,000 FEET PRESS ALT.	INTERMEDIATE
C	CRUISE (PARA. 4.2.3)			50 NM (2)	MAXIMUM RANGE CRUISE	20,000 FEET PRESS ALT.	
D	AIRWORK SEGMENT			NO CREDIT	MAXIMUM RANGE CRUISE	20,000 FEET PRESS ALT.	
E	CRUISE (PARA. 4.2.3)			50 NM	MAXIMUM RANGE CRUISE	20,000 FEET PRESS ALT.	
F	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
G	RESERVES	20 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
H							
I							
J							
K							
L							

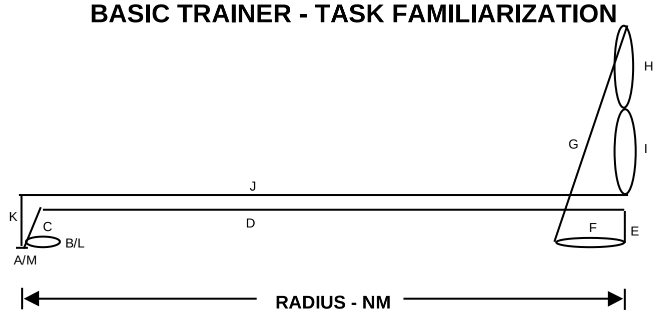
NOTES: (1) CLIMB SCHEDULE ENDS AT MAXIMUM RANGE CRUISE SPEED AT 20,000 FEET PRESS ALT.

(2) 50 NM INCLUDES CLIMB DISTANCE.

FIGURE D.2-31. Basic trainer - familiarization.

ANNEX 2

BASIC TRAINER - TASK FAMILIARIZATION



	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, & ACCEL TO PATTERN SPEED	20 MIN @ GROUND IDLE + FUEL TO ACCELERATE TO PATTERN SPEED AND CLIMB FROM SL TO 1000 FEET @ MAX THRUST. NO DISTANCE CREDIT. (1)					
B	VFR PATTERN	ONE PATTERN CONSISTING OF FUEL FOR 13 NM @ 1000 FEET PRESS ALT. @ PATTERN SPEED + FUEL TO ACCELERATE TO PATTERN SPEED AND CLIMB FROM SL TO 1000 FEET @ MAX THRUST. NO DISTANCE CREDIT. (1)					
C	CLIMB (PARA. 4.2.2)			(3)	MINIMUM TIME CLIMB SCHEDULE (2)	1000 FEET PRESS ALT. TO 5000 FEET PRESS ALT.	INTERMEDIATE
D	CRUISE (PARA. 4.2.3)			45 NM (3)	MAXIMUM RANGE CRUISE	5000 FEET PRESS ALT.	
E	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		5000 FEET PRESS ALT. TO 1000 FEET PRESS ALT.	
F	VFR PATTERN	FOUR PATTERNS EACH CONSISTING OF FUEL FOR 13 NM @ 1000 FEET PRESS ALT. @ PATTERN SPEED + FUEL TO ACCELERATE TO PATTERN SPEED AND CLIMB FROM SL TO 1000 FEET @ MAX THRUST. NO DISTANCE CREDIT. (1)					
G	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (2)	1000 FEET PRESS ALT. TO 22,000 FEET PRESS ALT.	INTERMEDIATE
H	MANEUVER		10 MINUTES		MAXIMUM RANGE CRUISE + 20 KCAS	18,500 FEET PRESS ALT. (4)	
I	MANEUVER				MAXIMUM RANGE CRUISE + 20 KCAS	10,500 FEET PRESS ALT. (5)	
J	CRUISE (PARA. 4.2.3)			45 NM	MAXIMUM RANGE CRUISE	6000 FEET PRESS ALT.	
K	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		6000 FEET PRESS ALT. TO 1000 FEET PRESS ALT.	
L	VFR PATTERN	TWO PATTERNS EACH CONSISTING OF FUEL FOR 13 NM @ 1000 FEET PRESS ALT. @ PATTERN SPEED + FUEL TO ACCELERATE TO PATTERN SPEED AND CLIMB FROM SL TO 1000 FEET @ MAX THRUST. NO DISTANCE CREDIT. (1)					
M	RESERVES	20 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	

NOTES: (1) PATTERN SPEED IS 120 PERCENT OF APPROACH SPEED (GEAR AND FLAPS DOWN)

(2) CLIMB SCHEDULE ENDS AT MAX RANGE CRUISE SPEED/CRUISE ALTITUDE

(3) 45 NM INCLUDES CLIMB DISTANCE

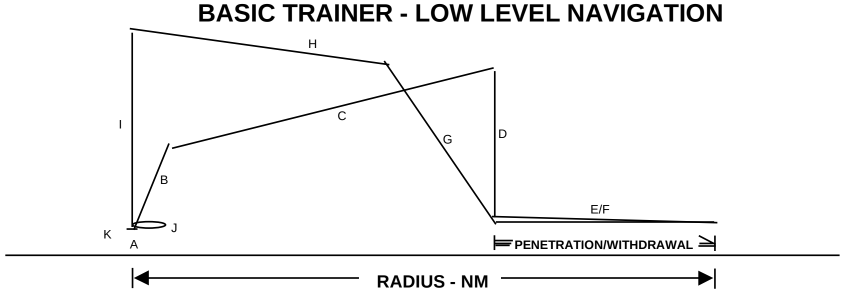
(4) MANEUVER IS CALCULATED AT THE AVERAGE ALTITUDE AS THE AIRCRAFT DESCENDS THROUGH THE ALTITUDE BAND FROM 22,000 TO 15,000 FEET PRESS ALT.

(5) MANEUVER IS CALCULATED AT THE AVERAGE ALTITUDE AS THE AIRCRAFT DESCENDS THROUGH THE ALTITUDE BAND FROM 15,000 TO 6,000 FEET PRESS ALT.

FIGURE D.2-32. Basic trainer - task familiarization.

ANNEX 2

BASIC TRAINER - LOW LEVEL NAVIGATION



	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + FUEL TO ACCELERATE TO CLIMB SPEED AND CLIMB FROM SL TO 1000 FEET @ MAX THRUST. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)			(2)	MINIMUM TIME CLIMB SCHEDULE (1)	1000 FEET PRESS ALT. TO 5000 FEET PRESS ALT.	INTERMEDIATE
C	CRUISE (PARA. 4.2.3)			45 NM (2)	MAXIMUM RANGE CRUISE	5000 FEET PRESS ALT.	INTERMEDIATE
D	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		5000 FEET PRESS ALT. TO 1000 FEET PRESS ALT.	
E	PENETRATION				250 KTAS	1000 FEET PRESS ALT.	
F	WITHDRAWAL				250 KTAS	1000 FEET PRESS ALT.	
G	CLIMB (PARA. 4.2.2)			(2)	MINIMUM TIME CLIMB SCHEDULE (1)	1000 FEET PRESS ALT. TO 5000 FEET PRESS ALT.	INTERMEDIATE
H	CRUISE (PARA. 4.2.3)			45 NM (2)	MAXIMUM RANGE CRUISE	5000 FEET PRESS ALT.	
I	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		5000 FEET PRESS ALT. TO 1000 FEET PRESS ALT.	
J	VFR PATTERN	THREE PATTERNS EACH CONSISTING OF FUEL FOR 13 NM @ 1000 FEET PRESS ALT. @ PATTERN SPEED + FUEL TO ACCELERATE TO PATTERN SPEED AND CLIMB FROM SL TO 1000 FEET @ MAX THRUST. NO DISTANCE CREDIT. (3)					
K	RESERVES	20 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
L							

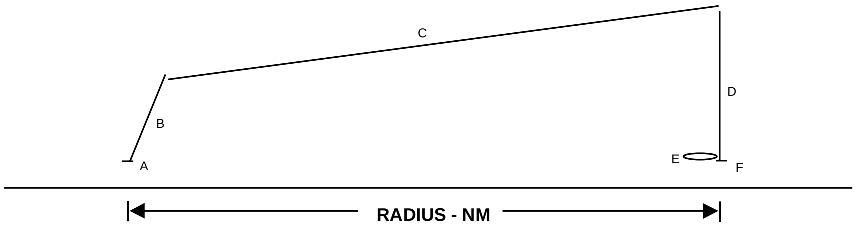
NOTES: (1) CLIMB SCHEDULE ENDS AT MAX RANGE CRUISE SPEED/CRUISE ALTITUDE

(2) 45 NM INCLUDES CLIMB DISTANCE

(3) PATTERN SPEED IS 120 PERCENT OF APPROACH SPEED (GEAR AND FLAPS DOWN)

FIGURE D.2-33. Basic trainer - low-level navigation.

BASIC TRAINER - HIGH LEVEL NAVIGATION



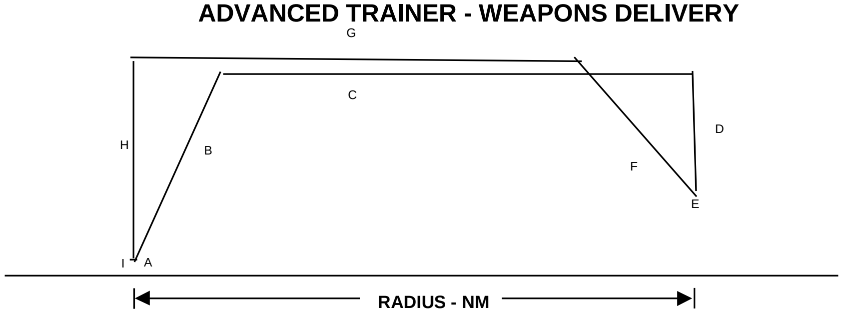
	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + FUEL TO ACCELERATE TO CLIMB SPEED AND CLIMB FROM SL TO 1000 FEET @ MAX THRUST. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (1)	1000 FEET PRESS ALT. TO OPTIMUM CRUISE	INTERMEDIATE
C	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE	OPTIMUM CRUISE	
D	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO 4000 FEET PRESS ALT.	
E	IFR PATTERN	THREE PATTERNS EACH CONSISTING OF FUEL FOR 50 NM @ 4000 FEET PRESS ALT. @ PATTERN SPEED + FUEL TO ACCELERATE TO PATTERN SPEED AND CLIMB FROM SL TO 1000 FEET @ MAX THRUST. NO DISTANCE CREDIT. (2)					
F	RESERVES	20 MIN + 5 % OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
G							
H							
I							
J							
K							
L							
M							

NOTES: (1) CLIMB SCHEDULE ENDS AT OPTIMUM CRUISE SPEED/ALTITUDE

(2) PATTERN SPEED IS 120 PERCENT OF APPROACH SPEED (GEAR AND FLAPS DOWN)

FIGURE D.2-34. Basic trainer - high-level navigation.

ADVANCED TRAINER - WEAPONS DELIVERY



	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)			(2)	MINIMUM TIME CLIMB SCHEDULE (1)	TAKEOFF TO 20,000 FEET PRESS ALT.	INTERMEDIATE
C	CRUISE (PARA. 4.2.3)			50 NM (2)	MAXIMUM RANGE CRUISE	20,000 FEET PRESS ALT.	
D	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		20,000 FEET PRESS ALT. TO 1000 FEET PRESS ALT.	
E	COMBAT	A VARIABLE NUMBER OF "RUNS" WHICH EACH CONSIST OF A 360 DEG TURN WITH MAX SUSTAINED G's @ SUSTAINED CORNER SPEED @ INTERMEDIATE THRUST FOLLOWED BY A 5000 FOOT ENERGY EXCHANGE. EXPEND STORES AFTER LAST RUN. NO DISTANCE CREDIT.					
F	CLIMB (PARA. 4.2.2)			(2)	MINIMUM TIME CLIMB SCHEDULE (1)	1000 FEET PRESS ALT. TO 20,000 FEET PRESS ALT.	INTERMEDIATE
G	CRUISE (PARA. 4.2.3)			50 NM (2)	MAXIMUM RANGE CRUISE	20,000 FEET PRESS ALT.	
H	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		20,000 FEET PRESS ALT. TO LANDING	
I	RESERVES	20 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
J							
K							
L							

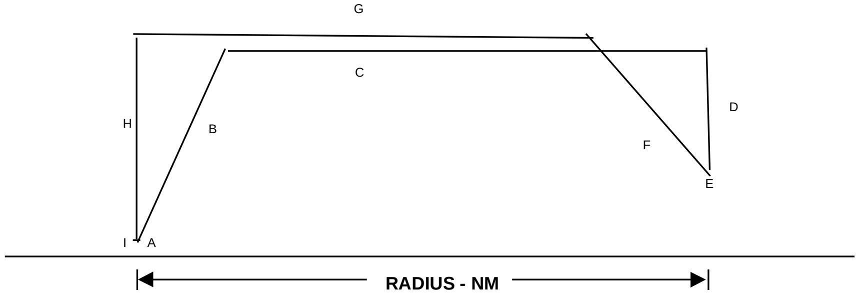
NOTES: (1) CLIMB SCHEDULE ENDS AT MAXIMUM RANGE CRUISE SPEED AT 20,000 FEET.

(2) 50 NM INCLUDES CLIMB DISTANCE

FIGURE D.2-35. Advanced trainer - weapons delivery.

ANNEX 2

ADVANCED TRAINER - AIR COMBAT MANEUVERING



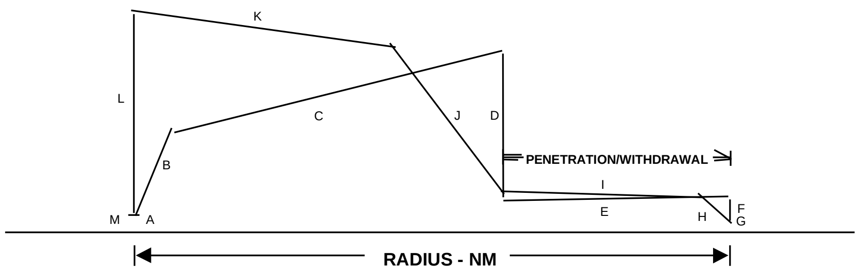
	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)			(2)	MINIMUM FUEL CLIMB SCHEDULE (1)	TAKEOFF TO 20,000 FEET PRESS ALT.	INTERMEDIATE
C	CRUISE (PARA. 4.2.3)			50 NM (2)	MAXIMUM RANGE CRUISE	20,000 FEET PRESS ALT.	
D	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		20,000 FEET PRESS ALT. TO 10,000 FEET PRESS ALT.	
E	COMBAT	THREE 360 DEG TURNS WITH MAX SUSTAINED G's @ SUSTAINED CORNER SPEED @ INTERMEDIATE THRUST FOLLOWED BY A VARIABLE HEIGHT ENERGY EXCHANGE.					
F	CLIMB (PARA. 4.2.2)			(2)	MINIMUM FUEL CLIMB SCHEDULE (1)	10,000 FEET PRESS ALT. TO 20,000 FEET PRESS ALT.	INTERMEDIATE
G	CRUISE (PARA. 4.2.3)			50 NM (2)	MAXIMUM RANGE CRUISE	20,000 FEET PRESS ALT.	
H	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
I	RESERVES	20 MIN + 5 % OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
J							
K							
L							

NOTES: (1) CLIMB SCHEDULE ENDS AT MAXIMUM RANGECRUISE SPEED AT 20,000 FEET.

(2) 50 NM INCLUDES CLIMB DISTANCE

FIGURE D.2-36. Advanced trainer - air combat maneuvering.

FORWARD AIR CONTROL (FAC)

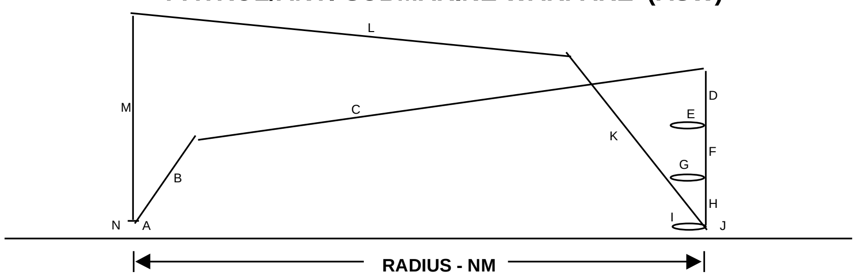


	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)			(3)	MINIMUM TIME CLIMB SCHEDULE (1)	TAKEOFF TO OPTIMUM CRUISE	INTERMEDIATE
C	CRUISE (PARA. 4.2.3)			150 NM (3)	OPTIMUM CRUISE	OPTIMUM CRUISE	
D	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO 5000 FEET PRESS ALT.	
E	PENETRATION (PARA. 4.2.4)				MAXIMUM CRUISE	5000 FEET PRESS ALT.	MAX CONTINUOUS
F	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		5000 FEET PRESS ALT. TO 2000 FEET PRESS ALT.	
G	COMBAT (2)		10 MINUTES	NO CREDIT	Virt	2000 FEET PRESS ALT.	INTERMEDIATE
H	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (4)	2000 FEET PRESS ALT. TO 5000 FEET PRESS ALT.	INTERMEDIATE
I	WITHDRAWAL (PARA. 4.2.4)				MAXIMUM CRUISE	5000 FEET PRESS ALT.	MAX CONTINUOUS
J	CLIMB (PARA. 4.2.2)			(3)	MINIMUM TIME CLIMB SCHEDULE (1)	5000 FEET PRESS ALT. TO OPTIMUM CRUISE	INTERMEDIATE
K	CRUISE (PARA. 4.2.3)			150 NM (3)	OPTIMUM CRUISE	OPTIMUM CRUISE	
L	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
M	RESERVES	20 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	

NOTES: (1) CLIMB SCHEDULE ENDS AT OPTIMUM CRUISE SPEED/ALTITUDE
(2) SEE PARA 4.1.5, 4.1.7
(3) 150 NM INCLUDES CLIMB DISTANCE
(4) CLIMB SCHEDULE ENDS AT MAX CRUISE SPEED/5000 FEET

FIGURE D.2-37. Forward air control (FAC).

PATROL/ANTI-SUBMARINE WARFARE (ASW)

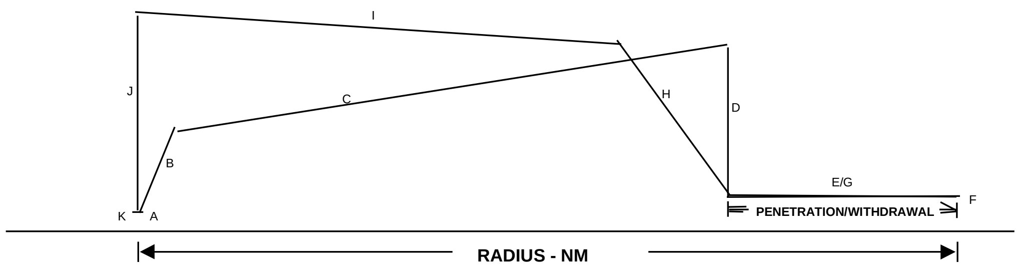


	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (1)	TAKEOFF TO OPTIMUM CRUISE	INTERMEDIATE
C	CRUISE (PARA. 4.2.3)				LONG RANGECRUISE	OPTIMUM CRUISE	
D	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO 20,000 FEET PRESS ALT.	
E	LOITER (PARA. 4.2.6)		1 HOUR	NO CREDIT	MAXIMUM ENDURANCE	20,000 FEET PRESS ALT.	
F	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		20,000 FEET PRESS ALT. TO 5,000 FEET PRESS ALT.	
G	LOITER (PARA. 4.2.6)		2 HOUR	NO CREDIT	MAXIMUM ENDURANCE	5,000 FEET PRESS ALT.	
H	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		5,000 FEET PRESS ALT. TO 200 FEET PRESS ALT.	
I	LOITER (PARA. 4.2.6)		1 HOUR	NO CREDIT	MAXIMUM ENDURANCE	200 FEET PRESS ALT.	
J	COMBAT	CLIMB TO 5000 FEET PRESS ALT. @ BEST CLIMB SPEED @ INTERMEDIATE THRUST AND DESCEND BACK TO 200 FEET PRESS ALT. CLIMB TIME AND FUEL AND DESCENT TIME ARE ACCOUNTED FOR. ALL STORES ARE RETAINED.					
K	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (1)	200 FEET PRESS ALT. TO OPTIMUM CRUISE	INTERMEDIATE
L	CRUISE (PARA.4.2.3)				LONG RANGE CRUISE	OPTIMUM CRUISE	
M	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
N	RESERVES	20 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	

NOTES: (1) CLIMB SCHEDULE ENDS AT LONG RANGE CRUISE SPEED/OPTIMUM CRUISE ALTITUDE

FIGURE D.2-38. Patrol/anti-submarine warfare (ASW).

MINELAYING



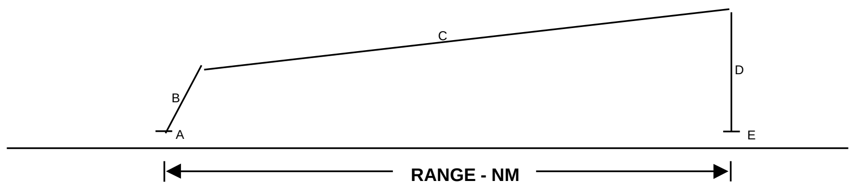
	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (1)	TAKEOFF TO OPTIMUM CRUISE	INTERMEDIATE
C	CRUISE (PARA. 4.2.3)				LONG RANGE CRUISE	OPTIMUM CRUISE	
D	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO 200 FEET PRESS ALTITUDE	
E	PENETRATION (PARA. 4.2.4)			300 NM/50 NM (4)	MAXIMUM CRUISE	200 FT PRESS ALT.	MAX CONTINUOUS
F	COMBAT (2), (3)	TIME AND FUEL FOR A 50 NM RUN @ Virt, 200 FT PRESS ALT. NO DISTANCE CREDITED. EXPEND STORES AFTER COMBAT					
G	WITHDRAWAL (PARA. 4.2.4)			300 NM/50 NM (4)	MAXIMUM CRUISE	200 FT PRESS ALT.	MAX CONTINUOUS
H	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (1)	200 FEET PRESS ALT. TO OPTIMUM CRUISE	INTERMEDIATE
I	CRUISE (PARA. 4.2.3)				LONG RANGE CRUISE	OPTIMUM CRUISE	
J	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
K	RESERVES	20 MIN + 5% OF INITIAL FUEL		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
L							

NOTES: (1) CLIMB SCHEDULE ENDS AT LONG RANGE CRUISE SPEED/OPTIMUM CRUISE ALTITUDE
(2) SEE PARA 4.1.5, 4.1.7
(3) INCLUDE FUEL FOR ACCELERATION TO COMBAT SPEED
(4) 50 NM IS THE DISTANCE FOR TACTICAL AIRCRAFT

FIGURE D.2-39. Minelaying.

ANNEX 2

FERRY MISSION



	SEGMENT	FUEL	TIME	DISTANCE	SPEED	ALTITUDE	THRUST SETTING (1)
A	WARM-UP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED	20 MIN @ GROUND IDLE + 30 SEC @ TAKEOFF / MAXIMUM / IRT (A/B IF REQUIRED) + FUEL TO ACCEL FROM OBSTACLE CLEARANCE TO CLIMB SPEED @ IRT. NO DISTANCE CREDIT.					
B	CLIMB (PARA. 4.2.2)				MINIMUM TIME CLIMB SCHEDULE (2)	TAKEOFF TO OPTIMUM CRUISE	MAX CONTINUOUS OR IRT / IRT
C	CRUISE (PARA. 4.2.3)				OPTIMUM CRUISE (4)	OPTIMUM CRUISE	
D	DESCENT (PARA. 4.2.8)	NONE	NONE	NO CREDIT		END CRUISE TO LANDING	
E	RESERVES	20 MIN + 5% OF INITIAL FUEL (3)		NO CREDIT	MAXIMUM ENDURANCE	SEA LEVEL	
F							
G							
H							
I							
J							
K							
L							

NOTES: (1) THRUST SETTINGS ARE NON-AUGMENTED/AUGMENTED.

(2) CLIMB SCHEDULE ENDS AT OPTIMUM CRUISE SPEED/ALTITUDE

(3) FOR BOMBER AND CARGO/TRANSPORT USE 30 MIN + 5% OF INITIAL FUEL

(4) FOR BOMBER AND CARGO/TRANSPORT USE LONG RANGE CRUISE SPEED

FIGURE D.2-40. Ferry mission.

AIR VEHICLE

JOINT SERVICE SPECIFICATION GUIDE

APPENDIX E

JOINT SERVICE ROTARY WING AIR VEHICLE FLIGHT PERFORMANCE DESCRIPTIONS

Note: A DRAFT military standard comprises the contents of the following Appendix E information (see E.1.0 through E.1.2).

DRAFT
MIL-STD-XXXX

"**NOTE**: This draft MIL-STD, prepared by the Joint Aircraft Commanders Group Flight Performance Rotary Wing Sub Group has not been approved and is subject to modification. It is NOT approved for use as a MIL-STD, but is included in the Air Vehicle JSSG as an aid to help tailor JSSG requirements for use in development of a specific program specification.

MILITARY STANDARD

JOINT SERVICE ROTARY WING AIR VEHICLE FLIGHT PERFORMANCE DESCRIPTION

E.1.0 SCOPE

E.1.1 Scope.

This draft military standard (JSSG-2001 Appendix E) specifies the flight performance data essential to document the characteristics and capabilities of a rotary wing air vehicle. It is the purpose of this standard to supply the Government with a clear and complete documentation of the air vehicle flight performance at a level of detail which is consistent with the current stage of design/development of the aircraft. Therefore, the data requirements are divided into three levels: Level I, Level II, and Level III. Level I (the minimum requirement) addresses the level of detail which would be available during the late conceptual design or early preliminary design stage of the air vehicle. Level II addresses the level of detail which would be available during the late preliminary design or early detailed design stage. Level III addresses the level of detail which would be available during the late detailed design or flight test stage. Each level is intended to be consistent with the corresponding level in ADS-10, Air Vehicle Technical Description (Reference a). At the discretion of the Government, selected sections of this draft standard may be added to or deleted. Exceptions to these requirements should be discussed with the appropriate technical representatives of the Government.

E.1.2 Use of Appendix E.

The information contained in this appendix is derived from a draft of a military standard that has not been published. It is included in the Air Vehicle JSSG to assist in tailoring requirements for the development of a specific air vehicle program specification. Table E-I provides the document user a linking tool to the paragraphs (digital viewers can click on the page number to hyperlink to the requirement).

TABLE E-I. Contents.

TABLE E-I. Contents. - Continued

TABLE E-I. Contents. - Continued

TABLE E-I. Contents. - Continued

TABLE E-I. Contents. - Continued

E.1.3 Purpose. This draft military standard (JSSG-2001 Appendix E) is a communications tool. It provides a standard set of data requirements for use by an offeror in providing documentation of air vehicle flight performance to the Government. Standardization of requirements is expected to greatly improve the clarity of communication between the offeror and the Government technical community. An effort has been made to be as general as possible to allow for documentation of unconventional configurations. It is inevitable, however, that designs will be developed which cannot be adequately documented by rigidly following this draft standard. In that case, it is important that the offeror keep in mind the purpose of this draft standard as a communications tool and modify the requirements to adequately describe the air vehicle flight performance.

E.1.4 Quantity of data. This draft standard is intended to prescribe a minimum quantity of documentation at each Level. If the offeror feels that supplementary information will improve the Government's understanding of the design, then such descriptions should be added.

E.1.5 Revisions. Revisions to the charts should be prepared and submitted by the contractor throughout the life of the contract unless specified otherwise by the Procuring Agency. Revisions are required whenever significant changes in vehicle configuration or data occur; for example,

1. A change in vehicle dimensions.

2. An accumulation of weight changes resulting in a significant performance change (Paragraph E.1.4).

3. A change in power plant designation, augmentation, or power plant rating.

4. The addition of external stores.

5. The availability of test data or new test data showing significant performance change (Paragraph E.1.4).

6. When specifically directed by the Procuring Agency.

E.1.6 Criteria. The following criteria will be used in forming a judgment as to whether a significant change in performance exits:

1. A change of 5 percent or more in drag.

2. A change of 5 percent or more in installed thrust (power).

3. A change of 5 percent or more in specific fuel consumption.

4. A change in weight which in itself results in a 5 percent or greater change in mission radius or range.

5. Any combination of two or more of the above resulting in a change of 5 percent or more in mission radius or range.

E.2.0 APPLICABLE DOCUMENTS

E.2.1 Referenced documents.

ADS-10B, "Air Vehicle Technical Description", US Army Aviation Systems Command, St. Louis, MO, October 1982.

E.3.0 DEFINITION OF TERMS

E.3.1 Abbreviation/acronym list.

AEFA	Army Engineering Flight Test Activity
AE	All engines operative
AE	All engines inoperative
ASW	Anti-submarine warfare
ASUW	Anti-surface warfare
BTU	British thermal units
C	Temperature in degrees Celsius or Centigrade
CAS	Close air support
C_D	Isolated rotor propulsive force(drag) coefficient (wind axis)
C_H	Isolated rotor propulsive force Coefficient (shaft axis)
C_L	Isolated rotor lift coefficient (wind axis)
C_N	Yawing moment coefficient
C_P	Engine power or rotor power coefficient
C_{Pc}	Engine power coefficient required for VROC.
C_{Ph}	Engine power coefficient required for HOGE.
C_T	Isolated rotor thrust coefficient (along shaft)
C_W	Air vehicle weight coefficient
CDRL	Contract data requirements list
C.G.	Aircraft center of gravity
CP	Contingency power (2.5-minute limit in OEI conditions)
D_e	Equivalent main rotor drag
ECS	Environmental control system
ECU	Environmental control unit
F	Temperature in degrees Fahrenheit
Fe	Equivalent flat plate drag area
FM	Figure of merit
ft	Feet
FUL	Fixed useful load
g	Acceleration due to gravity
gal	gallons
GPV	Generalized power variation: $(C_{ph} - C_{Pc})/(0.707{*}C_W^{1.5})$
GW	Aircraft weight
H	Geopotential altitude
H_d	Density altitude (geopotential)
Hg	Mercury
H_p	Pressure altitude (geopotential)
HOGE	Hover out of ground effect
HIGE	Hover in ground effect
IAW	In accordance with
ICAO	International Civil Aviation Organization
IGE	In ground effect (height above ground measured from extended landing gear)
IRP	Intermediate rated power (30-minute limit), military rated power
KCAS	Knots calibrated airspeed
KEAS	Knots equivalent airspeed

KIAS	Knots indicated airspeed
KTAS	Knots true airspeed
L/D_e	Ratio of lift to equivalent drag (total air vehicle)
lb	Pounds
MAGW	Maximum alternate gross weight
MCP	Maximum continuous power, normal rated power
min	Minutes
MRP	Maximum rated power (10-minute limit)
nm	Nautical mile
N_r	Rotor RPM
n_z	Normal load factor (body axes)
OEI	One engine inoperative
OGE	Out of ground effect
OWE	Operating weight empty
P	Static pressure
PMGW	Primary mission gross weight
P_s	Specific excess power
q	Dynamic pressure
r	Main rotor local radius
R	Main rotor radius
RFP	Request for proposal
RFQ	Request for quotation
ROC	Rate of climb
ROD	Rate of descent
S	Reference wing area
sec	Second
SL	Sea level
SLS	Sea level, standard temperature
SOW	Statement of work
SR	Specific range
STOL	Short take-off and landing
T	Temperature
TOGW	Take-off gross weight
TSFC	Thrust specific fuel consumption
V	Airspeed
V_{BE}	Airspeed for best endurance: the airspeed for minimum fuel flow
V_{BR}	Airspeed for maximum specific range
V_{LRC}	Airspeed for 99% of best range: the higher of the two airspeeds at which the value of specific range is 99% of its maximum (i.e., measured on the high side of the maximum).
VROC	Vertical rate of climb
V_{climb}	Airspeed for best rate of climb
V_{dive}	Maximum speed in a dive
V_H	Maximum level flight speed
V_{NE}	Never exceed speed
V_{rot}	Rotation speed
V_{stall}	Stall speed
VSTOL	Vertical/short take-off and landing
VTOL	Vertical take-off and landing

V_T	Rotor tip speed
VVR	Vertical velocity ratio: VROC/(ΩR*sqrt(C_W/2))
WE	Weight empty
WOD	Wind-over-deck
W_f	Engine fuel flow
ZFW	Zero fuel weight
ZFZP	Zero fuel zero payload (weight)
α_s	Main rotor shaft angle with respect to wind.
α_{tpp}	Main rotor tip path plane angle w.r.t. wind.
δ	Delta, pressure ratio
μ	Mu, advance ratio, V/ΩR
π	Pi, constant 3.141592654
θ	Theta, temperature ratio
ρ	Rho, air density
ρ_0	Rho, air density at standard day, sea level
σ	Sigma, geometric rotor solidity
σ'	Sigma, density ratio
σ_T	Sigma, thrust-weighted rotor solidity
Ω	Omega, rotor rotational speed

E.3.2 Nondimensionalization.

Rotor system dimensional forces shall be nondimensionalized by:

$$\rho*\pi R^2*(\Omega R)^2$$

Dimensional moments shall be nondimensionalized by:

$$\rho*\pi R^3*(\Omega R)^2$$

Dimensional power shall be nondimensionalized by:

$$\rho*\pi R^2*(\Omega R)^3$$

Airplane performance dimensional forces shall be nondimensionalized by:

$$q*S$$

E.4.0 REPORT ORGANIZATION AND FORMAT

E.4.1 General.

E.4.1.1 Report Content. The data requirements of this draft standard shall be documented in a report which is submitted to the Government IAW a higher level document (e.g., Instructions to Offerors in an RFP or RFQ, a task in a contractual SOW, a Data Item cited in a CDRL). The document shall include the following elements in the following order: summary, table of contents, list of figures, list of tables, the main body, list of references and appendices (if any). The content of the main body shall be IAW with sections 5 through 13 of this draft standard; it is preferred that the topics of the sections within the main body be in the same order as the topics in sections 5 through 13 of this draft standard.

E.4.1.2 Report Media. The complete report shall be provided as a hard copy (double sided, 8.5" by 11" paper preferred). In addition, all text and tables shall be provided in an electronic, machine readable and displayable format that is compatible with Procuring Agency's electronic data processing environment; the specific environment (including hardware and software) will be documented in the higher level document which cites this draft standard. It is desirable that all other parts of the report (e.g., graphs) be provided in a compatible electronic format as well.

E.4.1.3 Graphs and Tables. To the maximum extent practical, data shall be presented in graphical format.

a. If a graph has been constructed based on experimental information then the data points shall be included in symbol format.

b. Where accuracy would be enhanced and facilitated, equations for plotted curves (Offeror's choice) shall be presented.

c. The scales and grids used on graphs should facilitate interpolation and reading of data directly from the graphs.

d. The layout of graphs should facilitate comparisons between graphs. In general, this means that all graphs which show a particular parameter should use the exact same scale for that parameter; as a specific example, all graphs with airspeed on the x-axis and power on the y-axis should use the same ranges and physical lengths for each axis so that graphs can be physically overlaid to compare data.

e. Tables shall be provided when more detail than can be presented in graphic presentations is desired, and also, to provide certain types of computer inputs or single point factors. As with graphic data, the exact format of the table is a function of the variables to be tabulated. For points representing a function, there shall be enough points tabulated to allow linear interpolation between points without introducing significant errors.

E.4.2 Configuration Definition. Wherever data are requested for a "range of weights and/or drag values or coefficients", the following guidelines shall apply:

E.4.2.1 Range of Weights. The range of weights (or the corresponding weight coefficients) shall include the minimum and the maximum flying weights for the stated atmospheric conditions. The specified weights and configurations referred to here are those which are defined IAW the System Specification against which this draft standard is being applied. Weight definitions used for aircraft performance shall be as specified herein. Weight status used shall be as directed by the procuring agency. The values of weight coefficients used and the increment between them should be "rounded" and "convenient" numbers (e.g., weights and their increments end in two zeros).

E.4.2.1.1 Weight Empty. Weight empty is defined as the weight of the aircraft, complete by model design definitions, dry, clean and empty except for fluids in closed systems such as the hydraulic system. Weight empty includes total structure group, propulsion group, flight controls group, avionics group, auxiliary power plant group, electrical group, etc.

E.4.2.1.2 Basic Weight. Basic weight is defined as the weight empty adjusted for standard operational items such as unusable fuel, engine oil, oxygen, and all fixed armament.

E.4.2.1.3 Operating Weight. Operating weight is defined as the sum of basic weight and such things as crew, crew baggage, steward equipment, emergency equipment, special mission fixed equipment, pylons, racks and other non-expendable items not in basic weight. It is equivalent to takeoff gross weight less usable fuel, payload, and any items to be expended in flight.

E.4.2.1.4 Payload. Payload is defined as any item which is being transported and is directly related to the purpose of the mission as opposed to items that are necessary for the mission. Payload can include, but not be limited to, passengers, cargo, passenger baggage, ammunition, internal and external stores, and fuel which is to be delivered to another aircraft or site. Payload may or may not be expended.

E.4.2.1.5 Flight Design Gross Weight. Flight design gross weight (basic flight design gross weight) is defined as the highest flight weight authorized for the maximum positive and negative load factors for maneuvering flight.

E.4.2.1.6 Maximum Ground Weight. Maximum ground weight (maximum ramp weight/maximum taxi weight) is defined as the highest weight authorized for ramp, taxiway, and runway usage. It is usually a higher weight than the maximum takeoff gross weight defined in E.4.2.1.9.

E.4.2.1.7 Maximum Flight Weight. Maximum flight weight is defined as the highest weight authorized in flight. This weight may be greater than maximum takeoff gross weight as specified in E.4.2.1.9 if in-flight refueling is utilized.

E.4.2.1.8 Takeoff Gross Weight. Takeoff gross weight is defined as the sum of the operating weight, usable fuel weight, payload items required to perform a particular defined mission, and other items to be expended during flight. Takeoff gross weight shall be determined prior to starting engines for aircraft which have a maximum ground weight equal to maximum takeoff gross weight and shall be determined at liftoff for aircraft which have a maximum ground weight higher than maximum takeoff gross weight. In the latter case the fuel weight expended during warm-up, taxi, and takeoff are excluded.

E.4.2.1.9 Maximum Takeoff Gross Weight. Maximum takeoff gross weight is defined as the highest weight authorized at liftoff. An aircraft may have more than one maximum takeoff gross weight such as one for land based operations and one for carrier operations.

E.4.2.1.10 Mission Landing Weight. Mission landing weight is defined as the weight at the end of the mission as determined by the mission ground rules and shall include the fuel reserves.

E.4.2.11 Maximum Landing Weight. Maximum landing weight is defined as the greatest weight authorized for landing. An aircraft may have more than one maximum landing weight such as one for land based operations and one for carrier operations.

E.4.2.1.12 Primary Mission Gross Weight. The takeoff gross weight required to carry sufficient payload and fuel to perform the primary mission.

E.4.2.1.13 Combat Weight. Combat is defined as the weight at the target or combat area and is defined with fuel, air-to-ground ordnance, air-to-air ordnance, ammunition, expendable tanks, and cargo and other payload, except as noted below.

E.4.2.1.13.1 Mission Based Combat Weight. For a specific mission, combat weight is defined as mission takeoff gross weight less forty percent fuel unless otherwise specified.

E.4.2.1.13.2 Non-mission Based Combat Weight. Without a specific mission, combat weight is defined as mission takeoff gross weight less forty percent fuel unless otherwise specified.

E.4.2.1.14 Weight Definition Guide. For quick reference, the following guide (reference MIL-W-25140) is given to the above weight definitions:

WEIGHT EMPTY

+

Unusable fuel, engine oil, oxygen, and all fixed armament.

=

BASIC WEIGHT

+

Crew, crew baggage, steward equipment, emergency equipment, special mission fixed equipment, pylons, racks, and other non expendable items not in the basic weight.

=

OPERATING WEIGHT

+

Usable fuel, payload items required to perform a particular defined mission and other items to be expended during flight.

=

TAKEOFF GROSS WEIGHT

–

Load items expended in flight; such as fuel, stores, ammunition, cargo and paratroops.

=

LANDING WEIGHT

FIGURE E-1. Weight definition guide.

E.4.2.2 Drag. The range of drag values (or the corresponding drag coefficients) shall include the minimum ("clean") and maximum ("dirty") drag configurations which are feasible; it is expected that the minimum and maximum will be a function of air vehicle weight (i.e., there is limit as to how clean a heavy aircraft can be and dirty a light aircraft can be).

E.4.3 Units and Sign Conventions.

a. The units for data presented shall conform to the following guidelines: all data typically or historically presented to the pilot in English or nautical units (e.g. altitude, rate of climb, airspeed) shall be given in that set of units; all other parameters also shall be given in English units.

b. The sign conventions for all forces and moments shall be defined and illustrated in the report.

E.4.4 Nondimensional Data. Nondimensional flight performance information shall be presented in the form of a baseline carpet plot at a constant N_r/sqrt θ and accessory load in a specified condition for a range of C_W or C_L which is sufficient to derive gross weight values from the minimum to maximum flying weights for ambient temperatures from -40 deg C to +40 deg C and pressure altitudes from sea level to 16000 ft for conventional helicopters and to 25000 ft for fixed wing V/STOL aircraft. Compressibility effects shall be shown in the form of additional carpet plots at sufficient values of constant N_r/sqrt θ to represent the above temperature range. The effects of drag shall be shown in the form of carpet plots at the baseline N_r/sqrt θ for a sufficient number of configurations.

E.4.5 Rotor Speeds. For Levels I and II, all dimensional flight performance shall be presented for normal or design rotor speed (power on or off, as appropriate). For Level III, the dimensional presentation shall also include other allowable rotor speeds (autorotation and special cruise etc.).

E.4.6 Substantiation. The report shall include a substantiation of the origin and accuracy of the flight performance data presented therein. The depth of substantiation should be commensurate with the Level which is specified for the report. This substantiation shall include a description of the methodology used to produce the data with specific reference to analytical techniques (to include actual input data and a short description), wind tunnel data, and/or flight test data, as applicable, with corrections explained in detail. The substantiation documentation shall be included in the same section with the related specific flight performance information asked for by this draft standard. Copies of references (or portions thereof) shall be appended if they are not provided by other contract data requirements.

E.5.0 ISOLATED NONDIMENSIONAL MAIN ROTOR FLIGHT PERFORMANCE

E.5.1 Vertical Flight.

E.5.1.1 Level I. Isolated main rotor figure of merit (FM) vs blade-loading coefficient (C_T/σ) for OGE and 35 deg C conditions shall be provided.

E.5.1.2 Level II. All Level I data plus the isolated main rotor thrust coefficient (C_T) vs isolated main rotor power coefficient (C_P) in Hover Out of Ground Effect (HOGE), Hover In Ground Effect (HIGE) and VROC (Out of Ground Effect) of 500 ft/min conditions shall be provided for 35 deg C (HIGE data shall be based on a rotor-hub to ground-plane distance equivalent to the air vehicle hovering with the extended landing gear height equal to 5 ft).

E.5.1.3 Level III. In addition to all Level II information, enough information shall be provided to supply a complete description of rotor performance from HIGE at 2 ft landing gear height up to HOGE. The variation of C_P with Mach number shall be presented for HOGE. Also, induced velocity (nondimensionalized by average momentum velocity) at the rotor blade shall be presented as a function of r/R for 3 C_T's.

E.5.2 Forward Flight.

E.5.2.1 Level I. Data shall be presented for the rotor state at PMGW and 4000 ft/ 95 deg F and MAGW at 2000 ft/ 70 deg F (or alternatively, at PMGW and MAGW at sea level/ 103 deg F and 3000 ft/ 91.5 deg F) to show the ratio of main rotor lift to equivalent main rotor drag (L/D_e) as a function of advance ratio, (μ). The rotor Lift and details of the D_e calculation shall be presented in tabular form.

E.5.2.2 Level II. In addition to the Level I requirements, isolated rotor power coefficient, C_P/σ as a function of isolated main rotor lift (C_L/σ) and propulsive (C_D/σ) force coefficients for μ= 0.20, 0.30 and 0.40 and three rotor shaft angles (α_s= 0.0, 5.0 and 10.0 deg forward) shall be presented for 35 deg C. The main rotor side force shall be that which is required to counteract the force produced by that required of the anti-torque system.

E.5.2.3 Level III. All Level II data shall be presented to include the rotor tip path plane angle (α_{tpp}) for each condition. In addition, the variation of isolated rotor performance with advancing tip Mach number shall also be presented.

E.6.0 ISOLATED NONDIMENSIONAL ANTI-TORQUE SYSTEM

If the ability of parts of the system to produce anti-torque is inherently linked to the system being installed on the air vehicle, then data are required for that part of the system installed on the air vehicle. In addition, data shall be presented for any part of the system that can be analyzed as isolated.

E.6.1 Level I. Anti-torque system power coefficient C_P, (nondimensionalized using main rotor parameters) vs main rotor power coefficient (C_P) shall be presented for both HOGE and HIGE (5 ft) conditions, for 500 fpm VROC, and for the range of advance ratios (μ).

E.6.2 Level II. All Level I data plus data for the anti-torque system C_T and/or yawing moment coefficient C_N, as appropriate, as a function of anti-torque system power coefficient C_P, shall be provided for the air vehicle in right sidewards flight (OGE) for velocities of 15, 30 and 45 KTAS as well as for HOGE.

E.6.3 Level III. All Level II data plus data for the anti-torque system C_T and/or yawing moment coefficient C_N, as appropriate, shall be presented as a function of anti-torque system power coefficient C_P, and cockpit yaw control and component control position for the air vehicle at all permissible airspeeds and heading/sideslip angles. At airspeeds at or below the maximum lateral and rearward airspeeds, data shall be provided at airspeed increments of 15 KTAS or less and heading angle increments of 30 degrees or less; the airspeed/heading combination which is most critical in terms of power requirements shall be identified. At airspeeds above the maximum lateral airspeed, data shall be presented at sideslip angle increments of 5 degrees or less up to the limits of the sideslip envelope.

E.7.0 INSTALLED ENGINE PERFORMANCE

Powerplant performance (power, thrust, SFC) prediction data is provided by a thermodynamic cycle computer model, which represents a given engine's level of performance. The model simulates engine/component performance at specified altitudes, speeds, ambient conditions, and power settings, accounting for aircraft installation effects and fuel properties. A description of the propulsion model requires definitions of engine performance level, engine service time, and engine power setting.

E.7.1 Engine Performance Level Definitions.

E.7.1.1 Specification Performance. Specification performance is defined as the level of performance guaranteed by an engine development or production specification. This is the minimum acceptable performance that must be demonstrated before an engine can be qualified or certified for service use.

	Pre- Milestone 0	Phase 0	Phase I	Phase II				Phase III	Phase IV
		Concept Exploration and Definition	Demonstra-tion and Validation	Engineering and Manufacturing Development (E&MD)				Production and Deployment	Operations and Support
				Engine Test Milestones					
PERFORMANCE TASKS					PFQ/IFR	LPQ/ISR	FPQ/OCR		
Aircraft Studies	Estimated E&MD Spec	Estimated E&MD Spec	Estimated E&MD Spec	E&MD Spec	E&MD Spec	LPQ Minimum	FPQ Minimum	Production Status w/Endurance Testing	Production Status w/Lead-the-Fleet
Aircraft Specification	Estimated E&MD Spec	Estimated E&MD Spec	Estimated E&MD Spec	E&MD Spec	E&MD Spec	E&MD Spec	E&MD Spec	Production E&MD Spec	N/A
Flight Clearances	N/A	N/A	Calibrated Preliminary Nominal Estimate	E&MD Spec	PFQ Status	LPQ Status	FPQ Status	Production Status w/Endurance Testing	Production Status w/Lead-the-Fleet
Flight Manuals	N/A	N/A	N/A	E&MD Spec	E&MD Minimum	LPQ Minimum	FPQ Minimum	Production Minimum w/Endurance Testing	Production Minimum w/Lead-the-Fleet
Projected Mid-Life Estimates	N/A	N/A	N/A	N/A	N/A	Limited Product Spec w/Endurance Testing	Limited Product Spec w/Endurance Testing	Production Spec w/Endurance Testing and Lead-the-Fleet	Production Status w/Lead-the-Fleet

E.7.1.2 Minimum Performance. Minimum performance is defined as the level of performance which represents a predetermined statistical variation below the status performance of a family of engines at a given time. This statistical variation is usually represented as the number of standard deviations from the average, i.e. minus 2 sigma or minus 3 sigma, which defines the minimum. Performance variation within a family of engines is due to manufacturing and control tolerances.

E.7.1.3 Status Performance. Status performance is defined as the statistical average or nominal level of performance for a specified family of engines. During a development program, this could be the predicted level of performance representing the average of all component rig and engine test data acquired at a point in time. Status performance can also be the average level of performance representative of a family of production or fleet engines at a given time.

E.7.2 Engine Service Time Definitions.

E.7.2.1 New Engine. New engine is defined as a "zero time" engine. A new engine's performance is demonstrated during production acceptance, overhaul, etc. This overall level of performance is the best (most efficient) that the engine will deliver during service. Depending on the engine's control modes, an engine may deliver more power (thrust) over time, hover specific fuel consumption will deteriorate from the level demonstrated by a new engine.

E.7.2.2 Deteriorated Engine. Deteriorated engine is defined as a "non-zero time" engine exhibiting degraded performance resulting from a given amount of service usage. Generally, a deteriorated engine will deliver worse (less efficient) performance than a new engine, with the exception of power (thrust), which is dependent on the engine's control modes. Deterioration effects include clearance rub-out, accumulation of foreign matter, bending of blades, seal wear, etc. Service time may be specified by phrases such as "50 hours", or "the end of one hot section life", etc.

E.7.3 Engine Power Setting Definitions. Engine power setting rating definitions, except Idle Thrust (Power), depend on the type of engine to which they apply. They are defined below.

E.7.3.1 Idle Power. Idle power is defined as the minimum power setting for stable low power operation of the engine. The aircraft in which an engine is installed may require idle power to be greater than that required by the engine. These additional factors are a function of whether the aircraft is in the air or on the ground, and are categorized as follows:

a. Ground Idle. While the aircraft is on the ground, idle power may be further constrained by power extraction requirements, accessory generator speed requirements, and the power required to turn the rotor at the lowest collective setting (profile power).

b. Flight Idle. While the aircraft is in the air, idle thrust may be further constrained by engine acceleration time requirements (go-around at low altitude) or minimum combustor pressure limits (combustor blowout limits or minimum ECS bleed).

E.7.3.2 Engine Type Specific Power Settings.

a. Contingency Power. Contingency power is defined as the maximum operating condition at which the engine is capable of operating for the incremental time duration (typically 2.5 minutes) specified in the engine specification for an emergency situation (i.e., OEI), for a specified speed, temperature and altitude.

b. Maximum Power. Maximum power (also known as takeoff power) is defined as the maximum operating condition at which the engine is capable of operating for the incremental time duration (typically 10 minutes) specified in the engine specification, for a specified speed, temperature and altitude.

c. Intermediate Power. Intermediate power (also known as military power) is defined as the maximum operating condition at which the engine is capable of operating for at least an incremental time duration of 30 minutes, for a specified speed, temperature and altitude.

d. Maximum Continuous Power. Maximum continuous power (also known as normal power) is defined as the maximum operating condition at which the engine is capable of operating continuously, for a specified speed, temperature and altitude.

E.7.4 Power Available at Engine Output Shaft. Data shall be presented for the installed power available at Maximum Continuous Power (MCP), Intermediate Rated Power (IRP), and Maximum Rated Power (MRP) with All Engines Operating (AEO) and at Contingency Power (CP) with One Engine Inoperative (OEI) for the stated conditions. A breakdown of the engine installation losses from each source (e.g., engine inlet, engine bleed air, accessory pad, particle separator, exhaust system) shall be provided.

E.7.4.1 Level I. Installed power available at zero airspeed for Standard Day, 21 deg-C Day, and 35 deg-C Day shall be provided for SL to 16000 ft (25000 ft for fixed wing VSTOL) pressure altitude.

E.7.4.2 Level II. The information provided in Level I shall be augmented to include installed static power available for altitudes between 0 and at least 16000 ft (25000 ft for fixed wing VSTOL) for Standard Day and for temperatures between 5 deg F and 120 deg F (increments of 25 deg-F so that data at 70 deg-F and 95 deg-F are specifically included). For air vehicle configurations that cruise more efficiently at altitudes above 16000 ft, data shall be provided up to those pressure altitudes.

E.7.4.3 Level III. Same as Level II.

E.7.5 Other Engine Parameters.

E.7.5.1 Level I. Fuel flow at SLS, 2000 ft/21 deg-C, and 4000 ft/35 deg-C, for power settings at static conditions between idle and MRP (e.g., idle, 50% MCP, 75% MCP, MCP, IRP, MRP) shall be provided. Fuel flow data shall include a 5% margin for conservatism.

E.7.5.2 Level II. All Level I data plus data for fuel flow, net engine jet thrust, and momentum drag vs power setting and airspeed for the range of altitudes and temperatures of Paragraph E.7.1.2 shall be provided.

E.7.5.3 Level III. In addition to all Level II data, details shall be presented on sources of momentum drag to include mass flows and momentum recovery efficiency for each significant contributor to momentum drag.

E.7.6 Fuel. Fuel grade used for aircraft performance calculations shall be specified in the performance groundrules. The density and lower fuel heating value properties for the most commonly used fuels are shown below and represent the minimum values for each fuel grade. The densities presented in this paragraph are for 59^{o}Fahrenheit.

Aviation Fuel	Density	Fuel Heating Value
Gasoline, grades(ASTM D910)	6.0 lb/gal	18,700 BTU/lb
JP-5 Jet fuel(MIL-T-5624)	6.6 lb/gal	18,300 BTU/lb
JP-8 Jet fuel(MIL-T-83133)	6.5 lb/gal	18,400 BTU/lb
JP-10 Jet fuel(MIL-P-87107)	7.8 lb/gal	18,100 BTU/lb
Jet A-1 fuel(ASTM D1655)	6.7 lb/gal	18,400 BTU/lb

If a design requires special fuels, refer to the appropriate military or commercial fuel specification.

E.7.6.1 Alternate Design Criteria. Subject to the approval of the procuring activity, consideration may be made to use the average fuel characteristics based on a sampling of the delivered fuel grade. This should be considered when aircraft performance calculations on operational aircraft, or comparison analysis between an operational and a conceptual design aircraft need to be done. The table below represents the average fuel characteristics for a specified fuel grade:

Aviation Fuel	Density	Fuel Heating Value
Gasoline, grades(ASTM D910)	6.0 lb/gal	18,700 BTU/lb
JP-5 Jet fuel	6.8 lb/gal	18,450 BTU/lb
JP-8/Jet A-1 Jet fuel	6.8 lb/gal	18,570 BTU/lb
JP-10 Jet fuel	7.8 lb/gal	18,200 BTU/lb

E.8.0 AIR VEHICLE VERTICAL FLIGHT PERFORMANCE

E.8.1 Total Power Required.

E.8.1.1 Level I. Total air vehicle figure of merit (FM) vs normalized weight coefficient (C_W/σ) for OGE conditions at 35 deg C shall be provided.

E.8.1.2 Level II. All Level I data plus data for engine power coefficient, C_P/σ, vs air vehicle weight coefficient, C_W/σ, for HOGE, HIGE (5 ft), and 500 ft/min VROC shall be presented for 35 deg C. VROC capability at 95% IRP, 95% MRP, and MRP vs gross weight at 2000 ft/21 deg C and 4000 ft/35 deg C shall be furnished for the range of weights. The Generalized Power Variation (GPV) shall be presented as a function of Vertical Velocity Ratio (VVR).

E.8.1.3 Level III. In addition to the Level II information, the same parameters shall be presented for 6000 ft/35 deg-C. Also, enough non-dimensional information shall be presented to determine the variation of air vehicle hover flight performance between 2 ft extended landing gear wheel height and OGE. In addition, the variation of HOGE C_P/σ with main rotor tip Mach number shall be presented for the range of C_W/σ.

E.8.2 Download.

E.8.2.1 Level I. Download at HOGE shall be provided as a percentage of gross weight for PMGW at 4000 ft/35 deg C and for MAGW at 2000 ft/21 deg C.

E.8.2.2 Level II. For the same cases as in Level I, the downwash velocities at the fuselage waterline used as a reference point for determination of the vertical drag shall be shown as a function of station line. The reference drag, area and any other force contribution (engine exhaust, tail boom induced drag, etc.) used for determination of download shall also be provided. The variation of download as a percentage of gross weight for the series of possible HOGE Gross Weights shall be provided for the Level I atmospheres.

E.8.2.3 Level III. All Level II data plus download in HIGE (5 ft wheel height) shall be presented.

E.8.3 Altitude Capability.

E.8.3.1 Level I. Vertical flight altitude capability shall be presented for HIGE (5 ft), HOGE, and 500 fpm VROC at 95% IRP and 95% MRP (AEO) as a function of gross weight for Standard Day conditions at pressure altitudes from 0 to at least 16000 ft and for 21 deg C Day and 35 deg C Day conditions at pressure altitudes from 0 to at least 8000 ft.

E.8.3.2 Level II. All Level I data plus data at power settings of MRP with AEO and CP with OEI shall be presented.

E.8.3.3 Level III. The same information as Level II shall be presented.

E.9.0 AIR VEHICLE FORWARD FLIGHT PERFORMANCE

E.9.1 Level Flight Performance.

E.9.1.1 Cruise Definitions.

E.9.1.1.1 Cruise Altitude. Cruise altitude is defined as the altitude at which the cruise portion of the mission is conducted. For an unpressurized aircraft, the cruise altitude without oxygen masks shall not exceed 10,000 feet (H_p), with oxygen masks it shall not exceed 25,000 feet (H_p).

E.9.1.1.2 Optimum Cruise Speed/Altitude. Optimum cruise speed/altitude is defined as the speed/altitude combination at which the aircraft attains the maximum nautical miles per pound of fuel for a specified configuration and weight.

E.9.1.1.3 Constant Altitude Cruise. Constant altitude cruise is defined as flight at a constant altitude during the cruise portion of flight.

E.9.1.1.4 Cruise Climb. Cruise climb is defined as a cruise while climbing enroute so as to maximize nautical miles per pound of fuel as fuel is consumed.

E.9.1.1.5 Step Climb Cruise. Step climb cruise is defined as a cruise technique that is a compromise between constant altitude cruise and a cruise climb. In practice the desired gradual altitude increase of the cruise climb is approximated by increasing altitude in discrete steps.

E.9.1.1.6 Maximum Range Cruise Speed. Maximum range cruise speed is defined as the speed at which maximum nautical miles per pound of fuel is attainable at a specified configuration, weight and altitude.

E.9.1.1.7 Long Range Cruise Speed. Long range cruise speed is defined as the higher of the two speeds which yields 99 percent of the maximum nautical miles per pound of fuel for a specified configuration, weight and altitude. Optimum long range cruise takes place at the same altitude as the optimum value of maximum range cruise.

E.9.1.1.8 Average Cruise Speed. Average cruise speed is defined as the total distance covered in cruise portion of flight divided by the time for cruise.

E.9.1.1.9 Maximum Cruise Speed. Maximum cruise speed is defined as the highest level flight speed that can be maintained at the Maximum Continuous Power setting at the specified configuration, weight and altitude.

E.9.1.1.10 Specific Range(SR). Specific range is defined as nautical miles per pound of fuel consumed. It is usually expressed in nm/lb, and is defined as follows:

$$SR = V_{tas}/W_f$$

Where:

SR = specific range, nm/lb
V_{tas} = true airspeed, knots
W_f = fuel flow, lb/hr

E.9.1.1.11 Range Factor(RF). Range factor is defined as weight multiplied by specific range. This fuel mileage term is another way of measuring the aircraft's cruise range capability. It is usually expressed in nm and is defined as follows:

$$RF = SR * W$$

Where:

RF = range factor, nm
SR = specific range, nm/lb
W = aircraft weight, lb

E.9.1.1.12 Cruise Figure of Merit (FM). Cruise figure of merit is a term used to compare the cruise efficiency of aircraft and is defined as follows:

$$FM = RF * TSFC/V_{tas}$$

Where:

FM = cruise figure of merit
RF = range factor, nm
TSFC = thrust specific fuel consumption (uninstalled), per hour
V_{tas} = true airspeed, knots

E.9.1.1.13 Penetration Speed. Penetration speed is defined as the speed at which the aircraft ingresses to the target at a specified altitude.

E.9.1.1.14 Withdrawal Speed. Withdrawal speed is defined as the speed at which the aircraft egresses from the target at a specified altitude.

E.9.1.1.15 Maximum Speed.

E.9.1.1.15.1 Level Flight Maximum Speed(V_H). Level flight maximum speed is defined as the highest speed attainable in steady-state, level flight, at a load factor of 1.0 n_l for a specified altitude, temperature, weight, configuration and power setting. Level flight maximum speed is determined by the intersection of the power available power required curves with all applicable limitations applied.

E.9.1.1.15.2 Limit Speed(V_L). Limit speed is defined as the maximum allowable speed of the aircraft, with all applicable limitations applied, for a specified altitude, temperature, weight and configuration. Limit speed is independent of power available since it is not limited to level flight.

E.9.1.1.15.3 Dive Speed(V_D). Dive speed is defined as the maximum authorized speed to intentionally dive the aircraft. The dive conditions taken into consideration are altitude, flight path angle, power setting, deceleration device settings, recovery load factor, and any other pertinent factors.

E.9.1.1.16 Minimum Single Engine Speed. Minimum single engine speed is the lowest level flight speed attainable on a single engine at a 30 minute engine and drive system rating, for a specified altitude, temperature, weight and configuration.

E.9.1.2 Level I. A presentation of the ratio of air vehicle Gross Weight to equivalent drag (GW/D_e, based on engine power required) vs advance ratio (μ) shall be provided. Data shall be presented for PMGW at 4000 ft/ 35 deg C and MAGW at 2000 ft/ 21 deg C. In addition, a presentation of dimensional level flight performance shall be provided which includes: total engine power required, Specific Range and power available (MCP, IRP, MRP, CP @ OEI and transmission limit) as a function of true airspeed at 2000 ft/21 deg C and 4000 ft/ 35 deg-C. The presentation shall include a range of gross weights at a baseline drag level. A list of the specified configuration gross weights and their incremental drag difference from the baseline shall appear on the presentation. Instructions (which may include an auxiliary plot) to permit a drag correction calculation for the specific configurations, shall be included. The presentation shall also include lines which show V_{BE} and V_{BR}.

E.9.1.3 Level II. All Level I nondimensional data plus the engine power coefficient (C_P) vs gross weight coefficient (C_W) shall be provided for the range of advance ratios (μ) and air vehicle parasite drag areas at 35 deg C. All Level I dimensional information plus that for specific configurations (weight, drag, etc.) as described in the referencing RFP shall also be provided. If more detail than that presented in ADS-10 (Reference a.) is required to describe the derivation and buildup of the air vehicle lift, drag and moment, then it should be included here.

E.9.1.4 Level III. All Level II plus dimensional information for 6000 ft/ 95 deg C shall be provided.

E.9.2 Climb.

E.9.2.1 Climb Definitions. Climb is defined as that portion of flight when the aircraft is ascending from a lower geometric altitude to a higher geometric altitude.

E.9.2.1.1 Rate-of-Climb(R/C). Rate-of-climb is defined as a positive time rate of change of geometric altitude. It is equal to the vertical component of the flight path velocity. For a given configuration, weight, altitude, speed and power it is determined as follows:

$$R/C = K_c * (SHP_{Avail} - SHP_{Req'd}) * 33000 / GW$$

Where:

R/C	=	rate of climb, ft/min
K_c	=	empirical climb factor (varies, but typically = 0.875 in forward flight)
SHP_{Avail}	=	engine shaft power avail, HP
$SHP_{Req'd}$	=	engine shaft power required for level flight, HP
GW	=	aircraft weight, lb

E.9.2.1.2 Minimum Time to Climb. Minimum time to climb is defined as the shortest amount of time to climb from one speed/altitude condition to another. If only initial and final altitudes are specified, the initial and final speeds shall be assumed to lie on the minimum time to climb speed schedule.

E.9.2.1.3 Minimum Fuel to Climb. Minimum fuel to climb is defined as the smallest amount of fuel to climb from one speed/altitude condition to another. If only initial and final altitudes are specified, the initial and final speeds shall be assumed to lie on the minimum fuel to climb schedule.

E.9.2.1.4 Vertical Climb. Vertical climb is defined as a climb with no horizontal airspeed component.

E.9.2.1.5 Climb Speed. Climb speed is defined as the speed along the flight path at which climb is conducted for a specified altitude, weight, configuration and power setting.

E.9.2.1.5.1 Best Climb Speed. Best climb speed is defined as the steady state speed that results in the maximum rate of climb for a specified altitude, weight, configuration and power. It is that speed at which the difference between power available and power required is a maximum, coinciding with the “bucket” speed, speed for minimum power and speed for maximum endurance.

E.9.2.2 Level I. The vertical climb capability shall be provided as a function of gross weight, plotting rate-of-climb at sea level, without ground effect, with maximum, intermediate, or maximum continuous power as applicable. Hover ceiling shall be shown for standard and non-standard conditions as applicable.

E.9.2.3 Level II. The ROC capability shall be provided at the airspeed for best climb velocity (V_{climb}) vs gross weight for SLS, 2000 ft/21 deg-C, and 4000 ft/35 deg-C conditions using MCP, IRP, and MRP with AEO for the range of weight and drag configurations.

E.9.2.4 Level III. All Level II data plus data at 6000 ft/35 deg-C and 8000 ft/35 deg-C shall be provided.

E.9.3 Ceiling.

E.9.3.1 Ceiling Definitions. Ceiling is defined as the highest altitude at which a specified steady state rate-of-climb can be achieved.

E.9.3.1.1 Absolute Ceiling. Absolute ceiling is defined as the altitude at which the maximum steady state rate-of-climb potential is zero feet per minute, for a specified configuration, weight, speed and power setting.

E.9.3.1.2 Service Ceiling. Service ceiling is defined as the altitude at which the maximum steady state rate-of-climb potential is 100 feet per minute for a specified configuration, weight, speed and power setting.

E.9.3.1.3 Cruise Ceiling. Cruise ceiling is defined as the altitude at which the maximum steady state rate of climb potential is 300 feet per minute at Maximum Continuous Power fir a specified configuration, weight, and speed.

E.9.3.1.4 Combat Ceiling. Combat ceiling is defined as the altitude at which the maximum steady state rate-of-climb potential is 500 feet per minute for a specified configuration, weight, speed and power setting.

E.9.3.1.5 Hover Ceiling. Hover ceiling is defined as the altitude at which the maximum steady state rate-of-climb potential is zero feet per minute at zero airspeed for a specified configuration, weight, power setting, and wheel height (i.e., OGE or IGE).

E.9.3.2 Level I. Ceilings shall be presented for OEI forward flight at MCP, IRP, MRP, and CP as a function of gross weight for Standard Day conditions at pressure altitudes from 0 to at least 10000 ft and for 21 deg-C Day and 35 deg-C Day conditions at pressure altitudes from 0 to at least 8000 ft. OEI forward flight ceiling shall be defined as the maximum altitude at which a 100 ft/min ROC can be maintained over a 40 KTAS airspeed range.

E.9.3.3 Level II. In addition to all Level I data, forward flight ceilings at MCP and IRP with AEO shall be presented as a function of gross weight for Standard Day, 21 deg-C Day, and 35 deg-C Day conditions. AEO forward flight ceiling shall be defined as the maximum altitude at which a 100 ft/min ROC can be maintained at V_{climb}.

E.9.3.4 Level III. Level II information shall be presented.

E.9.4 Descent.

E.9.4.1 Descent Definitions. Descent is defined as that portion of flight in which the aircraft is descending from a higher geometric altitude to a lower geometric altitude.

E.9.4.1.1 Rate-of-Descent(R/D). Rate-of-descent is defined as a negative time rate of change of altitude (negative rate-of-climb). Rate-of-descent is usually expressed in feet per minute, and is defined as follows:

$$R/D = K_d * (SHP_{Descent} - SHP_{Req'd}) * 33000 / GW$$

Where:

R/D	=	rate of descent, ft/min
K_d	=	empirical descent factor (varies, but typically = 0.9 in forward flight)
$SHP_{Descent}$	=	engine shaft power to achieve desired rate-of-descent, HP
$SHP_{Req'd}$	=	engine shaft power required for level flight, HP
GW	=	aircraft weight, lb

E.9.4.1.2 Descent Speed. Descent speed is defined as the flight path airspeed during a descent to a lower altitude. The particular speed/altitude profile selected is based on the type of descent to be used: e.g.; emergency or maximum range descents.

E.9.4.1.3 Enroute Descent. Enroute descent is defined as a descent used in normal operations when there is no emergency. No distance is credited in descent.

E.9.4.1.4 Maximum Range Descent. Maximum range descent is defined as the best use of fuel to attain maximum range when descending from one altitude to another. Maximum range descent is made at or near maximum lift/drag speed. This descent is flown with power at the prescribed setting, aircraft configured as required, gear retracted, deceleration devices retracted, and at a specified speed schedule.

E.9.4.1.5 Penetration Descent. Penetration descent is defined as a descent utilized when descending to start terrain following at low altitude and high speed. This descent is flown at Flight Idle power setting, aircraft configured as required, gear retracted, deceleration devices deployed as required, and at a specified speed schedule. During descent other applicable placards must be observed.

E.9.4.1.6 Emergency (Minimum Time) Descent. Emergency descent is defined as a descent which provides maximum altitude loss in a minimum amount of time, without exceeding airspeed limits, in the event of some type of emergency. Power rating is set to Flight Idle, with the speed schedule specified.

E.9.4.1.7 Alternate Design Criteria. Subject to approval of the procuring activity, consideration may be made of alternate descent speed schedules, configurations, and power settings which utilize the unique capabilities of a particular design.

E.9.4.2 Level I. No Rate of Descent (ROD) information is required.

E.9.4.3 Level II. Autorotative ROD vs V shall be provided at 2000 ft/21 deg-C for MAGW and 4000 ft/35 deg-C at PMGW.

E.9.4.4 Level III. In addition to Level II information, Height/ Velocity diagrams shall be provided for SLS, 4000 ft/35 deg C and 5000 ft/ 5 deg C at SDGW and MAGW for OEI and AEI. The descent conditions which determine the height/ velocity envelopes shall be described.

E.10.0 POWER BREAKDOWN

E.10.1 Non-rotor Power Required (at engine output shaft). Non rotor power required shall be defined as power required at the engine output shaft less main rotor and anti-torque power. It shall include such items as drive system, electrical system, hydraulic system, ECU, etc.

E.10.1.1 Level I. Total non-rotor power required as a function of operating condition shall be presented. Data shall be provided for all normal operating conditions that have a significant effect on non-rotor power required (e.g., engine power used, rotor speed, air density).

E.10.1.2 Level II. All Level I data shall be presented plus a detailed breakdown of non-rotor power required by source.

E.10.1.3 Level III. Level II information shall be presented.

E.10.2 Rotor Power Required.

E.10.2.1 Level I. No data required.

E.10.2.2 Level II. Dimensional and non-dimensional power required at the engine output shaft shall be provided as a function of V for PMGW, at 4000 ft/35 deg-C showing the breakdown of power into at least the following categories: main rotor, anti-torque system, drive system, accessories, etc. The main rotor category shall include sub-categories of induced (including the effects of non-uniform inflow), profile, parasite, and non-ideal (where non-ideal includes stall and compressibility, preferably as separate categories, and excludes the effects of non-uniform inflow).

E.10.2.3 Level III. Same as Level II.

E.11.0 MISSION FLIGHT PERFORMANCE

E.11.1 Mission Flight Performance Definitions.

E.11.1.1 Range. Range is defined as the distance (including the distance covered in a climb) attainable on a one way flight with specified payload and fuel allowances. Payload, if any, shall be carried the entire distance unless otherwise specified. Distance in descent shall not be credited. Unless otherwise specified, range missions will be conducted without in-flight refueling.

E.11.1.2 Radius. Radius is defined as the distance (including distance covered in climb) to the midpoint of a mission having equal length legs from takeoff point to target and return. Distance in descent shall not be credited. When the mission definition requires that payload be dropped or off-loaded, it shall be done at the midpoint with no distance credited. Unless otherwise specified, distance covered in combat, maneuvering, loiter, or patrol shall not be included in the radius, and radius missions will be conducted without in-flight refueling.

E.11.1.3 Mission Types. The missions defined below are intended to portray the capabilities of the aircraft for specific mission conditions. The mission profiles for these missions, and for other representative operational missions, appropriate to each type aircraft, are given in an appendix (to be prepared for the published military standard).

E.11.1.3.1 Design Mission. The design mission(s) is defined as the primary mission(s) for which the aircraft was developed. This mission will normally be defined in procurement documents such as the prime item development specification which will include the flight profile, fuel allowances, and payload to be used.

E.11.1.3.2 Clean Mission. The clean mission is defined as a radius mission conducted without payload to show the maximum radius capability of the aircraft. This mission is usually a high-high-high profile.

E.11.1.3.3 Ferry Mission. The ferry mission is defined as a range mission conducted without payload to show the maximum range capability of the aircraft. Auxiliary and external fuel tanks which maximize the range shall be used as authorized by the procuring activity. The ferry mission profile and allowances shown in an appendix (to be prepared for the published military standard) shall be used unless otherwise specified. When an aircraft is being ferried as part of a deployment to another operating location, it carries the items of equipment included in operating weight (paragraph E.4.2.1.3).

E.11.1.3.4 In-flight Refueled Mission. For aircraft capable of in-flight refueling, the range for an in-flight refueled mission is defined as the distance (range or radius) attainable through receipt of replacement fuel during flight. Multiple refueling operations may be used if necessary.

E.11.1.4 Mission Categories.

E.11.1.4.1 Utility/Cargo/Troop Transport. Utility/cargo/ troop transport missions are radius missions in which either internal or external cargo or a load of troops is transported to a midpoint location. A hover is performed at the midpoint, followed by the off-loading of payload and subsequent return to base. Missions in support of Marine operations may be based aboard ship.

E.11.1.4.2 Search and Rescue(SAR)/Combat SAR (CSAR). SAR and CSAR are radius missions which require a dash to and hover at the midpoint, the on-loading of survivors or downed crewmen, and subsequent return to base. A search may be employed at the midpoint prior to picking up survivors. Missions may be based aboard ship.

E.11.1.4.3 Observation/Reconnaissance. The observation/recce mission is a radius mission whose role is to accomplish observation and reconnaissance of the battlefield as well as artillery spotting. Missions performed in support of Marine operations may be based aboard ship.

E.11.1.4.4 Armed Escort/Anti-Armor/Close Air Support (CAS). Armed escort, anti-armor and CAS are radius missions in which the aircraft carries an armament payload and engages targets in combat at the midpoint. Midpoint combat may consist of a hover, loiter or dash segment individually or in some combination. Missions performed in support of Marine operations may be based aboard ship.

E.11.1.4.5 Anti-Submarine/Anti-Surface Warfare (ASW/ASUW). ASW/ASUW missions are radius missions involving transit to a target area, followed by search or hover (depending on the sensors used), localization and attack followed by subsequent return to base. These missions are based aboard ship.

E.11.1.5 Times.

E.11.1.5.1 Mission Time. Mission time is defined as the time in the air starting at obstacle clearance and ending at touchdown.

E.11.1.5.2 Cycle Time. (Fixed Wing. Are there equiv. definitions for Rotary Wing?)

a. Land Operations. Cycle time is defined as the time of flight from the start of initial climb (omitting takeoff time) to the time when the engines are stopped after landing.

b. Carrier Operations. Cycle time is defined as the time from first aircraft in first group takeoff (starting with catapult launch) to first aircraft in second group takeoff. (First group lands after second group takeoff.) Example: 1 + 45 cycle time (1 hour and 45 minutes) makes mission time approximately 2 hours, allowing 15 minutes for the second group to takeoff.

E.11.1.5.3 Block Time. Block time is defined as the total time from engine start before takeoff to engine stop after landing.

E.11.2 Takeoff. Takeoff is defined as that phase of flight during which the aircraft leaves the ground and enters aerodynamic and thrust supported flight. It extends from starting the engines to the start of the initial hover or climb. Terminology used for the different portions of a rolling takeoff are shown in figure TBD.

E.11.2.1 Rotation Speed (V_{rot}). Rotation speed is defined as the speed at which body rotation is initiated from the ground run attitude to the liftoff attitude, for a specified altitude, weight, and configuration. Rotation speed must be equal to or greater than the ground minimum control speed. It must also be equal to or greater than the minimum speed at which the controls, including vectored thrust, if applicable, can generate sufficient moments to initiate rotation.

E.11.2.2 Stall Speed (V_s). Stall speed is defined (per MIL-STD-1797) at 1g normal to the flight path, for a specified altitude, weight, and configuration, as the highest of:

a. The speed for steady, straight and level flight at $C_{L_{max}}$, the first local maximum of the curve of lift coefficient vs. angle of attack which occurs as lift coefficient is increased from zero.

b. The speed at which uncommanded pitching, rolling, or yawing occurs.

c. The speed at which intolerable buffet or structural vibration is encountered.

NOTE: Although the local slope of the curve of lift coefficient vs. angle of attack should be at least zero or positive at all points less than $C_{L_{max}}$, a slightly negative local slope may be permissible if it can be shown by engineering analysis and simulation, and eventually verified by flight test, that no unsatisfactory flying qualities and/or performance characteristics will result.

E.11.2.2.1 Power-Off Stall Speed (V_{spo}). Power-off stall speed is defined as the stall speed without power.

E.11.2.2.2 Power-On Stall Speed (V_{sp}). Power-on stall speed is defined as the stall speed accounting for the stated power.

E.11.2.3 Liftoff Speed (V_{lo}). Liftoff speed is defined as the speed at which the aircraft leaves the ground for a specified altitude, weight, and configuration.

E.11.2.3.1 Land Operations. Liftoff speed shall be the highest of the following.

a. A speed corresponding to 110 percent of the out of ground effect power-off stall speed in the takeoff configuration. At the discretion of the procuring activity, a power-on stall speed will be considered in lieu of or in addition to the power-off stall speed.

b. A speed determined by the in ground effect lift coefficient in the takeoff configuration, power-on, for the maximum angle of attack allowable with the main landing gear oleo in the static position with the aircraft on the ground.

c. The minimum speed at which the aircraft has a climb gradient potential of 1/2 percent (0.005), with the power setting being used for takeoff, flaps in the takeoff position, landing gear extended, out of ground effect. For multi-engine aircraft this potential shall be obtainable with the most critical engine inoperative (engine windmilling, propeller feathered).

d. 105 percent of the out of ground effect static air minimum control speed, or if flight test data is available, dynamic air minimum control speed. Both static and dynamic air minimum control speeds shall be as defined in MIL-STD-1797.

e. The minimum speed at which the aircraft can initiate rotation to the appropriate takeoff altitude, plus the speed change during rotation.

f. The minimum speed which permits attaining obstacle clearance speed at or before the aircraft clears a height of 50 ft. above the runway.

g. The minimum speed based on flight control limiting with margins applied as appropriate, subject to the approval of the procuring activity.

E.11.2.3.2 Shipboard Operations.

E.11.2.3.2.1 Wind-Over-Deck (WOD).

E.11.2.4 Ground Minimum Control Speed (V_{mcg}).

E.11.2.5 Height-Velocity (H-V) Avoid Region.

E.11.2.6 Ground Run Distance.

E.11.2.7 Total Takeoff Distance. Takeoff distance shall be that normally obtainable in service operation at sea level with ICAO standard atmospheric conditions and on hard surfaced runways having a rolling coefficient of friction as specified in paragraph E.11.2.11.1. For estimated data, the minimum distances shall be increased at least 15 percent until verified by flight test.

E.11.2.8 Ground Effect. A hovering helicopter generally exhibits some effect on power required as a function of proximity to the ground. The benefit is more evident at low height above ground level, diminishing to non-existence usually by two rotor diameters' height above ground level.

E.11.2.8.1 Out of Ground Effect (OGE). Hover OGE performance should be presented for rotor heights greater than two diameters above ground level.

E.11.2.8.2 In Ground Effect (IGE). Hover IGE performance should be presented for at least two wheel heights which are considered to be well within ground effect, such as ten foot and 40 foot. The relationship between either $Thrust_{IGE}/Thrust_{OGE}$ versus h/D or $SHP_{(Req'd\ IGE)}/SHP_{(Req'd\ OGE)}$ versus h/D should be provided, for h/D up to 2.0.

E.11.2.9 Coefficient of Friction (μ). The coefficient of friction, μ , as used in this document is defined s the ratio of the total landing gear system retardation effect, exclusive of aerodynamic effects, to the momentary gross weight of the aircraft.

E.11.2.9.1 Rolling. The rolling (unbraked) coefficient of friction for a dry, hard runway shall be equal to 0.025, for firm dry sod, 0.05.

E.11.2.9.2 Braking. The braking coefficient of friction for a dry, hard runway shall be equal to 0.30; for firm dry sod, 0.25.

E.11.3 Tactical Missions.

E.11.3.1 Level I. A mission description for each specified in the document which cites this standard shall be included. The description shall include the following for each mission leg:

a. Type of mission activity (HOGE, HIGE, Cruise, Reserve etc.) and Atmospheric condition (pressure altitude and free air temperature).

b. Gross Weight at mission leg start and associated VROC capability (if HOGE mission activity).

c. Forward flight velocity and duration.

d. Ordnance load or cargo load.

e. Fuel flow, mission leg fuel and specific range.

f. Total power required and power available.

g. Rate of Climb OEI at V_{climb} for cruise legs of Self Deployment mission, if applicable.

E.11.3.2 Level II. Present same information as required by Level I.

E.11.3.3 Level III. Present same information as required by Level II.

E.11.4 Mission Radius.

E.11.4.1 Level I. Mission radius as a function of expendable ordnance or cargo shall be shown for gross weight at HOGE conditions and 100% takeoff power for the Primary mission profile with a variable mission radius (cruise out equals cruise back). The warm-up, battle station approach and departure (HOGE/NOE), battle station and reserve legs shall be the same as the specified Primary Tactical mission. The Mission radius information shall be shown for 2000 ft/21 deg C and 4000 ft/35 deg C.

E.11.4.2 Level II. Present same information as required by Level I.

E.11.4.3 Level III. Present same information as required by Level II.

E.12.0 MANEUVERING FLIGHT PERFORMANCE

E.12.1 Maneuver Definitions. Maneuver is defined as the act of change altitude, airspeed, and/or direction of flight. The maneuver diagram represents the performance capability and limits of an aircraft for a given set of flight conditions. Maneuverability defines the aircraft's capability to attain a maneuver state. Agility defines the manner in which an aircraft transitions from one maneuver state to another.

E.12.1.1 Flight Envelope. Flight envelope is defined as the boundary of altitude and speed combinations within which flight is possible for a given weight, load factor and configuration.

E.12.1.2 Load Factor. Load factor is defined as the resultant force divided by the aircraft weight. All forces, aerodynamic, propulsive and weight must be taken into account in the appropriate axis system.

E.12.1.2.1 Normal Load Factor(body axis)(n_z). Normal load factor in the body axis system is defined as the resultant force normal to the xy body axis plane divided by the aircraft weight. This load factor is used when defining structural limitations.

E.12.1.2.2 Normal Load Factor(wind axis)(n_l). Normal load factor in the wind (stability) axis system is defined as the resultant force normal to the xy wind axis plane divided by the aircraft weight. This load factor is used when defining maneuver capability.

E.12.1.2.2.1 Sustained Load Factor. Sustained load factor is defined as the number of g's attainable, without a change in energy (P_s=0), during steady state flight for a specified configuration, weight, altitude, speed and power setting. Care must be taken when applying structural limits since they are usually stated in body rather than wind axes

E.12.1.2.2.2 Instantaneous Load Factor. Instantaneous load factor is defined as the number of g's attainable, during maneuvering flight allowing for changes in the energy state ($P_s \neq 0$), for a specified configuration, weight, altitude, and speed. Maximum instantaneous load factor, for a given speed, occurs when the maximum usable lift coefficient is achieved, except where limited by structural or other considerations. Care must be taken when applying structural limits since they are usually stated in body rather than wind axes. Dynamic overshoot(s) is not allowed in this definition. Dynamic overshoot is a condition where lift coefficient is increased for a short time as a result of pitch rate.

E.12.1.3 Specific Excess Power(P_s). Specific excess power (P_s) is defined as the time rate of change of specific energy and is a measure of the capability of the aircraft to change energy levels for a specified configuration, altitude, speed, and power setting. Specific excess power is usually expressed in feet per minute, and is defined for helicopters as follows:

$$R/C = K_c * (SHP_{Avail} - SHP_{Req'd}) * 33000 / GW$$

Where:

R/C	=	rate of climb, ft/min
K_c	=	empirical climb factor (varies, but typically = 0.875 in forward flight)
SHP_{Avail}	=	engine shaft power avail, HP
$SHP_{Req'd}$	=	engine shaft power required for level flight, HP
GW	=	aircraft weight, lb

Specific excess power for tilt rotors is defined as follows:

$$P_s = 60*81.689\ V_{tas}[T\cos\alpha + F_G\cos\alpha - D - F_{RAM}]\ /W$$

Where:

D	=	Drag
$F_G\cos\alpha$	=	Horizontal component of gross engine thrust (FNET = FG - F_{RAM})
F_{RAM}	=	Engine ram drag
$T\cos\alpha$	=	Horizontal component of prop thrust
V_{tas}	=	true airspeed, knots
W	=	aircraft weight, lbs

E.12.1.4 Specific Energy(E_s). Specific energy (also known as energy height) is defined as the total energy (potential plus kinetic) divided by the weight for a specified speed and altitude. Specific energy is usually expressed in feet, and is defined as follows:

$$E_s = H + V_{tas}^2/(2g)$$

Where:

H	=	geopotential altitude, ft
V_{tas}	=	true speed, ft/sec
g	=	gravitational acceleration, ft/sec^2

E.12.1.5 Energy Exchange(ΔE). Energy exchange is defined as the amount of specific energy required during a maneuver to increase from one energy state to another. The calculation for the amount of fuel required to perform an energy exchange is shown in Paragraph TBD.

E.12.1.6 Combat Speed. Combat speed is defined as the highest speed attainable in level flight at combat weight with Takeoff (Maximum) power at combat altitude.

E.12.1.7 Corner Speed.

E.12.1.7.1 Sustained Corner Speed. Sustained corner speed is defined as the speed at which the maximum sustained rate of turn can be achieved for a specified configuration, weight, altitude and power. It occurs where turn rate is the maximum attainable without an accompanying change in energy (P_s=0), and is shown as a point d on figure TBD.

E.12.1.7.2 Instantaneous Corner Speed. Instantaneous corner speed is defined as the speed at which the aircraft attains its highest rate of turn for a specified configuration, weight, altitude and power setting (point a on figure TBD). Other points of interest on figure TBD are: The lowest speed at which the maximum lift and maximum structural load factor lines intersect (point b on figure TBD), and the speed which yields the minimum turn radius (point c on figure c.

E.12.2 Required Maneuvers.

E.12.2.1 Level I. Time histories of the maneuvers referenced in the document which cites this standard shall be presented. As a minimum, the maneuvers shall be described using the following parameters as functions of time: Flight path airspeed; Air Vehicle X, Y, and Z position with respect to the ground; Air Vehicle pitch, roll, and heading angles; Air Vehicle pitch, roll, and yaw rates; Rotor speed; Rotor shaft power; Engine power required and available; Power available from speed/altitude loss; Air Vehicle normal load factor at center of gravity. In addition, control positions (preferably those in the cockpit) are desired, if available.

E.12.2.2 Level II. Provide Level I information.

E.12.2.3 Level III. Provide Level II information.

E.12.3 Longitudinal Acceleration.

E.12.3.1 Level I. Maximum longitudinal acceleration and deceleration capability and corresponding fuselage attitude for conditions of constant altitude using MRP shall be presented as a function of V at a light, medium, and heavy gross weight for 2000 ft/21 deg-C, and 4000 ft/35 deg-C.

E.12.3.2 Level II. Provide Level I information.

E.12.3.3 Level III. Provide Level II information.

E.12.4 Sustained Load Factor.

E.12.4.1 Level I. Maximum $C_{W/}\sigma$ capability vs μ at both a representative Primary and Maximum Alternate configuration shall be shown for a sustained flight condition where no change of airspeed and/or altitude is used as additional energy for the maneuver. Limit considerations such as rotor control system endurance loads, sustained maneuver tip path plane pitch rate, vibration levels and stability shall be stated.

E.12.4.2 Level II. In addition to Level I information, normal load factor, turn rate and turn radius as a function of V shall be presented for a light, Primary Mission and Maximum Alternate Configuration at MRP or drive system power limit for 2000 ft/21 deg C, and 4000 ft/35 deg C.

E.12.4.3 Level III. Provide same information as required by Level II.

E.12.5 Transient Load Factor.

E.12.5.1 Level I. Maximum C_W/σ as a function of μ shall be presented for a Primary and Maximum Alternate configuration for a transient maneuver condition. The Air Vehicle transient capability is defined as that level which can be maintained or sustained for up to 3 seconds. If this level of C_W/σ is different than that for the sustained condition (12.4.1), then the limiting factors shall be stated.

E.12.5.2 Level II. In addition to Level I information, the Maximum transient normal load factor shall be presented as a function of V for a light, Primary, and Maximum Alternate configuration at 2000 ft/21 deg C and 4000 ft/35 deg C for MRP or drive system power levels. Airspeed and altitude loss/gain required shall be shown as well as entry airspeed and rotor tip path plane pitch rate.

E.12.5.3 Level III. Provide Level II information.

E.12.6 Decelerating Turn.

E.12.6.1 Level I. Flight path deceleration in a constant-altitude turn due to maximum transient normal load factor shall be presented as a function of V for a light, Primary, and Maximum Alternate configuration at 2000 ft/21 deg C, and 4000 ft/35 deg C conditions. The corresponding turn rate and radius plus fuselage pitch and roll attitudes are also desired.

E.12.6.2 Level II. Provide Level I information.

E.12.6.3 Level III. Provide Level II information.

E.12.7 Lateral Acceleration.

E.12.7.1 Level I. Lateral acceleration capability vs VROC for PMGW configuration at 4000 ft/ 35 deg C and MAGW configuration at 2000 ft/ 21 deg C conditions using MRP or drive system limit shall be shown.

E.12.7.2 Level II. In addition to Level I information, provide information for IRP.

E.12.7.3 Level III. Provide Level II information.

E.13.0 DIRECTIONAL CONTROL CAPABILITY

E.13.1 Level I. For 2000 ft/ 21 deg C and 4000 ft/35 deg C, the allowable wind velocity as a function of azimuth shall be shown for the applicable handling qualities control margin for a representative Primary and Alternate Configuration.

E.13.2 Level II. Level I information shall be shown also for the required maximum landing slope.

E.13.3 Level III. Provide Level II information.

CONCLUDING MATERIAL

Custodian:
- Army - AV
- Navy - AS
- Air Force - 11

Agent:
- Air Force - 11

Preparing Activity:
- Navy - AS

Project No. 1510-0002

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3. DOCUMENT TITLE
AIR VEHICLE JOINT SERVICE SPECIFICATION GUIDE

4. NATURE OF CHANGE *(Identify paragraph number and include proposed rewrite, if possible. Attach extra sheets as needed.)*

5. REASON FOR RECOMMENDATION

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c. ADDRESS *(Include Zip Code)* Commander; AIR 4.1C, Suite 2140, Bldg.2185; Naval Air Systems Command Headquarters; 22347 Cedar Point Rd, Unit 6; Patuxent River, Maryland; 20670-1161	**IF YOU DO NOT RECEIVE A REPLY WITHIN 45 DAYS, CONTACT:** Defense Standardization Program Office (DLSC-LM) 8725 John J. Kingman road, Suite 2533, Ft. Belvoir, VA 22060-2533 Telephone (703) 767-6888 AUTOVON 427-6888

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