NOT MEASUREMENT SENSITIVE

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DEPARTMENT OF DEFENSE
JOINT SERVICE SPECIFICATION GUIDE

AIR VEHICLE LANDING SUBSYSTEM REQUIREMENTS AND GUIDANCE

This specification guide is for guidance only.

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Comments, suggestions, or questions on this document should be addressed to AFLCMC/EZSS, BLDG 28 RM 133, 2145 MONAHAN WAY, WPAFB OH 45433-7017 USA or e-mailed to ENGINEERING.STANDARDS@US.AF.MIL. Since contact information can change, you may want to verify the currency of this address information using the ASSIST Online database at https://assist.dla.mil.

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FOREWORD

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

2. This specification guide replaces Appendix A, “Air Vehicle Landing Subsystem,” in JSSG-2009A, “Air Vehicle Subsystems.”

3. The purpose of this Joint Service Specification Guide (JSSG) is to provide guidance for use by Government and Industry program teams in developing program-unique specifications. This document shall not be placed on contract.

CONTENTS

1. SCOPE

1.1 Scope.

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

1.2 Structure.

The specification guide structure replicates the structure of the air vehicle subsystems specification except it places each corresponding section 3 requirement and section 4 verification together.

1.3 Overview.

This specification guide provides tailoring guidance and background information for individual paragraphs of the air vehicle subsystems specification. Guidance gives recommendations on how to tailor the specification paragraph. Where (TBS) appears, the guidance paragraph provides recommended values or text that the using service may use to insert in the (TBS). When contractors are expected to complete the (TBS), the guidance paragraph will so state. The using service makes the final decision on whom completes the (TBS) in the specification. Finally, lessons learned are provided to give insight to past events that could affect the tailoring of the specification.

1.4 Deviations.

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

1.5 Environmental impact.

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

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

2. APPLICABLE DOCUMENTS

2.1 General.

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

2.2 Government documents.

2.2.1 Specifications, standards, and handbooks.

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

INTERNATIONAL STANDARDIZATION AGREEMENTS

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

(Copies of these documents are available at https://quicksearch.dla.mil and https://nso.nato.int.)

DEPARTMENT OF DEFENSE SPECIFICATIONS

JSSG-2006	Aircraft Structures
JSSG-2010	Crew Systems

MIL-PRF-5041	Tires, Ribbed Tread, Pneumatic, Aircraft
MIL-B-8075	Brake Control Systems, Antiskid, Aircraft Wheels, Instructions for Preparation of Specifications for
MIL-L-8552	Landing Gear, Aircraft Shock Absorber (Air-Oil Type)
MIL-B-8584	Brake Systems, Wheel, Aircraft, Design of
MIL-S-8812	Steering System, Aircraft, General Requirements for
MIL-A-8860	Airplane Strength and Rigidity
MIL-A-8863	Airplane Strength and Rigidity Ground Loads for Navy Acquired Airplanes
MIL-A-8865	Airplane Strength and Rigidity Miscellaneous Loads
MIL-L-22589	Launching System, Nose Gear Type, Aircraft
MIL-PRF-83282	Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Metric, NATO Code Number H-537

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-203	Aircrew Station Controls and Displays: Location, Arrangement and Actuation of, for Fixed Wing Aircraft
MIL-STD-805	Towing Fitting and Provisions for Military Aircraft, Design Requirements for
MIL-STD-1568	Materials and Processes for Corrosion Prevention and Control in Aerospace Weapons Systems
MIL-STD-1587	Material and Process Requirements for Aerospace Weapon Systems
MIL-STD-18717	Design Criteria for Naval Aircraft Arresting Hook Systems
MIL-STD-81259	Naval Airframe Interface Requirements for Tie-Downs

(Copies of these documents are available online at https://quicksearch.dla.mil.)

2.2.2 Other Government documents, drawings, and publications.

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

AIR FORCE MANUALS AND DESIGN HANDBOOKS

AFM 86-3	Planning and Design of Theater of Operations Air Bases

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

(Copies of these documents are available to qualified users. Contact AFLCMC/EZSS, BLDG 28 RM 133, 2145 MONAHAN WAY, WPAFB, OH 45433-7017 USA; DSN 674-5476; COMMERCIAL (937) 904-5476; ENGINEERING.STANDARDS@US.AF.MIL.)

USAF TECHNICAL REPORTS

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

(Copies of these documents are available at https://dtic.mil to qualified users.)

2.3 Non-Government publications.

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

SAE INTERNATIONAL

SAE ARP1107	Tail Bumpers for Piloted Aircraft
SAE ARP1821	Aircraft Ground Flotation Analysis Methods
SAE AS50141	Tube, Pneumatic Tire, Aircraft

(Copies of these documents are available from https://www.sae.org/.)

AMERICAN SOCIETY OF MECHANICAL ENGINEERS

ASME B46.1	Surface Texture (Surface Roughness, Waviness, and Lay)

(Copies of this document are available from https://www.asme.org.)

AMERICAN SOCIETY OF TESTING AND MATERIALS

ASTM D1883	Standard Test Method for California Bearing Ratio (CBR) of Laboratory-Compacted Soils

(Copies of this document are available from https://www.astm.org.)

TIRE AND RIM ASSOCIATION

Tire and Rim Association (TRA) Aircraft Year Book

(Copies of this document are available at http://www.us-tra.org/.)

2.4 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 laws and regulations unless a specific exemption has been obtained.

2.5 Streamlining.

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

3. REQUIREMENTS

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4.4 Subsystem characteristics

3.4.1 Landing subsystem.

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

3.4.1.1 Landing gear.

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

REQUIREMENT RATIONALE (3.4.1.1)

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

REQUIREMENT GUIDANCE (3.4.1.1)

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

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

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

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

REQUIREMENT LESSONS LEARNED (3.4.1.1)

During conventional conflicts when deployment of helicopters on large transport-type air vehicles (C-17 or larger) are to be used, standard skid gear is adequate. During non-conventional conflicts such as guerilla warfare or terrorism, deployment on smaller transport air vehicles may be a factor thereby increasing restrictions on the helicopter to be transported. The Army had a requirement during the Middle East conflict to move small teams of armed reconnaissance helicopters rapidly to locations that would not accommodate large transport air vehicles. The skids on these helicopters were changed to an underslung cross tube design and equipped with a gear set allowing the helicopter to be lowered and raised as a unit to accommodate the restricted confines of a smaller transport.

4.4.1 Landing subsystem

4.4.1.1 Landing gear.

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

VERIFICATION RATIONALE (4.4.1.1)

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

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

VERIFICATION GUIDANCE (4.4.1.1)

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

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

VERIFICATION LESSONS LEARNED (4.4.1.1)

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

3.4.1.1.1 Gear arrangement.

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

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

REQUIREMENT RATIONALE (3.4.1.1.1)

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

REQUIREMENT GUIDANCE (3.4.1.1.1)

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

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

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

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

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

REQUIREMENT LESSONS LEARNED (3.4.1.1.1)

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

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

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

4.4.1.1.1 Gear arrangement.

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

VERIFICATION RATIONALE (4.4.1.1.1)

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

VERIFICATION GUIDANCE (4.4.1.1.1)

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

VERIFICATION LESSONS LEARNED (4.4.1.1.1)

Measured field data showed that most operational high speed turns are at 0.2g’s or less. The F-111 has some maximum turns at 0.25g’s. However, the 0.5g requirement (63-degrees turnover) will often keep the air vehicle from catching a wing tip during a lateral skid that often occurs in a ground-looping incident.

REQUIREMENT RATIONALE (3.4.1.1.2)

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

REQUIREMENT GUIDANCE (3.4.1.1.2)

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

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

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

REQUIREMENT LESSONS LEARNED (3.4.1.1.2)

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

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

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

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

4.4.1.1.2 Pitch stability.

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

VERIFICATION RATIONALE (4.4.1.1.2)

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

VERIFICATION GUIDANCE (4.4.1.1.2)

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

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

VERIFICATION LESSONS LEARNED (4.4.1.1.2)

(TBD)

3.4.1.1.3 Extended clearances.

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

REQUIREMENT RATIONALE (3.4.1.1.3)

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

REQUIREMENT GUIDANCE (3.4.1.1.3)

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

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

REQUIREMENT LESSONS LEARNED (3.4.1.1.3)

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

4.4.1.1.3 Extended clearances.

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

VERIFICATION RATIONALE (4.4.1.1.3)

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

VERIFICATION GUIDANCE (4.4.1.1.3)

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

VERIFICATION LESSONS LEARNED (4.4.1.1.3)

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

3.4.1.1.4 Retraction clearances.

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

REQUIREMENT RATIONALE (3.4.1.1.4)

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

REQUIREMENT GUIDANCE (3.4.1.1.4)

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

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

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

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

REQUIREMENT LESSONS LEARNED (3.4.1.1.4)

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

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

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

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

4.4.1.1.4 Retraction clearances.

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

VERIFICATION RATIONALE (4.4.1.1.4)

If a simulator is provided (strongly recommended), it may be suitable for verification of clearances.

Verification on the air vehicle will usually be required.

VERIFICATION GUIDANCE (4.4.1.1.4)

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

VERIFICATION LESSONS LEARNED (4.4.1.1.4)

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

3.4.1.1.5 Anti-rotation in retracted position.

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

REQUIREMENT RATIONALE (3.4.1.1.5)

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

REQUIREMENT GUIDANCE (3.4.1.1.5)

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

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

REQUIREMENT LESSONS LEARNED (3.4.1.1.5)

This requirement reflects the statement made in AFSC DH 2-1. It was originally included in ARDCM 80-1 (Handbook of Information for Aircraft Designers [HIAD]) as a result of a fleet wide retrofit of the C-133 from trouble caused by not stopping the tires from rotating within the wheel well.

In addition to the C-133, several other air vehicles have had to provide nose gear snubbers on a retrofit basis. As mentioned in the rationale, hazards of rotating nose wheels include excessive vibration, electronic interference, and stones thrown from the rotating tire treads. The design solutions have ranged from fuselage mounted snubbers to simple cantilevered devices mounted on the doors. There have generally been no detrimental effects on the tires. It is recommended that the rubbing be accomplished against the tires rather than against the wheel, which can suffer defacing damage.

Main gear snubbing is usually achieved by pre-braking associated with gear-up selection. This reduces or eliminates the gyroscopic loads. Generally, the pressure is relieved with the gear in the stowed position to preclude extension and touchdown with brake pressure applied.

4.4.1.1.5 Anti-rotation in retracted position.

Demonstration that the wheels do not rotate in the retracted position shall be shown by (TBS).

VERIFICATION RATIONALE (4.4.1.1.5)

The effectiveness of the proposed snubber is best demonstrated with actual hardware. A landing gear simulator is a convenient device for this purpose; however, it is usually evaluated on the air vehicle. On the main gear, it is important to evaluate the sequence and timing between brake pressure application and cessation of wheel rotation.

VERIFICATION GUIDANCE (4.4.1.1.5)

The TBS should reflect a demonstration that the rotating wheel is stopped before fully retracting for braked wheels or stopped when fully retracted for non-braked wheels. Retraction should be commanded with the wheel rotating at a speed not less than 75 percent (75%) of the liftoff speed at maximum gross weight.

VERIFICATION LESSONS LEARNED (4.4.1.1.5)

(TBD)

3.4.1.1.6 Clearance with flat tire and flat strut.

In the event of a flat tire and flat strut, the lowest part of the landing gear structure, door fairing, or air vehicle components, including external stores, shall not be closer than (TBS) from ground.

REQUIREMENT RATIONALE (3.4.1.1.6)

The objective is to provide a clearance requirement to ensure that no part of the air vehicle will engage the barrier cable installation when landing under the most adverse sequence of landing gear failures. By combining tire and strut failures, it will also ensure that neither single failure will cause inadvertent engagement. The recommended ground clearance limit is six inches for safety considerations.

REQUIREMENT GUIDANCE (3.4.1.1.6)

TBS should reflect the minimum acceptable distance from the ground and or arresting cable installation to the lowest points on the air vehicle for all phases of its ground operation on through rotation. For this requirement, the wheel, brake, and tire are not considered a part of the landing gear structure. It is also assumed that the wheel and tire are intact and that the rolling radius is the flat tire radius.

Air vehicle geometry, wheel, brake, tire sizing, and landing gear configurations are the controlling parameters in meeting this requirement.

REQUIREMENT LESSONS LEARNED (3.4.1.1.6)

This is an expansion of the existing requirement of AFSC DH 2-1 to include lessons learned on recent air vehicle accidents.

With the extensive use of arresting systems within the Air Force, most runways are equipped with arrestment cables at the ends of runways. Some runways also have midpoint barrier installations. Therefore, it is very important not to have a rigid member of the air vehicle extending low enough to engage the barrier cable in the event of a flat tire or a flat strut. The YF-16 was designed with a gear member extending low enough to engage the cable with a flat tire. This resulted in significant damage. Six-inch ground clearance under these circumstances should be a target for design.

4.4.1.1.6 Clearance with flat tire and flat strut.

Ground clearance after tire failure and strut deflation shall be determined by analysis.

VERIFICATION RATIONALE (4.4.1.1.6)

An analysis is the most economic approach to evaluating ground clearances for all the potential air vehicle configurations. An analysis would be required to determine the critical combinations if a test were selected for demonstration.

VERIFICATION GUIDANCE (4.4.1.1.6)

The analysis should take into account the ground clearance after a tire failure or strut deflation. The analysis should include deflection and dynamic effects for the landing gear and airframe, and where applicable, for the arresting cable.

VERIFICATION LESSONS LEARNED (4.4.1.1.6)

(TBD)

3.4.1.1.7 Gear stability.

Landing gear shall have natural or augmented damping so that the amplitude of any landing gear oscillations after (TBS 1) cycles is reduced to (TBS 2) or less of the original disturbance, with the following exceptions: (TBS 3) . The damping requirement applies to all initial displacements of the landing gear under the following conditions: (TBS 4).

REQUIREMENT RATIONALE (3.4.1.1.7)

This requirement is necessary to establish an acceptable level of dynamic stability. The primary concern is the damping of steered landing gear to prevent shimmy. The same criteria also may be applied to other landing gear oscillations induced by airfield roughness or brake system operation.

REQUIREMENT GUIDANCE (3.4.1.1.7)

TBS 1 and TBS 2 should be completed by requiring the amplitude be reduced to 1/3 of the original amplitude within three cycles. This has been recognized as standard by the airframe industry for damping of steered landing gear. Suitability for other oscillations has not been verified.

TBS 3 should permit some types of oscillation to be excluded from the general damping criteria. Examples include brake chatter and squeal and bogie beam pitching. The blank should include success criteria for each item excluded from the general requirement.

TBS 4 should be used to establish the range of operating conditions to be considered in application of the damping criteria. This should include air vehicle speed and weight conditions, type of airfield surface, and wear surfaces worn to the operational limit.

Gear damping characteristics are controlled by tire dynamics characteristics and landing gear components' stiffness and damping characteristics, individually and "as installed." If friction damping is utilized, wear of the friction surfaces should be assumed and accounted for in the design. Air vehicle ground speed range defines the range of concern.

The landing gears (main and nose) should be free of detrimental oscillations induced by runway roughness, tire balance or design, brake vibrations, or gear natural responses. The oscillations include fore and aft, torsional, and vertical modes.

REQUIREMENT LESSONS LEARNED (3.4.1.1.7)

This is a tailorable statement for shimmy damping and other vibration patterned after the requirement of MIL-S-8812. This requirement has been improperly placed in the steering system design specification for years. It is a general landing gear requirement, steered and non-steered. It was improperly placed in the steering system specification because the nose gear shimmy damping is most frequently controlled by modification to steering system components and most shimmy occurs on the nose gear. Originally, the criteria was generated in response to Dr. W. J. Moreland's study of shimmy and published in WADC TN 55-1 (1955) and in the Journal of Aeronautical Sciences, Vol. 21, No. 12, Sec. 54. This was further expanded and studied by J. Edman of Bendix under contract to WADC, and the results were published in WADC TR 56-197, dated July 1956.

Shimmy and various forms of gear vibration have historically been a serious landing gear problem. Nose gear shimmy has been a problem on the A-37, T-38, F-5, F-104, F-15, C-141A, T-6, and numerous other air vehicles. Solution of the problems include change of tires, balancing tires, adding friction dampers, changing hydraulic dampers, improving maintenance and servicing procedures, and changing materials.

Based upon industry evidence, main gear shimmy is most likely on dual wheel installations. The C-17 did experience shimmy of the main landing gear due to the bogey's unique configuration. A couple of commercial air vehicles have encountered such a problem. The solutions have been to add additional damping to the system.

Prevention of bogie pitch is generally a design problem of multiple axle (4 wheel and 6 wheel bogies), and by proper analysis and design, the problem is avoided.

Brake chatter and squeal are landing gear vibration phenomena, but the damping criteria proposed may not necessarily apply. The source of the vibration is the brake assembly. Therefore, system response and compatibility is a function of the design of that component. F.A. Biehl's "Aircraft Landing Gear Brake Squeal and Strut Chatter Investigation" in *The Shock and Vibration Bulletin*, February 1969, provides an explanation of the phenomenon and a method of analysis.

4.4.1.1.7 Gear stability.

Landing gear subsystem damping shall be verified analytically and substantiated by (TBS).

VERIFICATION RATIONALE (4.4.1.1.7)

Various component design parameters used in the shimmy analysis are estimated or calculated because the review is accomplished before the hardware is delivered on a development program. Therefore, it is necessary to verify the assumptions or calculations by system and component tests. Then the system response is verified by the ground vibration test of the installed gear. Frequently, the results are different from that which was estimated and the analysis should be modified accordingly to establish safety for first actual air vehicle operation. The blank should be filled with the minimum acceptable program to substantiate the stability analysis.

VERIFICATION GUIDANCE (4.4.1.1.7)

TBS: The vertical, fore and aft, and torsional damping should be verified by analysis. The parameter used in the analysis should be supported by test measurements of actual hardware and air vehicle stiffness data.

VERIFICATION LESSONS LEARNED (4.4.1.1.7)

Many dynamic analyses are dependent on accurate determination of the landing gear and backup structure stiffness data, which is not always easy to obtain. Often ground vibration test results (GVT) are used to support the analysis. It is prudent to have an agreed to list of parameters and to know how they are measured or determined prior to the conduct of the analysis.

In certain cases, a full-scale test on a laboratory dynamometer can be beneficial to determine there is sufficient dampening within the system to avoid use/costs of dampers or to fine-tune the amount of dampening needed. The test is expensive due to test fixtures, simulated backup structure, and use of actual landing gear components. Flight-testing can also be used to excite the structure by running the particular gear over planks fixed to the runway at a 45-degree angle.

3.4.1.1.8 Alignment.

The landing gear shall be aligned relative to the airframe to minimize degradation of the tire, wheel, or brake life that results from misalignment throughout the life of the air vehicle.

REQUIREMENT RATIONALE (3.4.1.1.8)

This requirement is presented to reflect the desired performance.

REQUIREMENT GUIDANCE (3.4.1.1.8)

Gear design and material selection of the wearing elements are the parameters that control or influence the ability to meet this requirement. In particular, the camber and caster of the gear should be such as to minimize the yaw and toe-in/toe-out of the wheel and tire assembly.

The geometry of the gear should not allow tire rollover or scuffing.

REQUIREMENT LESSONS LEARNED (3.4.1.1.8)

There have been cases where the gear design and installation practices allowed excessive misalignment on new gears as well as where the material selection allowed excessive wear, allowing excessive misalignment. Both resulted in a degradation in expected tire and wheel life.

Investigations into premature wheel failure and tire wear on both the F-15 and A-10 air vehicles indicated that the failures or excessive wear were due to improper gear alignment.

Provision of a 360-degree free swiveling capability best minimizes excessive wear due to tailwheel misalignment.

4.4.1.1.8 Alignment.

Landing gear alignment shall be determined analytically and substantiated by inspection.

VERIFICATION RATIONALE (4.4.1.1.8)

Reviews of design drawings and continual monitoring of the development are adequate to determine compliance with this requirement.

VERIFICATION GUIDANCE (4.4.1.1.8)

Throughout the design phase, the gear alignment should be monitored through inspection of drawing and the production of the gear and airframe. The tire wear and wheel loads should be monitored during flight-testing and into initial field demonstration.

VERIFICATION LESSONS LEARNED (4.4.1.1.8)

(TBD)

3.4.1.1.9 Growth.

The landing gear structural arrangement and critical fuselage clearances shall permit a (TBS) growth in the maximum takeoff weight without major airframe modifications or gear geometry changes.

REQUIREMENT RATIONALE (3.4.1.1.9)

Over the lifetime of most air vehicles, the maximum takeoff gross weight has significantly increased from the original design. To prevent major modifications to airframe, the wheel well should have sufficient volume (clearance) to install a stronger gear, wheel and brake, and tires.

REQUIREMENT GUIDANCE (3.4.1.1.9)

Consider strength criteria, gross weight, clearances, volume, gear location and design aspects, static and fatigue, and pin and lug sizing strut wall thicknesses.

TBS: As a minimum, allow for at least 25 percent (25%) growth in maximum takeoff gross weight.

There is a history of air vehicle development and difficulties in redesigning wheel well to accommodate larger gears.

REQUIREMENT LESSONS LEARNED (3.4.1.1.9)

The gears of the F-15, F-16, and B-1 were redesigned to larger size or increased load capability to accommodate air vehicle gross weight increases from their original designs. The air vehicle gross weight increases were 77 percent (77%), 78 percent (78%), and 32 percent (32%), respectively.

4.4.1.1.9 Growth.

Analysis shall be performed to determine maximum air vehicle growth capability as determined by the clearances and volume available within existing wheel well envelopes, the results of which shall be supported by inspection.

VERIFICATION RATIONALE (4.4.1.1.9)

An analysis of all critical growth loads, at all critical areas where interference with airframe structures may result, is required. The analysis should show that the dimensional growth of the landing gear structure will not exceed the established clearances. Inspection should be performed on the air vehicle to ensure the clearances used in the analysis are maintained.

VERIFICATION GUIDANCE (4.4.1.1.9)

The analysis should examine the volume and clearance between the gear and wheel well structure, as well as with other gear components. Sufficient clearance should be available to allow increases in thickness and size of pins, lugs, actuators, cylinders and any other structural member to support the required growth in the air vehicle gross weight. The analysis should include consideration for rework of joints and pins.

VERIFICATION LESSONS LEARNED (4.4.1.1.9)

During the design and verification phase, the analysis and requirement are often deleted or ignored. This is due to pressures to achieve lower air vehicle weight and lower cost, which are in direct conflict with this requirement. Historical and air vehicle data show that every production air vehicle has grown in weight after it has gone into service. This data may have to be presented to program management in order to maintain this requirement in contractual documents.

With existing computer analysis and Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) capabilities, this can be readily accomplished with a good degree of confidence.

3.4.1.1.10 Service life.

With the stated exceptions, the service life shall be (TBS).

REQUIREMENT RATIONALE (3.4.1.1.10)

Design life of the landing gear subsystem is a significant driver of life cycle costs. This requirement is necessary to establish a minimum acceptable service life for design. This is to ensure minimum cost, but acceptable utility of the completed system.

Consumable portions of the landing gear subsystem should be defined due to direct effects to the logistics cost and support of the equipment. There are numerous design techniques and materials available that meet the design conditions that provide varying lengths of service life. Therefore, the objective of this requirement is to express the logistic needs of the system in a manner that will influence the design and material selected to produce the desired life.

REQUIREMENT GUIDANCE (3.4.1.1.10)

TBS should be filled in with the following:

a. Landing gear structure: TBS should be stated in terms of the minimum acceptable number of landings or years of service. The anticipated utilization of the system should be defined. It may also be desirable to reference or define the logistics support plan for the major landing gear components. The number selected for this requirement will usually be the same as used for the basic airframe service life.

b. If tires are used: The TBS should be filled in with the number of landings that the main gear tire and nose tire should achieve due to thread wear only. The tire usage spectrum should be based on a mix of the overall aircraft design usage spectrum missions.

c. If wheels are used: TBS should reflect an accelerated life performance of a specified number of miles at a specified overload. This allows a reasonable test program and produces a limited life wheel. The number selected is a function of the type of air vehicle on which it will be installed and the overall logistic plan.

d. If brakes are used: TBS should state how many landings the heat sink material is capable of sustaining without replacement, the life capability of the structural member of the brake assembly, and a definition of the operational spectrum that the brake assembly will see in service. Section 3.4.1.11, "Components," has more information on brakes.

e. If an arresting hook is used: TBS should state the required number of engagements the hook system will take before replacement as well as list the components that can be replaced sooner, such as "ground contact" items.

f. If a drag chute is used: TBS should state the life of the drag chute in number of deployments, how often it should be replaced, and the environmental operating conditions.

REQUIREMENT LESSONS LEARNED (3.4.1.1.10)

If damage tolerant criteria is used exclusively, it would eliminate the use of material such as 300M steel which does not have an inspectable flaw size used to verify the two-lifetime capability with a flaw. Therefore, if this type of material is to be allowed, it will be necessary to maintain the four fatigue life requirements as dictated by Miner's rule that has successfully been used on B-1, F-16, F-15, and many other aircraft.

Service life of various landing gear components is a function related to various modes of failure. The primary modes and causes of failure include structural, corrosion, overload in performance, wear, inadequate design, erratic performance, and abuse.

There are numerous examples of fatigue failures due to stress concentrations resulting from inadequate design. Emphasis should be placed on design details to avoid high KT. Fatigue failures have occurred on virtually every landing gear in the inventory, including B-52, B-66, KC-135, C-130, C-141, Century Series fighters, F-4, F-111, all trainers, and the A-37. Careful attention should be paid to lug areas and holes.

Choice of material for the application also has a significant influence on the success of the application. Selection of the wrong alloy and improper protection system can produce corrosion and stress corrosion failures. Stress corrosion failures of landing gear components has been particularly prevalent. Examples include B-52, KC-135, C-141, Century Series fighters, and F-4. Most of these failures were with aluminum parts heat-treated to the T6 temper. The alloys which were most susceptible were 7075 and 7079. A large portion of these failures occurred in components that had high-sustained stresses, such as outer cylinders that were pressurized. Stress corrosion failures with these alloys were not as prevalent when used as beam members in axial loading.

Many landing gear structural failures occur in overstressed parts. Examples of landing gears with overstress failures include virtually every air vehicle in the inventory. This appears be a very difficult deficiency to avoid. This may result from design errors or from subjecting the hardware to conditions not considered by the original design. Common design errors include failure to consider dynamic loading and secondary loading due to deflection of the landing gear or mounting structure. Any change in air vehicle operational needs during development should be reviewed for structural implications to avoid design deficiencies.

Numerous landing gear failures have been caused by inadequate process and manufacturing control. Prime examples are the F-101 pin and C-17 cross shaft failures stemming from damage due to grinding of the chrome plating.

Frequently, major components are lost from the inventory due to insufficient material to permit rework dictated by corrosion or wear. This consideration and allowance should be included in the initial design. This consideration is best illustrated by the commercial landing gears for airline usage. The material for rework is mandatory for airline usage and should be seriously weighed for evaluation of Air Force applications. Only in cases of extreme weight criticality should this be waived.

Use of hard thermoplastic material in the construction of tubing clamps may result in chafing damage when dirt or sand enters the voids between the tube and clamp. Recommend the use of elastomeric material or other soft rubbery material in the construction of the clamp.

4.4.1.1.10 Service life.

Service life shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.1.10)

It is intended to verify this requirement in a manner consistent with the remainder of the structural verification program. Utilization of laboratory, flight tests, and service tests covers the total usage spectrum.

VERIFICATION GUIDANCE (4.4.1.1.10)

TBS should list the particular test and analysis for each individual consideration, since there will be different types of tests for landing gear structures, tires, wheels, brakes, drag chutes, and arresting hooks.

VERIFICATION LESSONS LEARNED (4.4.1.1.10)

Rarely does the baseline design spectrum used in both analysis and testing of the gear match the actual spectrum experienced out in the field. The efforts in the integrity program is to provide recording and algorithms capabilities to obtain actual loading of the fleet air vehicles, combine this data in an analytical program to determine useful life remaining and overhaul criteria.

3.4.1.2 Ground operation.

4.4.1.2 Ground operation.

3.4.1.2.1 Ground flotation.

The landing gear shall have ground flotation capability to permit the air vehicle (TBS).

REQUIREMENT RATIONALE (3.4.1.2.1)

The purpose of this requirement is to ensure that the load the air vehicle applies to the airfield is compatible with the bearing strength of the airfield surface. Details of the requirement are very dependent upon the air vehicle mission and basing concepts. The primary consideration for a large cargo air vehicle, for example, might be to ensure ability to operate on existing commercial jet air vehicle airfields without causing an unacceptable rate of pavement deterioration. Tactical cargo and fighter air vehicles, on the other hand, may need to be designed to perform a specified mission on an unpaved airfield.

REQUIREMENT GUIDANCE (3.4.1.2.1)

In many cases, this airfield compatibility is a primary system characteristic and is addressed in detail in the System Specification. If this is the case, reference to the System Specification will be sufficient. Some system documents, however, fail to define the requirement in adequate engineering terms. If this is the case, this requirement should be expanded to include the significant engineering parameters. The exact wording should be tailored for each system using the following parameters.

TBS should clearly state the user’s mission requirements for the type of airfields he wants to operate on and should reflect the number of times he expects to perform these missions. The tire pressure should not exceed 300 PSI and the tire footprint area should be a minimum of 50 square inches for operation on bituminous surfaces.

The following should be considered in determining flotation equipment:

a. Air vehicle Gross Weight Condition
b. Air vehicle Center of Gravity Position
c. Type of Airfield Surface (Paved or Unpaved)
d. Strength of Airfield Surface
e. Level of Operation (Frequency or Total Number)
f. Tire Operating Limits

It should be understood that flotation requirements are usually in conflict with brake sizing, wheel well volume, and location. Flotation requirements often affect the outer mold lines of the air vehicle, the number of tires, and tire pressures. This is a result of obtaining the largest tire profile at the lowest possible pressure with the biggest wheel spacing (on multiple wheel configurations), which forces the air vehicle to give a large space to store the gear in during flight.

REQUIREMENT LESSONS LEARNED (3.4.1.2.1)

Flotation criteria were previously identified in AFSC DH 2-1.

Air Vehicle Conditions: In the case of paved airfields, it is usually best to specify the maximum gross weight that will be used for ground operations. The center of gravity position may not be too critical for paved airfields, however, specification as nominal, average, or most critical makes the requirement more exact. The gross weight and center of gravity specified for unpaved airfield operations will usually be specified in terms of a specific mission condition. A specific weight should not be specified.

a. Type of Airfield Surface. The requirement should at least specify a paved or unpaved surface. Paved is considered to include rigid concrete surfaces, flexible asphalt surface, and combination rigid and flexible surfaces. Unpaved means bare soil without vegetation with soil of any combination of sand, silt, or clay. Specification of landing mat or membrane surfaced airfields is not recommended. Experience has indicated that performance of these surfaces to applied loads is highly variable and difficult to predict. In addition, the type of surface in use at the time the air vehicle becomes operational may be much different from that in use at air vehicle conception. Landing mat and membrane development cycles are not keyed to air vehicle development.

b. Strength of Airfield Surface.

   1. Paved Airfields - Possible approaches to this parameter include the following:

      (a) Provide a list of the airfields to be used. This will require that a pavement evaluation report for each airfield be provided to the contractor. This is the most exact method but may be difficult to accomplish due to lack of pavement evaluation data.

      (b) Analyze the pavement evaluation reports of airfields to be used, and develop a single chart to summarize most critical pavement characteristics. This has the same disadvantage as approach “a,” but it has an advantage in that it avoids the necessity for the Air Force to identify positively the final list of airfields to be used.

      (c) Analyze an existing operational air vehicle and develop a rigid pavement and a flexible pavement requirements chart for operation at a condition comparable to the new air vehicle requirement. See F.A. Biehl’s “Aircraft Landing Gear Brake Squeal and Strut Chatter Investigation” in The Shock and Vibration Bulletin, February 1969, for an explanation of the phenomenon and a method of analysis to develop the chart. This approach has been used successfully. Although less exact, it permits establishment of a requirement without knowledge or examination of the exact airfields to be used.

      (d) Specify that the airfields to be used are light, medium, or heavy load airfields as specified by AFM 88-6. The manual, in turn, then provides details of the pavement construction. A fallacy in this approach is that it assumes that all of the airfields will comply with AFM 88-6 criteria. In fact, very few military airfields comply entirely. Commercial and foreign airfields are constructed to different criteria.

      (e) Specify the minimum Aircraft Classification Number (ACN)/Pavement Classification Number (PCN) of the airfield to be operated on. The ACN/PCN is the latest method used by the military and civil operations to classify the strength of a runway. The ACN/PCN approach has been in place since 1983 when it was adopted by the International Civil Aviation Organization (ICAO). The ACN/PCN establishes standard pavement parameters for computation and sets four soil subgrade strengths. Additional information on this approach can be found in SAE ARP1821. Previously, the Load Classification Number (LCN) method was the preferred approach.

(f) It should be noted that high tire pressures (greater than 300 PSI) used on recent air vehicles are inflicting irreversible damage to bituminous taxiways. Initial tire sizing is very important and should allow for future growth without causing pavement damage.

2. Unpaved Airfields:

(a) The strength of unpaved airfields is usually expressed in terms of the California Bearing Ratio (CBR). The CBR is defined and measured in accordance with ASTM D1883. The U.S. Army Corps of Engineers recommends use of a CBR 4 for design because this is the minimum strength that is suitable for airfield construction. This concept assumes that an area will not be used for air vehicle operation unless it is suitable for operation of airfield construction equipment. Recently, joint Army and Air Force operational analysis has indicated that CBR 6 is a more practical limit to operation. A CBR 9 was used for C-5A and C-17 air vehicle development. This was selected solely on the basis that it appeared to provide the same bearing strength as the landing mat on CBR 4 originally specified. The latter requirement was abandoned because of the inability to predict landing mat performance to repeated landing accurately.

(b) An alternative to specification of CBR is to use a cone penetrometer reading known as Airfield Index (AI). CBR measurement is a tedious process not practical for extensive measurements during air vehicle tests on unpaved surfaces. AI measurements can be made rapidly. Consequently, nearly all air vehicle test data is presented in terms of AI rather than CBR. AI and CBR correlation varies from soil to soil. This is because CBR is a measure of confined bearing strength of soil, whereas AI is a measure of bearing strength plus soil cohesion. Presently, flotation technology is in a state of transition from CBR to AI. CBR should be used until a suitable procedure for correlation of ground flotation to AI is published.

c. Level of Operation. The level of operation intended on a selected airfield type and strength is a significant factor. Short time overloads of paved airfields may be necessary or desirable. Specification of unlimited operation for cases that actually involved very limited use, results in extreme weight and cost penalty to the air vehicle. Design levels for normal operation on paved airfields may be selected from those specified in AFM 88-6. The level of operation on unpaved airfields should be determined by analysis of the mission to be performed. An alternative is to determine the estimated capability of an existing air vehicle on the specified unpaved surface and then relate the new air vehicle requirement to the capability of the existing air vehicle.

d. Tire Operating Limits. Frequently, it is desirable to establish a limit on the amount of tire deflection permitted to meet the ground flotation requirement. Most ground flotation analysis methods are very sensitive to tire deflection (under inflation). Theoretically, this provides the required flotation. In practice, it is not achievable because tires will not perform properly or have satisfactory life. A suggested limit is 40 percent (40%) deflection for bias ply tires. This should be adjusted, however, in the case of flotation requirements applied to destination conditions. For example, a cargo air vehicle may be required to deliver cargo to an unpaved airfield. Tire limits should be applied to the original takeoff conditions rather than the destination conditions. En route deflation to permit use of low pressure at the destination was applied to the C-5A aircraft. This approach is not recommended because it adds excessive complexity to landing gear and wheels.

4.4.1.2.1 Ground flotation.

The flotation capability shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.2.1)

Bases for the procedures are results of US Army Corps of Engineers test of pavement and soil sections. All tests were accomplished at low speeds with ground carts. The failure criterion for paved airfields is surface cracking. The failure criteria for unpaved airfields are three inches or permanent rutting. All tests on unpaved surfaces were accomplished by straight rolling on an unbraked wheel.

Verification of unpaved airfield flotation by demonstration or test is not considered practical. The primary problem is establishment of a safe airfield with uniform strength characteristics at the specified value. Flight test of the air vehicle on an unpaved airfield may be desirable to develop flight handbook procedures and to evaluate system suitability qualitatively. This test, however, should not be established as a verification method for the stated flotation requirement.

VERIFICATION GUIDANCE (4.4.1.2.1)

TBS should be filled in with analysis using standard acceptable industry method for unprepared, semi-prepared, and prepared runway surfaces. The analysis should reflect the air vehicle’s mission requirements for the type of operation requested by the user.

VERIFICATION LESSONS LEARNED (4.4.1.2.1)

The analysis is based on using the procedures contained in ASD-TR-70-43 for paved airfields and ASD-TR-68-34 for unpaved airfields. For commercial aircraft, International Civil Aviation Organization Aerodrome Design Manual Part 3, Pavements, Second Edition 1983, describes their ACN/PCN analysis procedure. The Air Force civil engineering office developed a software program entitled, “Pavement-Transportation Computer Assisted Structural Engineering (PCASE)” to calculate the ACN for military aircraft.

The rigid pavement procedures of ASD-TR-70-43 evaluate concrete stress at the center of the slab due to a loading at the center of the slab. Air Force Civil Engineering, U.S. Army Corps of Engineers, and Federal Aviation Agency rigid pavement design methods evaluate concrete stress at the edge of the slab due to a loading at the edge. This approach results in maximum stress up to 25 percent (25%) greater than the method used by ASD-TR-70-43. This increase is somewhat offset by assumption of level transfer to adjacent concrete slabs. In the event that ground flotation requirements are closely related to design of a specific pavement, it may be best to evaluate the landing gear design by the exact method of the appropriate agency.

It often has been noted that when more than one tire pressure is used to meet the flotation requirement, the user may be reluctant to change the tire pressure for any individual mission. Thus, it is more preferable to meet the requirement with the normal tire pressure.

The C-5 had an on-board inflation and deflation system to meet the flotation requirement. This was subsequently removed due to lack of use and unscheduled maintenance to fix leaks. Thus, consider carefully the use of onboard inflation and deflation devices, and ensure they can meet maintenance requirements.

3.4.1.2.2 Ground handling.

4.4.1.2.2 Ground handling.

3.4.1.2.2.1 Jacking provisions and conditions.

4.4.1.2.2.1 Jacking provisions and conditions.

3.4.1.2.2.1.1 Axle jacking.

Axle jacking shall be capable of raising (TBS 1) weight air vehicle high enough to perform required maintenance while exposed to (TBS 2) crosswind from any direction.

REQUIREMENT RATIONALE (3.4.1.2.2.1.1)

This requirement establishes axle-jacking capability.

REQUIREMENT GUIDANCE (3.4.1.2.2.1.1)

TBS 1 should usually reflect the need to jack up a maximum design gross weight air vehicle.

TBS 2 lists a crosswind limit set at a value which can realistically be expected in service usage and when the user would expect to still be performing maintenance functions requiring jacking. Arbitrarily, this value should be 15 knots to be consistent with structural design criteria. The structural load factors will be defined by the applicable structures criteria document.

Air vehicle gross weight, center of gravity location, strength of the jack pad, and attachment are influences on meeting this operational need.

This requirement is an expansion of MIL-A-8860 criteria to include crosswind limits.

REQUIREMENT LESSONS LEARNED (3.4.1.2.2.1.1)

None.

4.4.1.2.2.1.1 Axle jacking.

During the flight test program, jacking capability and provisions on the air vehicle shall be evaluated to the specified limits of the system. Crosswind compatibility shall be verified by analysis.

VERIFICATION RATIONALE (4.4.1.2.2.1.1)

The risk and time associated with exposing valuable test air vehicle to high crosswinds during flight test are too high. Therefore, analysis of crosswind capability is satisfactory. However, it is important to demonstrate the basic axle jacking capability on the air vehicle to evaluate component compatibility and design capability.

VERIFICATION GUIDANCE (4.4.1.2.2.1.1)

Required jacking capability and provisions should be demonstrated on the air vehicle. Jacking should be demonstrated in the wind available, and performance under the full wind velocity should be verified by analysis. Jacking demonstration should use an air vehicle configured to the most critical weight and center of gravity location. At a minimum, the following demonstrations should be accomplished using only production support equipment: (1) replacement of the main wheel, tire, and brake with tire inflated; (2) replacement of nose wheel and tire with nose tire initially deflated; and (3) replacement of main wheel and tire with main tire initially deflated.

VERIFICATION LESSONS LEARNED (4.4.1.2.2.1.1)

If the air vehicle is to be operated in a worldwide environment, then the jacking interface needs to meet the international requirements for international support equipment (such as NATO STANDARD AASSEP-1 and STANAG 3098).

3.4.1.2.2.1.2 Fuselage jacking.

See JSSG-2006, Aircraft Structures Joint Services Specification Guide, “Maximum Airframe Jacking Weight” requirement.

4.4.1.2.2.1.2 Fuselage jacking

See JSSG-2006, Aircraft Structures Joint Services Specification Guide, “Maximum Airframe Jacking Weight” verification.

3.4.1.2.2.1.3 Landing gear towing.

Interfaces shall be provided on the landing gear for pushing or towing the air vehicle at (TBS 1) gross weight up or down a (TBS 2) slope on a (TBS 3) surface.

REQUIREMENT RATIONALE (3.4.1.2.2.1.3)

This is to ensure the air vehicle and the landing gear subsystem can withstand the loads imparted while towing and to ensure that the interface between the air vehicle and towing equipment are adequately defined.

REQUIREMENT GUIDANCE (3.4.1.2.2.1.3)

TBS 1 should reflect maximum design gross weight usage. The air vehicle should be able to be pushed or pulled over a required slope that reflects the expected usage.

TBS 2 should typically be 3-degree slope.

TBS 3 should address towing under maximum conditions and should probably be limited to dry concrete surfaces, but any special case can be reflected in this requirement. Towing at angles other than straight-ahead is implied by the operational concept of the requirement. Towing provisions should be compatible with STANAG 3278.

Details of the tow bar and tow bar attachment, strength of the landing gears for horizontal loads, runway surface conditions, available coefficient of friction, and angle of load application have influence on meeting the requirements stated above. The detail characteristics of the towing vehicle also affect meeting the requirement.

This requirement is clarification of criteria, which have been implied in MIL-STD-805 and MIL-A-8862. As stated, it is a new requirement even though a similar requirement has been individually applied to numerous air vehicles.

REQUIREMENT LESSONS LEARNED (3.4.1.2.2.1.3)

Compatibility with the nose gear steering system is a serious consideration. On some gears, towing is permitted to the limits of the powered system, but any additional input can result in damage to the steering system. This interface is very important.

Several gears have been damaged because the towing vehicle exceeded the limit drag force, sheared the safety pin, replaced the pin with a stronger material, and then repeated the high drag force pull. Instead of shearing the pin, the excessive load is reacted by the nose gear and structural failure occurs. This occurred on the F-5.

Depending on the air base, frequent use of the tow bar is a possibility. Therefore, simple and reliable installation is a clear requirement.

Consideration should be given to the air vehicle brake modulating system to prevent overloading the nose landing gear and air vehicle backup structure when the air vehicle brakes are being used during towing. Special concern is the use of on and off brake pressure at maximum towing speeds.

The interface of the tow bar to tow vehicle should be evaluated for large gap tolerances. A loose connection can generate high impact loads under normal stopping operations. These loads can exceed the standard design criteria of MIL-A-8863.

4.4.1.2.2.1.3 Landing gear towing.

Performance of the towing system shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.2.2.1.3)

Since there is considerable interface with the Aerospace Ground Equipment (AGE) and the air vehicle, this requirement is best verified with all the parts operating as a system on the air vehicle.

VERIFICATION GUIDANCE (4.4.1.2.2.1.3)

TBS: Towing capability should be verified by analysis, inspection of drawings and layouts, and a ground test demonstration with production and international support equipment. The demonstration should start with a stationary air vehicle and as a minimum include at least the following:

a. Towing at the maximum weight, with engines off, at most critical towing angle up the required slope.
b. Towing at maximum weight, with engine off, at most critical towing angles down the required slope.
c. Towing at angles outside of the powered steering range. Emergency fore and aft pulling provisions should be verified by analysis.

VERIFICATION LESSONS LEARNED (4.4.1.2.2.1.3)

Adequate provisions and documentation should be established to prevent any towing action that will cause damage to the air vehicle, steering system, or the towing implements. If there are physical stops on the steering system, then either quick disconnects are needed on the gear or the ground equipment need to have shear pins or some other device to prevent overloading the gear if towing angle limits are exceeded.

3.4.1.2.2.1.4 Emergency towing.

The landing gear shall have the following provisions for emergency towing: (TBS).

REQUIREMENT RATIONALE (3.4.1.2.2.1.4)

There are options available for emergency towing of the main and nose landing gear. Normally, this requirement is used for identifying towing lugs or rings.

REQUIREMENT GUIDANCE (3.4.1.2.2.1.4)

TBS should reflect the expected gear towing in the fore and aft directions under the emergency conditions expected to occur in field usage. The interface should be compatible with available ground equipment, both domestic and international.

Details of the tow vehicle attachment, tow ring design details, strength of the gear, and operating terrain control meeting this operational need.

REQUIREMENT LESSONS LEARNED (3.4.1.2.2.1.4)

This requirement reflects the criteria of MIL-STD-805 and the implied performance of MIL-A-8862. It is a clarification.

Some recent large air vehicles have received a deviation to equipping each main gear with emergency towing lugs. However, provisions for installation are provided. The risk that is taken by this action is the availability of the lugs when the need arises. If the need for emergency towing arises in a relatively remote area, the probability of having tow lugs located in the proximity is low.

The probability of needing emergency towing capability is very high for each off-runway situation. If the air vehicle is remotely dispersed or an emergency is inadvertently encountered due to an incident, the use of lugs is very likely. This is assuming that the air vehicle is in an environment for which it is not normally intended to operate.

4.4.1.2.2.1.4 Emergency towing.

Performance of the main gear towing system shall be demonstrated on the air vehicle during the ground test program.

VERIFICATION RATIONALE (4.4.1.2.2.1.4)

The capability of using the main gear as a towing attach point to extract that air vehicle from certain undesirable positions should be specified in accordance to the user expectations.

VERIFICATION GUIDANCE (4.4.1.2.2.1.4)

Towing capability should be verified by analysis, inspection of drawings and layouts, and a ground test demonstration with production and international support equipment. The demonstration should start with a stationary air vehicle.

VERIFICATION LESSONS LEARNED (4.4.1.2.2.1.4)

(TBD)

3.4.1.2.2.1.5 Towing interface.

The interface between the air vehicle and tow vehicle shall be as follows: <u>(TBS).</u>

REQUIREMENT RATIONALE (3.4.1.2.2.1.5)

This requirement is to define configuration or performance requirements to insure compatibility of the air vehicle towing fittings and the tow bar or tow vehicle. Other areas to be considered include steering of the air vehicle during towing and communications between the towing crewmembers.

REQUIREMENT GUIDANCE (3.4.1.2.2.1.5)

TBS should provide dimensions of towing fittings that are the subject of an international standardization agreement. Air vehicles intended for worldwide operation should comply to insure compatibility with towing equipment in various countries (that is, NATO STANAG 3278). Consider a requirement that the tow fittings be compatible with the appropriate standard tow bar. This requirement should be coordinated with ground equipment specification requirements.

Normally it should be required that the air vehicle be designed to permit the air vehicle to be steered by the tow vehicle. It may be desirable to require that this be done without disconnecting the air vehicle steering system.

Air vehicle size and weight, quantity of air vehicles to be built, and type of operation (worldwide or local) are primary factors to be considered in establishment of this requirement.

REQUIREMENT LESSONS LEARNED (3.4.1.2.2.1.5)

Most of the items covered by this requirement were included in MIL-STD-805 and AFSC DH 2-1.

a. Most existing air vehicles can be towed without disconnecting the steering, provided that the normal steering range is not exceeded. Tow bar shear pins are provided to prevent damage in the event the steer angle is inadvertently exceeded. Experience indicates that these pins are sometimes replaced by high strength pins, and nose gear damage results from exceeding the steering limit. The steering limit should be clearly marked on the air vehicle because it is too difficult for the tow operator to detect angle limits or see markings on the nose gear strut. Air vehicle markings should be at least 5 degrees inside of absolute mechanical limits.

b. On most current air vehicles, it is possible to disconnect the steering during towing so that the tow angle may exceed the normal steering angle. After disconnect of the steering system, it should be possible to turn the gear up to ±180 degrees from the straightforward position. A lesser angle (±120 degrees) may be sufficient for towing, but again, could result in structural damage, if exceeded.

c. The method used to disconnect the steering is very critical. If frequently used, the resultant wear may increase free play to the point that nose gear shimmy becomes a problem. Failure to reconnect the steering or incorrect connections have been problems on some past designs. Automatic disconnect methods avoid most of these problems but should also include a method to detect that the landing gear is out of the normal steering range and return it to the proper position for taxi. Particular attention should be given to proper detection of the 180-degree position because most landing gears are unstable if driven in reverse at high speeds.

d. Nose gear designs, such as the T-37, which require peculiar AGE (such as “stiff knees”) during towing to preclude collapse of the gear, have encountered difficulty. Such a design approach is currently considered undesirable. This was highlighted by AFLC/AFALD in their Lessons Learned.

e. It is difficult for tow vehicle operators to push back a tailless air vehicle. The absence of a long fuselage makes it difficult for the operator to sense his position relative to the centerline. This may be additionally problematic if the wheelbase/track ratio is low since the sensitivity to the tow bar angle is greater. A visual indicator of angle should be provided on the nose strut that is visible to the tow operator. Something as simple as large tick marks painted at 60, 0, +60 on the upper strut and a single tick mark below the pivot could be sufficient.

4.4.1.2.2.1.5 Towing interface.

Towing interface shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.2.2.1.5)

Due to the complex interaction of the air vehicle and support equipment, verification should be accomplished by demonstration.

VERIFICATION GUIDANCE (4.4.1.2.2.1.5)

TBS: Towing interface should be verified by analysis, inspection of drawings and layouts, and a ground test demonstration with production and international support equipment.

VERIFICATION LESSONS LEARNED (4.4.1.2.2.1.5)

(TBD)

3.4.1.2.2.1.6 Mooring provisions.

Mooring provision shall be compatible with (TBS 1) and shall be capable of withstanding (TBS 2) with all surfaces locked at (TBS 3) gross weight.

REQUIREMENT RATIONALE (3.4.1.2.2.1.6)

Landing gear should be compatible with standard mooring patterns. This is a performance requirement for the landing gear with mooring equipment attached. The amount of crosswind identified should be the same as that selected for structural design. Nominally, the value is 70 knots and it applies to any gross weight.

REQUIREMENT GUIDANCE (3.4.1.2.2.1.6)

TBS 1 should reflect the expected mooring arrangement that the landing gear will see in service.

Mooring patterns, mooring attachment details, mooring methods, and attachment strength control this requirement.

TBS 2 should reflect the mooring capability of withstanding a 70-knot wind from any horizontal direction, with all air vehicle surfaces locked.

TBS 3 should be filled in with all gross weight configurations. Preloading of the mooring provisions resulting from strut compression beyond the gross weight static position should be included.

Mooring fitting strength and mooring loads control meeting this requirement.

REQUIREMENT LESSONS LEARNED (3.4.1.2.2.1.6)

The strength requirement is derived from the legacy specification MIL-A-8865. This indicates mooring in a 70-knot crosswind. The MIL-A-8865 requirement is a direct derivative of ANC-2, which requires mooring in a 75 mph wind.

Several recent air vehicles have waived the mooring requirements. This is a using command decision. If the mooring is not to be used to survive in adverse weather, it may be more expedient to dispatch to air vehicle to other bases rather than to take the risk of weather damage.

Mooring attachments should be made as air vehicle equipment versus support equipment for ease of use. Some air vehicles have the mooring attachments as support equipment for weight savings purposes. Equipment is only installed when required. Problems arise in having adequate quantities of mooring rings available for use and at the needed locations where aircraft are deployed.

Generally, the gear design uses the same attachment for mooring and emergency towing. The towing lug makes a convenient attachment for a mooring cable.

The drawings 61A101D, “Tie Down-Aircraft Chain Type,” and 61A101B10, “Hook-Tie Down Aircraft Chain Type,” can provide tie down details. The inside diameters of tie down rings should not be less than one inch.

MIL-STD-81259 provides standard mooring patterns for shipboard use. Air Force patterns are either on 15, 20, or 30 ft grids according to Unified Facilities Criteria (UFC) Airfield and Heliport Planning and Design, UFC 3-260-1.

If possible, the same attachment for emergency towing and mooring should be used on main gears to minimize the weight to accommodate this capability.

Caution should be used in nose gear mooring arrangements to avoid damaging control equipment when the mooring cables are installed.

4.4.1.2.2.1.6 Mooring provisions.

The mooring provisions shall be verified by (TBS 1). Mooring conditions shall be verified by (TBS 2). Design characteristics and component compatibility shall be evaluated.

VERIFICATION RATIONALE (4.4.1.2.2.1.6)

AGE - Air vehicle interface is best demonstrated on the actual air vehicle. Analysis cannot adequately evaluate this characteristic.

VERIFICATION GUIDANCE (4.4.1.2.2.1.6)

TBS 1: Mooring provisions should be verified by analysis, inspection of drawings and layouts, and a ground test demonstration.

TBS 2 should reflect the ability to moor the air vehicle in a demonstration using only production support equipment. Resistance to wind loads while moored, including preload of the shock absorbers, should be verified by analysis.

VERIFICATION LESSONS LEARNED (4.4.1.2.2.1.6)

(TBD)

3.4.1.2.3 Ground Foreign Object Debris (FOD).

Landing gear forward of engine inlets shall be designed and located to minimize FOD and water ingestion into the engine.

REQUIREMENT RATIONALE (3.4.1.2.3)

This requirement is presented to reduce detrimental engine performance due to water or other contamination thrown by the landing gear during ground operations.

REQUIREMENT GUIDANCE (3.4.1.2.3)

(TBD)

REQUIREMENT LESSONS LEARNED (3.4.1.2.3)

Special nose tires which incorporate chines may be required to deflect water away from the engines.

4.4.1.2.3 Ground FOD.

Ground FOD shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.2.3)

A combination of analysis, demonstration, or flight test is used to determine water deflection angles or debris path.

VERIFICATION GUIDANCE (4.4.1.2.3)

Typically, analysis is sufficient to determine if there are potential concerns with the nose tires deflecting debris toward engine inlets or other critical components on the air vehicle. Water spray patterns are investigated as part of wet runway takeoff and landing performance. Verification of air vehicles on flooded runways may be required. Air vehicles operating off semi-prepared airfields should be flight tested to verify amount of damage due to rock impacts or unusual loading with deflectors that go through standing water.

VERIFICATION LESSONS LEARNED (4.4.1.2.3)

The C-17 experienced significant damage to antennas, main landing gear (MLG), door leading edges, and MLG surface finish due to thrown rocks from semi-prepared operations. Rock deflectors were explored but high loads were found while testing on a flooded portion of the runway. These loads prevented the incorporation of deflectors.

3.4.1.3 Structure.

4.4.1.3 Structure.

3.4.1.3.1 General provisions.

See JSSG-2006, Aircraft Structures Joint Service Specification Guide.

4.4.1.3.1 General provisions.

See JSSG-2006, Aircraft Structures Joint Service Specification Guide.

3.4.1.3.1.1 Material selection.

Material selection shall be made in accordance with (TBS 1), except as modified by (TBS 2).

REQUIREMENT RATIONALE (3.4.1.3.1.1)

Alloy selection, manufacturing processing, protective finishes, surface finishes, plating methods, and material properties are important factors in the success of the landing gear design. The major modes of failure for landing gear equipment are frequently structural, and this is a very important consideration.

REQUIREMENT GUIDANCE (3.4.1.3.1.1)

TBS 1 should be filled in with requirements from MIL-STD-1568 and MIL-STD-1587.

TBS 2 should be completed by reference to the document used to tailor the standards.

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.1)

The material selection methods and corrosion control plans identified in MIL-STD-1568 and MIL-STD-1587 are a compilation of experience and lessons learned by the Air Force Materials Laboratory and the ASD/industry counterparts. They evolved into AFML 70-7, “Do’s and Don’ts of Materials Application.” This unofficial documentation has been directly inserted in several development programs’ System Specifications. It reflects much of the experience of the landing gear industry and lessons learned in landing gear service difficulties. Much of the criteria were contained in MIL-L-8552, Amendment 1, and reflect the former Aeronautical Systems Division/Ogden Air Logistics Center Task Group lessons learned. There have been many lessons learned in landing gear material and processes. Ogden ALC personnel contributed significant improvements and observations in this area. In addition to guidance provided in MIL-STD-1568 and MIL-STD-1587, the following items apply to landing gear design and processing as recommended practices:

a. Where steel forgings are used, use only vacuum arc remelt parts.

b. The preferred method of cold straightening of steel parts hardened to tensile strength of 200,000 psi and above would be to temper the parts while in a straightening fixture.

c. Magnetic particle inspection should be performed on all finished steel parts that are heat treated in excess of 200,000-psi ultimate tensile strength.

d. Many parts are received with forging laps or inclusions that were in the part at the time of manufacture. These defects may not be detrimental to the service of the part; however, they may give false indications of cracks when the part is magnetic particle inspected years later at the depot. Inspectors cannot determine whether these indications are forging laps or actual fatigue cracks. The part may be rejected. These defects should be removed as much as possible during manufacturing.

e. Bushings should be limited to non-ferrous materials for the principal static and dynamic joints.

f. All joints should be bushed to facilitate depot rework.

g. Considerable numbers of problems have been experienced where bushing materials have been made from Teflon and phenolic type materials. These should not be used without verification of wear life expectancy or a rework procedure available for refurbishment of the bearing. Consideration should be given to the need and also to the placement of adequate grooves and their configuration for providing lubrication to all areas of the joint.

h. All surfaces, except holes under 0.75 inch in diameter, of structural forging forged from stress-corrosion susceptible alloys which, after final machining, exhibit transverse grain exposed in the surface, should be shot peened or placed in compression by other suitable means.

i. All interior surfaces of hollow landing gear components, pins, and fasteners should have suitable corrosion protection to prevent degradation of capability.

j. Areas of components considered to be critical in fatigue should have a surface roughness in the finished product not to exceed 63 rhr, as defined by ASME B46.1, or should be shot peened, with a surface roughness prior to peening of not over 125 rhr. Unmachined aluminum die forging should be approximately 250 rhr, except surfaces where flash has been removed.

k. Efforts should be made to reduce stress concentrations, such as using stress relief heat treatments (except aluminum alloys), and to optimize grain flow orientation, such as using “wet installed” inserts and pins and extensive use of surface cold working.

l. Avoid cross drilling of joint pins. Drilling operations result in material surface damage and stress risers that are difficult to control.

m. Consideration should be given to the location of drain holes to ensure they will properly drain and reduce the probability of corrosion.

n. The short transverse grain direction, if exposed, should not be subjected to any sustained tensile loads.

4.4.1.3.1.1 Material selection.

Material selection shall be verified.

VERIFICATION RATIONALE (4.4.1.3.1.1)

The landing gear becomes an integral part of the airframe structure, and review of materials and processes is accomplished in the same manner as the rest of the structure.

VERIFICATION GUIDANCE (4.4.1.3.1.1)

Material selection should be in accordance with the required standards.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.1)

(TBD)

3.4.1.3.1.2 Roughness and runway repair profile criteria.

The landing gear shall operate without degradation of performance or service life on surfaces with the following roughness characteristics: (TBS).

REQUIREMENT RATIONALE (3.4.1.3.1.2)

The roughness of the runway surfaces to be used by the air vehicle is a major consideration in design of the landing gear. The largest loads generally experienced by the landing gear are generated by the aircraft's dynamic response from operations over the required level of surface roughness. Loadings generated from operations on unpaved airfields may also establish limits on landing gear arrangement and aircraft weight and tire size to ensure that the air vehicle is not immobilized by the specified roughness.

REQUIREMENT GUIDANCE (3.4.1.3.1.2)

TBS should be filled in with one or two aspects of roughness. The first should be a discrete bump or dip criterion that establishes the maximum roughness to be encountered. The second is the frequency of occurrences of the various levels or roughness. The air vehicle gross weight condition and operating requirements should also be stated. In the case of paved airfields, this is usually all weights to maximum gross weight and all ground speeds to the maximum required for takeoff and landing. In the case of air vehicles to be operated from unpaved airfields, the gross weight is usually limited to that required for missions to be performed from unpaved airfield.

The paved airfield curve should be specified for all air vehicles along with a requirement for negotiation of one-inch step bumps. The semi-prepared (matted soil) airfield curve and a two-inch step bump should be specified for most air vehicles to be operated on unpaved surfaces. The unprepared airfield curve and a four-inch step bump are considered severe and are rarely used.

For forward field operation, bomb damage repair criteria needs to be established. During the Have Bounce Program, bump profiles corresponding to categories A, B, C, D, E, and I bumps were defined based on repair mat profiles. It was found that most existing air vehicles were limited to category A or B bump profiles. It was shown through testing that gear could be easily modified or designed to handle C, D, and even I bumps, if needed. It is recommended that for wartime operation over bomb damage repair, the gear be designed to category E bump criteria as a minimum to provide the quickest turnaround for the Rapid Runway Repair (RRR) group and for the most effective wartime operations.
Performance parameters include gross weight, ground speed, lift characteristics, and frequency of operation on unpaved airfields.

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.2)

This requirement was previously stated in MIL-A-8862. The criteria are based on airfield roughness surveys conducted by the Air Force Flight Dynamics Laboratory in the early 1960's. The Have Bounce Program defines repair profiles and provides the basis for RRR philosophies. Wartime operational scenarios should dictate the capabilities needed for operation.

Laboratory testing and on air vehicle demonstration has shown that the gear can be designed, without any significant impact to gear weight, to handle bomb damage repair profiles of 4.5 inches in height. The internal changes can be accomplished on existing gear designs or incorporated on new designs as required. By being able to handle greater bump heights, the fatigue life of the gears and air vehicle structure are improved and the time to repair the runway to a condition to launch air vehicles is significantly reduced.

4.4.1.3.1.2 Roughness and runway repair profile criteria.

Performance during and after operation on surfaces of specified roughness shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.3.1.2)

Performance is a result of a complex interaction of air vehicle systems and the environment. Consequently, this requirement is best verified by air vehicle test. Testing can be accomplished on discrete bumps constructed to duplicate the specified roughness. Testing on a specified random roughness is usually impossible. An approach used in the past is to conduct taxi tests on two or three airfields to validate a dynamic response analytical model. The requirement is then verified by the validated analysis.

VERIFICATION GUIDANCE (4.4.1.3.1.2)

TBS should reflect an analysis of all expected bump and roughness profiles that the air vehicle will traverse during ground operations up through rotations as applicable to the user mission requirements. The analysis should be substantiated with air vehicle operations over known bumps and repair profiles.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.2)

The significance of airfield roughness to performance of a given air vehicle is somewhat dependent upon the characteristics of the air vehicle. Analysis should be used to select most critical roughness for test. Usually a bump or dip wavelength critical for one design will not be critical for another.

Several simulated rough surfaces have been constructed at Edwards Air Force Base (AFB) for evaluation of existing air vehicles. These surfaces may not be suitable for test of a new design because they do not represent the most critical condition. Test on these surfaces, however, may be useful for validation of a dynamic response analysis model.

Portable surfaces to simulate roughness were constructed for evaluation of the C-5A air vehicle. These surfaces may be fastened to paved runways for taxi testing. These surfaces were in storage and available for use as of early 1977. The Air Force program manager at the Lockheed-Georgia Company should be contacted concerning availability of these surfaces.

3.4.1.3.1.3 Failure tolerance.

In the event of landing gear structural failure, the following failure modes shall be prohibited: (TBS).

REQUIREMENT RATIONALE (3.4.1.3.1.3)

This requirement is to establish limits on structural failure modes to minimize secondary effects.

REQUIREMENT GUIDANCE (3.4.1.3.1.3)

TBS should be completed by a statement of prohibited failure modes. It may also be necessary to further define the conditions of failure. As an example, a statement for a transport air vehicle might read, "Pierce a crew station or passenger seating area or result in spillage of enough fuel from any part of the fuel system to constitute a fire hazard. It should be assumed that failure occurs during takeoff or landing and that landing gear loads are acting in the upward and aft directions except when the air vehicle departs the runway."

Equipment affecting safety of flight, if located in the wheel well, should be protected from tire blowout.

Hydraulic brake lines located on or near the landing gear should be protected against tire disintegration related damage.

Landing gears should permit rapid replacement of main wheels, tail wheels, or nose wheels.

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.3)

There are numerous causes of gear structural failure and every precaution is taken to avoid such events. However, action can be taken by design to control the modes of failure. Every effort should be taken to keep failed landing gear components from the cockpit area from severing hydraulic lines or from penetrating the fuel tank areas. The results of such an inability are obvious. This occurred with the F-89 and commercially on the 747. Subsequent redesigns have corrected these modes of failure.

There was an incident with the KC-135 in which the bogie beam experienced a failure and the failed parts pierced the water tank adjacent to the wheel well. With proper control of failure modes, this could have been avoided.

The Navy has experienced numerous landing gear failures that struck the fuel tanks and caused fires. However, with proper precautions and cautions, this problem has been minimized.

A means should be provided (such as a large washer behind the axle nut) to ensure wheel retention on the axle in case of a bearing failure.

4.4.1.3.1.3 Failure tolerance.

Failure tolerance shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.3.1.3)

(TBD)

VERIFICATION GUIDANCE (4.4.1.3.1.3)

Analysis should permit a wide variety of options to be studied and evaluated.

TBS: An analysis of probable gear failure locations and surrounding air vehicle structure should be accomplished to minimize adverse effects.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.3)

In the past, the cost and risk were too high to permit evaluation by test or demonstration.

3.4.1.3.1.4 Strength.

The landing gear subsystem shall not (TBS).

REQUIREMENT RATIONALE (3.4.1.3.1.4)

The landing gear subsystem should be strong enough to support all of the operational missions specified in the air vehicle specification for all environments and conditions in which it is expected to operate.

REQUIREMENT GUIDANCE (3.4.1.3.1.4)

TBS should be stated as follows:

a. Exhibit detrimental permanent set, yielding, or damage due to ground, flight, operational, and logistics limit load envelopes specified in the air vehicle specifications.
b. The structural components should not temporarily deform to the extent that functional performance is significantly affected within the flight and ground envelope conditions.
c. Catastrophically fail due to ground, flight, operational, and logistics ultimate load envelopes at a 1.5 safety factor or as specified in the structural loads documents.

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.4)

(TBD)

4.4.1.3.1.4 Strength.

The strength of the landing gear subsystem shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.3.1.4)

Verification of the yield and plastic deformation range of the structure should be such as to preclude such deformation that would prevent the landing gear subsystem from performing as commanded or required to complete the mission.

VERIFICATION GUIDANCE (4.4.1.3.1.4)

TBS should reflect the analytical and test method listed in the structural specifications for verification of air vehicle structure.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.4)

(TBD)

3.4.1.3.1.5 Durability.

The landing gear structure shall be designed for at least (TBS 1) lifetime representative spectrums based on operational loads and the air vehicle service life.

The landing gear systems shall be designed for at least (TBS 2) lifetime representative spectrums based on operational loads and the air vehicle service life.

The landing gear components shall be designed for at least (TBS 3) lifetime representative spectrums based on operational loads and the air vehicle service life.

The landing gear actuation system, including the backup structure, actuators, doors and mechanisms, and locking details, shall be capable of (TBS 4) retraction/extension cycles, of which (TBS 5) (cycles shall include emergency extensions).

REQUIREMENT RATIONALE (3.4.1.3.1.5)

Landing gear subsystem should have design lifetimes to ensure the system will last the life of the air vehicle.

REQUIREMENT GUIDANCE (3.4.1.3.1.5)

TBS 1: For non-damage tolerant structure the lifetimes should be four (4), for structure design to damage tolerant criteria, the lifetimes should be two (2).

TBS 2: System life operation should reflect two (2) lifetimes of operation.

TBS 3: For components that are not considered limited life should be four (4) lifetime capable.

TBS 4: The actuations system and all its components should have the capability of 10,000 cycles.

TBS 5: 500 cycles of the number for TBS 4 are for emergency extensions.

The actuation number of cycles should take into account the number of touch and go cycles as well as the normal and emergency operation.

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.5)

(TBD)

4.4.1.3.1.5 Durability.

The durability of the landing gear subsystem shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.3.1.5)

Based on the latest structural design practices and determination of the operational cycles of the landing gear through all phases of air vehicle operations, the expected life of the gear and its systems should be determined.

VERIFICATION GUIDANCE (4.4.1.3.1.5)

TBS should be filled in with analysis, testing, and material properties validation that supports the required life of the systems needed to meet air vehicle mission and life requirements.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.5)

(TBD)

3.4.1.3.1.6 Corrosion protection.

Landing gear systems shall be able to operate, with proper maintenance in corrosion producing environments as defined in (TBS), without degrading strength, life, and performance requirements of the landing gear or aircraft.

REQUIREMENT RATIONALE (3.4.1.3.1.6)

Many landing gear are made from high strength steels such as 4340, 300M, and Aeromet 100, which are very susceptible to stress corrosion cracking. Proper surface finishes and maintenance procedures are critical to prevent premature failures.

REQUIREMENT GUIDANCE (3.4.1.3.1.6)

The TBS is usually the same environments identified for the aircraft such as precipitation, humidity, and saltwater breezes.

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.6)

Corrosion is one of the leading causes for field failures in landing gear over the life cycle of a weapons system. Cadmium plating had been the primary choice, but it is identified as a hazardous material. New environmentally friendly materials have been developed as suitable alternates. The latest of these materials is a low hydrogen embrittlement zinc-nickel plating developed by Hill AFB. The commercial industry has also started using the material.

Landing gear are exposed to FOD and maintenance induced damage that compromise the surface finish protection. The Technical Order data should identify standard materials and processes to remove scratches and pits and restore surface finishes.

4.4.1.3.1.6 Corrosion protection.

The corrosion protection systems shall be verified by inspection of drawings and component testing of surface finishes.

VERIFICATION RATIONALE (4.4.1.3.1.6)

In many cases, the surface finishes are identical to systems currently used in the field. No additional testing is required based on similarity. If new systems are introduced, testing is required to verify that surface finishes can withstand the natural environment and other fluid exposures such as fuel and hydraulic fluids.

VERIFICATION GUIDANCE (4.4.1.3.1.6)

(TBD)

VERIFICATION LESSONS LEARNED (4.4.1.3.1.6)

(TBD)

3.4.1.3.1.7 Flat tire and flat strut operation.

In the event of a flat tire or a depressurized shock absorber, the gear shall be capable of _(TBS)_ without structural damage to the gear or the air vehicle.

REQUIREMENT RATIONALE (3.4.1.3.1.7)

The objective of the requirement is to establish performance capability of the landing gear under the emergency condition for a selected component failure, which has a reasonably high probability of occurring.

Consideration is also given to ensure that sufficient ground clearance is maintained, particularly on air vehicles that have external stores and fuel tanks. It is possible to have ground contact with these stores while performing normal landing and takeoff operations.

REQUIREMENT GUIDANCE (3.4.1.3.1.7)

TBS should describe an average landing condition. For example, a flat strut-landing requirement could be a landplane-landing-weight air vehicle landing at 6-feet/second vertical contact velocity. It will also be necessary to identify ground-handling limits that might be expected under these conditions.

Air-oil characteristics of the strut, metering pin-orifice combination, wheel frangibility, and operating techniques have significant impact on this requirement.

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.7)

This is a new requirement not previously defined prior to system development. This emergency capability has been implied and left to the undefined risk of the using commands. Some portion of the criteria has been contained in MIL-A-8862 for flat tire design load conditions. There has been a requirement for design strength dating back to ANC-2, but only an implied operational capability that has never been demonstrated.

Frequently, if the gear is not properly positioned upon touchdown, the necessary system actuations can be jeopardized. Landing with a flat strut, for example, may result in loss of anti-skid control.

Without warning or prior notice, this type of system malfunction can lead to numerous difficulties.

In the event the condition is unknown to the pilot, no precautions will be taken, so a limit on performance is necessary to prevent loss of air vehicle.

4.4.1.3.1.7 Flat tire and flat strut operation.

Landing gear energy absorption performance with a deflated strut or flat tire shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.3.1.7)

Normally, this can be accommodated during the jig drop test program. It provides a controlled environment with no risk to an air vehicle. In the event difficulties are encountered when demonstrating this emergency condition, the laboratory is a more suitable environment. In the event that a test program is not planned, an analysis of the condition is the least that can be expected.

VERIFICATION GUIDANCE (4.4.1.3.1.7)

TBS should reflect verification by analysis and laboratory drop test.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.7)

It is difficult to laboratory test both the flat strut and flat tire test and ensure there will not be any damage to the air vehicle. You can test to verify that there will be no damage to the gear during a flat strut landing and that the wheel will not come apart when landed with a flat tire. However, it is too risky to demonstrate on the air vehicle, and there will always be a possibility of some damage to the air vehicle when it operates with a flat strut or flat tires.

3.4.1.3.1.8 Energy absorption.

The landing gear subsystem shall absorb sufficient landing energy such that (TBS 1) is not exceeded under the following conditions: (TBS 2).

REQUIREMENT RATIONALE (3.4.1.3.1.8)

This requirement is to establish shock absorption performance capable of meeting structural load criteria defined in the system structural criteria documents.

REQUIREMENT GUIDANCE (3.4.1.3.1.8)

TBS 1 should reflect the desired sink speed(s).

TBS 2 should be filled in with the air vehicle weight(s).

A number of sink speed and weight combinations can be specified to match a number of different operating conditions.

Normally, these requirements are established as 10 feet/second sink speed at landplane landing weight and 6 feet/second at maximum landing weight. If special system design conditions exist, they should also be reflected in these performance requirements as an addition to these criteria. In the past, a reserve energy criterion of 12.5 feet/second sink speed at landplane landing weight was imposed, with minor failures permitted. This represents a 50 percent (50%) margin in energy capacity since the velocity function is squared in calculating the absorbed energy.

The vertical travel of the wheels during operation of the shock absorber struts should be sufficiently long to ensure that ground loads that are based on load factors determined by drop tests will not be appreciably more critical than other loading conditions for the carry-through structure.

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.8)

The sink speed or vertical energy requirements for shock absorber and landing gear design are currently defined in MIL-A-8863. The standard vertical contact velocity has grown from 9 feet/second to 10 feet/second at landplane landing weight. Both the contact velocity and the landing weight are frequent items of deviation and discussion. They should be established as a direct result of operational analysis of the intended air vehicle.

Recent examples of special consideration of sink speed included C-5A and Advanced Medium Short Take Off and Landing Transport (AMST). The C-5A rightfully assessed the operational concept and reduced the landplane landing weight contact velocity to 9 feet/second in lieu of the required 10 feet/second. This better meets the operational usage of the air vehicle and results in weight saving.

On the AMST, the operational concept of the air vehicle calls for flights in and out of short bare field runways in a hostile environment. Under these circumstances, the operational concept is to increase the sink speed to reduce the stopping distance. A design contact velocity for this condition will be established by analysis of the landing performance requirements. The C-17 air vehicle that came out of the AMST program was designed to operate at 14.5 ft/sec-sec sink speed at mission weight for this very reason.

Another example of rational criteria is the use of higher sink speeds for trainer air vehicle. Since the operator is inexperienced, the probability of high-speed contact is significantly increased. Therefore, the normal criteria is 13 feet/second sink speed or higher as determined by the user.

4.4.1.3.1.8 Energy absorption.

Landing gear shock absorption performance shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.3.1.8)

Normally, this requirement is satisfied by demonstration during a jig drop test. The test not only assesses the ability to absorb the vertical energy, it also serves to evaluate rebound, spring rates, damping in both directions, and other dynamic characteristics.

There are several air vehicles that have flown on calculated metering pin-orifice combinations with relative success. Most Navy gears have calculated pins, but they are ultimately evaluated by dropping the total airplane in a fatigue drop test.

VERIFICATION GUIDANCE (4.4.1.3.1.8)

TBS should be accomplished by analysis and laboratory testing, with demonstration during flight-testing.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.8)

(TBD)

3.4.1.3.1.9 Ride quality.

The landing gear subsystem shall provide a ride such that the vertical accelerations at the pilot's station shall not exceed (TBS 1) on a (TBS 2).

REQUIREMENT RATIONALE (3.4.1.3.1.9)

The objective of the requirement is to establish quantitative ride quality requirements that can be verified. Runway roughness has long been recognized as affecting the peak design loads and the fatigue life of the basic airframe structure. Ride quality relates to pilot comfort and his ability to function in the cockpit dynamic environment induced by ground loads and air vehicle response.

REQUIREMENT GUIDANCE (3.4.1.3.1.9)

TBS 1 should be filled by insertion of the acceptable acceleration limits.

TBS 2 runway surface roughness should be specified in detail and should match up with the structural ground roughness criteria specified in the air vehicle specification.

As a minimum, the criteria should be based on pilot functional capability. In other words, criteria should reflect the maximum levels of oscillation at which the pilot can continue to perform required control functions. Aircrew physical comfort should also be considered.

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.9)

The prime example of problems for which this criteria is intended is the XB-70. The location of the cockpit relative to the nose gear amplifies the vertical travel of the nose gear shock strut. The problems that the designer is trying to avoid are primarily physiological. The environment has been known to be so hostile that the pilot was unable to read the instruments or to provide vocal communication.

There are numerous solutions to the problem of ride quality. The most common of recent times has been to use dual chambered shock struts. This design solves the ride quality problem, but introduces severe landing gear maintainability problems. In the F-4, C-5A, and F-15, it has been difficult to seal the high-pressure chamber, and there is no way to determine the status of the cylinder without disassembly. Development of adequate servicing and inspection techniques has been difficult. The FB-111 uses dual pistons, but has a single air chamber. It has been a relatively good performer in the field.

4.4.1.3.1.9 Ride quality.

Ride quality shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.3.1.9)

An analysis permits evaluation within the full operational spectrum. However, in order to obtain confidence in this review, it is necessary to verify discrete points by actual taxi test on the airplane over a known runway profile.

VERIFICATION GUIDANCE (4.4.1.3.1.9)

TBS: Ride quality should be verified by analysis, substantiated by component laboratory testing and demonstrated on the air vehicle during flight testing.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.9)

(TBD)

3.4.1.3.1.10 Landing gear servicing.

The (TBS) types of landing gear servicing shall be accomplished without removal of components or jacking of the complete air vehicle.

REQUIREMENT RATIONALE (3.4.1.3.1.10)

This requirement is to ensure that consideration is given to maintenance requirements in design of the landing gear installation and fairing. Designs that require air vehicle jacking and strut removal not only increase maintenance costs but also increase the possibility of maintenance accidents.

REQUIREMENT GUIDANCE (3.4.1.3.1.10)

TBS should be filled with at least the following: “gas charging, oil replacement, and inspection for proper servicing.”

Internal shock strut design, which impedes fluid flow and location of the drain, are the major considerations in meeting this requirement.

It should be possible to complete a full re-service of each shock-strut with both fluid and nitrogen in no more than 30 minutes.

It should be possible to determine the amount of extension for all struts without removing any cowling or without using a measuring device other than a scale. A scale integral with the strut is desirable.

If serviced with fluid, the shock absorber struts should utilize the same type of fluid as used in the air vehicle hydraulic system. On Navy air vehicles without a hydraulic system, MIL-PRF-83282 is preferred.

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.10)

This requirement was previously contained in MIL-L-8552 and represents an application of lessons learned and an attempt to standardize maintenance procedures. This is part of the overall effort to improve air vehicle maintainability.

The maintenance of shock absorbers is a very important factor in achieving desired performance and life. Strut servicing with fluid and charging agent should be as simple as possible under all load conditions to ensure that line maintenance personnel accomplish the required functions.

Most struts require complete removal or pulling of the piston to drain the fluid. The hazards of oil spillage should be readily apparent. Recent efforts have been made to attempt to influence designers to provide drainage capability without removal. This requirement is intended to continue this pursuit.

Strut filling is another important function that is potentially compromised on most designs. There is no way of telling fluid level without complete deflation and refilling. It is unfortunately easier to add nitrogen and adjust the extension rather than to assess the fluid level. This results in inadequate fluid for metering during energy absorption. This then can result in excessive load and possible structural damage.

4.4.1.3.1.10 Landing gear servicing.

Landing gear servicing shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.3.1.10)

Initially design features such as servicing will be reviewed by routine engineering discussions and inspection of drawings. After the air vehicle is in flight test status, maintenance function will be evaluated on a routine basis.

VERIFICATION GUIDANCE (4.4.1.3.1.10)

TBS should be filled in with inspection and demonstration and substantiated during flight-testing. This should take into account all servicing actions.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.10)

(TBD)

3.4.1.3.1.11 Repeated operation.

The landing gear subsystem shall be capable of performing its required shock absorption function within (TBS 1) after positioning for landing and shall not prevent accomplishment of (TBS 2) successive landings with (TBS 3) between landings.

REQUIREMENT RATIONALE (3.4.1.3.1.11)

Unless care is exercised in design, the internal shock absorber chamber arrangement can impede fluid flow. Assemblies with this characteristic have difficulty in performing the basic energy absorption function upon extension if they have been stowed with the centerline above horizontal and the fluid is required to flow from chamber. The purpose of this requirement is to establish a time limit consistent with system needs for fluid flow between chambers to ensure proper metering during energy absorption. The consequences of improper flow are foaming, improper metering, and cavitation. All of which result in excessive load and potential structural failure. It is recommended that the blank have two minutes inserted if no specific system requirements are identified or are unidentifiable.

REQUIREMENT GUIDANCE (3.4.1.3.1.11)

TBS 1 should reflect the minimum time from when the strut is fully extended to touchdown.

TBS 2 is the number of time landing or touch-and-go's that are performed within a given operation or training missions.

TBS 3 gives the minimum amount of time that expires between any set of landing or touch-and-go.

This requirement is intended to define the energy absorption capability for touch and go landings. The most severe succession of consecutive landings, which can reasonably be expected in service, should be identified for design. It is recommended that successive design conditions such as landplane landing at 10 feet/second, level-landing attitude, be identified within a five-minute period.

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.11)

Internal strut design with proper drainage routes controls this capability. Whether or not the strut fluid foams upon extension controls whether there is sufficient fluid beneath the orifice to ensure that only fluid is metered during the energy absorption stroke.

This performance characteristic was previously identified in MIL-T-6053. It represents a condition that can be developed when the air vehicle is used in training by landing with a series of touch and go landings. If the internal shock absorber design permits foaming of the fluid during the metering process, the second landing will encounter a portion of the energy stroke where gas will be metered through the orifice instead of oil, and the peak loads will be very high.

Fluid flow between chambers should be carefully considered in the internal strut design.

It would be beneficial to study design details of existing struts that are stored above the horizontal and successfully meet the extensive time requirements without any adverse effects.

Various circumstances affect the metering characteristics of a gas-oil shock absorber, including the ability to recirculate the oil, rebound characteristics of the strut, and temperature. Recirculation and rebound are a function of internal design and the temperature affects the air curve from which the taxi loads are determined. Higher temperature will result in noticeable load increases. The source of temperature increase can be changes in the ambient air or internal strut friction.

4.4.1.3.1.11 Repeated operation.

Repeated operation shall be verified <u>(TBS).</u>

VERIFICATION RATIONALE (4.4.1.3.1.11)

The laboratory drop test is the best method of demonstrating this requirement because the exact condition of installation and performance can be duplicated and controlled. It is significantly less expensive than trying to measure the loads and analyze the effects of this condition on the air vehicle during the flight test program.

VERIFICATION GUIDANCE (4.4.1.3.1.11)

TBS should reflect the number of successive drops to be done in a row with a specified minimum time between them. For those struts that are stored past horizontal, thus having air-oil inversion, it may be desirable to conduct an analysis and laboratory demonstration to ensure the oil drains into the proper chamber in time.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.11)

(TBD)

3.4.1.3.1.12 Friction control.

Shock absorber friction in the landing gear subsystem shall not cause (TBS).

REQUIREMENT RATIONALE (3.4.1.3.1.12)

This requirement is intended to minimize operational problems due to high mechanical friction of the shock absorber. Mechanical friction may cause severe operational problems in strut servicing and weapons loading. Quantitative requirements are not well defined because this characteristic has not been considered in detail on past designs. It is suggested that detailed study of a proposed air vehicle may result in suitable quantitative requirements. Areas of study could include strut extension as a function of strut pressure changes and change in elevation of external stores stations when weapons are loaded.

REQUIREMENT GUIDANCE (3.4.1.3.1.12)

TBS should specify as a minimum: “adverse effects in shock absorber servicing, air vehicle landing and taxi, and mission loading or unloading.”

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.12)

Static strut function on the A-10 air vehicle created a hazardous condition for weapons loaders in that at a certain load the strut would suddenly break away causing a significant change in elevation of the weapons loading point.

During some landings on early F-15 aircraft, one strut would stroke before the other due to differences in mechanical friction. The resultant asymmetric loading prevented the other strut from stroking for several seconds. The air vehicle ground rollout was in a skewed attitude adversely affecting control during this time.

4.4.1.3.1.12 Friction control.

Shock absorber friction control shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.3.1.12)

Careful analysis and design best meet this requirement. Except for some bearing material and seal changes, little can be done with existing hardware that proves unsuitable. Nevertheless, final proof of suitability is a demonstration on the air vehicle. In some cases, specific tests such as weapons loading, fueling, or servicing may be specified in detail to verify the function characteristics.

VERIFICATION GUIDANCE (4.4.1.3.1.12)

TBS should reflect inspection of drawing and layout to support an analysis of strut friction and ratcheting effects on air vehicle operations. The analysis may be supported with laboratory testing of bearing. The final verification should be operational demonstrations on the air vehicle for those critical stroking situations.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.12)

(TBD)

3.4.1.3.1.13 Reparability.

Where joints and wear surfaces are required, they shall accommodate reparability by <u>(TBS).</u>

REQUIREMENT RATIONALE (3.4.1.3.1.13)

Experience has shown that it is essential that a means be provided to permit rework of landing gear joints and wear surfaces. Failure to establish such a requirement results in high operating costs because expensive landing gear forgings must be replaced when contact surfaces are corroded or worn out of tolerance. Landing gear functional and structural requirements do not ensure that parts can be refurbished.

REQUIREMENT GUIDANCE (3.4.1.3.1.13)

This requirement is primarily intended to prevent scrapping of major landing gear forging due to normal wear and corrosion.

TBS should be completed by the following statement: “providing a minimum of 0.060 inch allowance on the diameter of each pinned joint and a minimum of 0.030 inch allowance on each non-circular wear surface.” Allowance means that up to this much material may be removed for insertion of bushings or other repair. Deletion of this requirement should be considered for prototype and other limited life air vehicles.

Small linkage parts that are more economical to replace than repair should be excluded from the requirement. The following is a suggested statement: “This requirement should not apply to any component such as small linkage parts that are more economical to replace than repair.”

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.13)

This requirement is intended to reflect the detail requirements currently documented in AFSC DH 2-1, AFSC DH 1-2, MIL-L-8552, and lessons learned on recent systems and commercial experience of airlines.

There are numerous air vehicles that have experienced wear in the joints. Examples would include KC-135 bushed axle and beam, B-52 pistons, and C-141 axle bogie beam fretting. Therefore, to save the expense of repair or replacement, it is vital to allow enough material for rework.

Joint designs have proved to be extremely critical in maintaining hardware in the fleet. Lessons learned include use of positive lubrication for all joints, static and dynamic. All joints should be bushed. All pressed fit or matched fit joints should be avoided. These features have contributed to great cost at the depot level during overhaul. They should be considered in the original design recognizing the service life commitment of "roughness and runway repair profile criteria" in this specification guide.

Commercial airline usage has made extensive use of lubrication and replaceable bushings to achieve extended use of major landing gear components. It is impossible to legislate against corrosion or wear. Only minimized detrimental effects can be included in design.

Extreme difficulty has been encountered in the use of keyways and threaded parts on the B-52. These have been the source of stress concentration and have resulted in numerous field failures from fatigue cracking.

4.4.1.3.1.13 Reparability.

Reparability shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.3.1.13)

Close engineering monitoring of design details during the development program is the only effective means of transfer of lessons learned. These lessons learned come from using commands and AFLCMC Engineering monitors.

VERIFICATION GUIDANCE (4.4.1.3.1.13)

TBS should be filled in with inspection of engineering drawings and analysis.

Strength and life analysis should be accomplished on the rework capability designed into the joints to ensure that the gear performance capability is not compromised when the joints are reworked.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.13)

(TBD)

3.4.1.3.1.14 Empennage protection.

Empennage protection, if used, shall be provided by (TBS 1) and shall incorporate the following features: (TBS 2) .

REQUIREMENT RATIONALE (3.4.1.3.1.14)

This requirement is aimed at protecting the empennage from damage during ground usage when the brakes are applied while the air vehicle is rolling backwards or the air vehicle is over rotated on take-off or landing, or during shipboard towing operations for all allowable sea state conditions.

REQUIREMENT GUIDANCE (3.4.1.3.1.14)

TBS 1 should be filled in with the appropriate empennage protection device.

TBS 2 should reflect the expected performance of the empennage protection device for those mission profiles that the air vehicle will see. It should list the number of times the bumper will be used and type of operation, such as passive bumper versus an extendable bumper.

Special control features include retraction, automatic extension based on throttle setting and gear position, emergency extension capability, and position indication.

Depending on the characteristics that are identified in the blank, various parameters influence and control this requirement. System design, component design details, and system interfaces are general areas of control.

Tail bumpers are frequent safety features that represent protection of more expensive and delicate airframe hardware that is jeopardized by extreme tail down landings, abrupt rotation on takeoff, and ground maneuvering.

REQUIREMENT LESSONS LEARNED (3.4.1.3.1.14)

This is a new requirement, not previously documented in design requirements. Since these special features affect the cost, it is necessary to state the requirements in the original documentation. Most of the special features are using command preferences, and they should be consulted extensively on these requirements. Since they are cost drivers, the user should be apprised and willing to accept their effect on reliability and maintainability.

Tail bumper design is a direct function of the protection to be provided. A simple ground handling protection device can be simply a hard point to prevent ground contact of the rest of the airframe. It would be infrequently encountered and usually be a simple manual device. If the protection desired comes from over rotation on takeoff or high attitude landing, the device becomes an energy absorber. If the strikes are frequent enough, the designer should consider a replaceable contact.

Another feature that is optional is the ability to position the bumper from the pilot’s station. Retractable bumper wheels or skids should extend during regular and alternate or emergency extension of the landing gear. A position indicator should be provided. If aerodynamic degradation occurs from having the bumper permanently extended, consideration should be given to providing a retractable feature.

If the bumper is contacted on takeoff or landing, there is a firm need to isolate the hydraulic system to prevent spikes of peak pressure being applied to the system.

The unit should be readily inspectable.

SAE ARP1107 is a useful reference for recommended practice for design and installation of tail bumpers.

4.4.1.3.1.14 Empennage protection.

Empennage protection shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.3.1.14)

The need for a bumper should be determined before an air vehicle is produced. Analysis is the only logical means to evaluate the full range of operational capabilities. The effectiveness of the bumper to provide the intended protection should be evaluated on the air vehicle. It can be accomplished as part of the routine observations. Some effort should be made to record frequency of strike to assist in evaluation of the operational adequacy.

VERIFICATION GUIDANCE (4.4.1.3.1.14)

TBS should be filled in with dynamic analysis of the air vehicle. The empennage protection operation and controls should be evaluated by air vehicle test.

Dynamic analysis should be conducted of all air vehicle ground and rotational operations to determine the need and the type of bumper.

VERIFICATION LESSONS LEARNED (4.4.1.3.1.14)

(TBD)

3.4.1.4 Velocity and directional control

4.4.1.4 Velocity and directional control

3.4.1.4.1 Braking.

Braking shall be provided with the capability to (TBS).

REQUIREMENT RATIONALE (3.4.1.4.1)

This requirement is necessary to establish performance requirements for the braking system.

REQUIREMENT GUIDANCE (3.4.1.4.1)

TBS should be filled in with the level of performance expected. Differential control of braking is a desirable feature to permit the pilot to use the brakes for directional control. Anti-skid control should be considered, but may be optional. There may be reason to have both a secondary and an emergency braking system.

Consideration should be given to a protection circuit or indication to the pilot of an incipient skid so as to minimize the potential of a tire blowout.

REQUIREMENT LESSONS LEARNED (3.4.1.4.1)

This is a reflection of the criteria previously stated in MIL-B-8584, AFSC DH 2-1, and AFSC DH 1-6. It reflects the lessons learned from WWII aircraft and has been standard criteria for over ten years. The only recent innovation has been the use of anti-skid control on emergency brake systems and the double redundancy of dual actuation lines for normal and emergency systems.

4.4.1.4.1 Braking.

Braking shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.4.1)

Since the requirement is for a level of performance, the only suitable demonstration is for the total system.

VERIFICATION GUIDANCE (4.4.1.4.1)

Brake performance should be verified by analysis and laboratory tests. System performance should then be substantiated during flight-testing.

VERIFICATION LESSONS LEARNED (4.4.1.4.1)

(TBD)

3.4.1.4.2 Directional control.

Directional control provided by the landing gear shall be as: (TBS 1). Ground directional control characteristics shall permit the pilot to control the air vehicle under the following crosswind conditions: (TBS 2).

REQUIREMENT RATIONALE (3.4.1.4.2)

Specific performance will be allocated to the landing gear steering, braking, propulsion, and flight control systems. Two major requirements to be defined. The first requirement is the expected performance during takeoff and landing with crosswinds and different runway coefficients of friction. The second requirement is the turn radius needed for ground maneuvering of the air vehicle for taxiways and runways. Both should be defined because the allocation to the landing gear steering system will be different for each case. The requirement to meet both is usually a steering system design driver.

REQUIREMENT GUIDANCE (3.4.1.4.2)

TBS 1 should reflect the ground maneuverability of the air vehicle for all phase of ground operations. Normally for high speed, small steering angles are required, whereas for taxi and ground apron operations, large steering angle control is needed. The system design and air vehicle control should be designed to reflect the full operational capability that meets the user's requirements and completes the mission. The following should be considered in determining the appropriate directional control:

a. Air vehicle geometry
b. Landing gear geometry
c. Width of runways and taxiways
d. Type of airfield surface (wet or dry)
e. Cargo handling (loading dock compatibility)
f. Takeoff and landing speeds
g. Thrust reversal
h. Crosswind

TBS 2 should specify the crosswind condition limits under which the pilot should be able to control the air vehicle.

Since it is a full system requirement, the capability of the steering system is combined with various other techniques to identify the directional control capability desired for the total air vehicle.

REQUIREMENT LESSONS LEARNED (3.4.1.4.2)

a. A method frequently used to specify the ground maneuvering requirements is to establish the maximum width permitted for the air vehicle to make a 180-degree turn on a dry pavement without use of differential braking. This characteristic is usually presented in the flight handbook for each current air vehicle.

b. In some cases, obstacle clearance by the air vehicle may be more restrictive than pavement width available for ground turning. The flight handbook also normally provides characteristic data for current air vehicle.

c. Excessive reliance should not be placed on use of differential braking for ground maneuvering. Minimum radius turns using this approach are difficult to accomplish with precision. In addition, this condition frequently results in the most critical landing gear loads. If used extensively, this will result in landing gear reliability problems. Directional control by differential braking is very unsuitable for air vehicle operation on soft surface airfields because it causes extreme surface damage. Turnaround requirements should not be so restrictive that they can be met only by a pivot turn.

d. If it is expected that the air vehicle will have a reverse thrust capability, it may be desirable to establish a direction reversal requirement more severe than can be accomplished by a normal 180-degree continuous turn. Operation of C-130, YC-14, and YC-15 air vehicle has shown that direction reversal by several movements of the air vehicle, including backing of the air vehicle, is a practical operation. Pilot experience has shown that the number of movements should be restricted to three.

e. Air vehicle ground directional control is usually severely degraded if the airfield surface is icy, wet, or soft. This should not be ignored. However, establishment of a requirement for ground maneuvering on anything other than a dry concrete surface should be avoided. Experience has shown that verification of compliance on any other surface is impossible due to difficulty of accurate control of the many test variables.

f. Airfield geometry for standard construction is controlled by the following manuals, which may be useful in establishment of requirements:

    1. AFM 86-3, Planning and Design of Theater of Operations Air Bases

    2. AFM 86-8, Airfield and Airspace Criteria

Some systems have tried to maintain a steering tolerance of 0.2 degrees, which has proven to be very difficult to rig and maintain.

Overall landing gear arrangement and basic ground stability are significant factors in crosswind operating performance. This requirement should be compatible with the ground stability requirement.

Flight test experience has revealed that shock strut characteristics can influence crosswind-landing response. High breakout loads of the strut combined with aerodynamic characteristics of the air vehicle may result in failure of the air vehicle to attain a wings-level attitude during rollout. This may appear to the pilot as poor directional control.

This requirement should apply to operation on dry concrete airfield surfaces only. Crosswind performance is degraded on low coefficient of friction surfaces. However, verification of a stated requirement on such surfaces is difficult. Flight test evaluation on adverse surfaces should be accomplished for flight handbook data.

Systems to preposition landing gear for crosswind takeoffs and landings have been used on some air vehicle to improve crosswind-operating characteristics. Recent examples are the B-52 and C-5A. These systems are recommended only when justified by analysis of air vehicle handling qualities and pilot workload for crosswind operation.

4.4.1.4.2 Directional control.

Directional control performance of the landing gear system shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.4.2)

Due to the many variables involved in the air vehicle ground directional control characteristics, the only suitable verification method is test of the complete air vehicle. This normally is accomplished in three stages. The first is an evaluation for typical operation. This is a continuous process throughout the flight test program. The second is a planned evaluation for minimum radius turns on a dry paved surface. This is accomplished not only to evaluate the minimum radius turns that can be achieved by various pilot techniques, but also to measure resultant structural loads. The third phase, which will vary between air vehicle programs, is evaluation of directional control under adverse conditions. Adverse conditions can include wet surfaces, soft surfaces, or failure of some air vehicle systems.

VERIFICATION GUIDANCE (4.4.1.4.2)

TBS: Performance of the ground control of the air vehicle should be demonstrated during taxi and flight-testing for all operational missions and ground maneuverability.

VERIFICATION LESSONS LEARNED (4.4.1.4.2)

Verification of the steering system's ability to hold the air vehicle to 25 ft within 1000 ft is difficult to demonstrate on the air vehicle due to crown of the runways, alignment of the air vehicle to the centerline or line of reference, and centering of the steering system. More consideration is needed on how to verify whether the air vehicle can hold a straight-line track as it travels down the runway. (Modify to include no numbers.)

3.4.1.4.3 Emergency directional control.

Emergency ground directional control provided by the landing gear, if required, shall be provided with the following characteristics: (TBS).

REQUIREMENT RATIONALE (3.4.1.4.3)

Some type of emergency directional control system should be provided to permit completion of the design mission or safe recovery of the air vehicle after failure of the normal directional control system. The design approach to provide an acceptable capability is highly dependent upon successful criteria established by this requirement. It may be possible to meet the requirement with existing normal systems, or it may be necessary to provide secondary or redundant steering systems. In many cases, differential braking may qualify as the emergency directional control system.

REQUIREMENT GUIDANCE (3.4.1.4.3)

TBS should be filled in with consideration given to the following performance requirements for the emergency directional control system:

a. The emergency directional control system should permit the air vehicle to complete the operational mission after failure of the normal directional control systems. Completion includes recovery of the air vehicle to the base of origination without damage due to failure of the normal directional control system.

b. After failure of the normal directional control system, it should be possible for the air vehicle to maintain a path along the centerline of the runway (±10 feet) after landing (Sea level, Standard day).

c. The emergency directional control system should permit the air vehicle to maneuver from the soft surface runway without assistance from external power or equipment. Maneuver includes the ability to turn 180° in a maximum width of 100 feet.

d. No single point failure should cause loss of ground directional control.

The following parameters should be considered: air vehicle weight, air vehicle speed, type of runway surface (hard and soft), and control precision.

REQUIREMENT LESSONS LEARNED (3.4.1.4.3)

(TBD)

4.4.1.4.3 Emergency directional control.

Emergency ground directional control characteristics provided by the landing gear shall be verified by: (TBS).

VERIFICATION RATIONALE (4.4.1.4.3)

Verification is to ensure that emergency directional control is achieved.

VERIFICATION GUIDANCE (4.4.1.4.3)

TBS should reflect verification by analysis of system operation after the insertion of failures, either single point or normal control systems. The analysis may be supported by bench testing of system components with induced failures and air vehicle tests.

VERIFICATION LESSONS LEARNED (4.4.1.4.3)

With the advent of digital control systems, verification of failures and emergency systems has been a multi-phase verification. While computer simulations model various failures, the computer logic response should be watched. This should be followed by an "iron-bird" type of simulation to see if the hardware responds properly with the response of the software code for the inserted failure modes.

3.4.1.4.4 Braking and skid control.

4.4.1.4.4 Braking and skid control.

3.4.1.4.4.1 Braking control interface.

Braking control shall be applied by the following means: (TBS).

REQUIREMENT RATIONALE (3.4.1.4.4.1)

Rather than define the classical method of applying brakes through the rudder pedals, this requirement is adjustable according to the situation. If the mission(s) or the state-of-the-art dictate a change in concept, the blank should reflect the desires.

REQUIREMENT GUIDANCE (3.4.1.4.4.1)

TBS should reflect the braking control method used. If no new method is used then the phrase, "foot pressure on the tip of the rudder pedal" should be inserted.

If foot pressure on the tip of the rudder pedal is used, the following should be considered:

a. Maximum breakout force at the tip of the pedal
b. Minimum force for full braking
c. Maximum force.
d. Maximum breakout force
e. Maximum force for full braking
f. Maximum travel
g. Travel for initial braking
h. Deceleration rate/application force gradient (mean)
i. Deceleration rate/application rate tolerance.

REQUIREMENT LESSONS LEARNED (3.4.1.4.4.1)

This requirement reflects the criteria previously contained in MIL-B-8584. The intent was to standardize the brake application methods so that transition by pilots from one air vehicle to another will not result in confusion in the event of an emergency, which requires fast application of brakes. The initial source of the requirement is not known.

Refer to JSSG-2010 for further information on brake activation controls. This is a critical control and the use of a non-standard activation method should not be permitted without consulting with the crew systems design group.

Brake controls should be provided to both the pilot and co-pilot. In any position of the foot there should not be a tendency for the pilot to apply brake effort unintentionally during the normal use of the rudder pedals or during arrested landings. Equal positive action of the brake system should be provided when the air vehicle is moving forward or aft with the same effort on the brake pedal or brake-operating control.

Some foreign air vehicles utilize a hand lever for brake application.

Pedal position for pilots of varying heights and leg lengths can be a problem.

The MIL-B-8584 paragraph on “Power operated systems, Types II and III” calls for landplane landing weight pedal brake force of 65 to 85 pounds. This has been found to be too high for comfortable pilot control. The forces were reduced to the 35 to 65 pound range for the B-2 and 50 to 75 pound range for the C-17. It is recommended that the pedal force for landplane operation be in the 35-65 pound force range. It may be desirable to restate the requirement as follows: "Brake pedal forces shall not to exceed 60 lbs for a 10 ft/sec squared at landplane landing weight deceleration and 150 lbs for maximum braking.”

4.4.1.4.4.1 Braking control interface.

Braking control interface shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.4.4.1)

Since braking control suitability is subjective, the evaluation is qualitative and subject to personal preferences. A mock-up or actual air vehicle should be used for preliminary evaluation. Final review is subject to program limitations.

VERIFICATION GUIDANCE (4.4.1.4.4.1)

TBS should be filled in with mock-up evaluation, air vehicle taxi, and flight-testing.

VERIFICATION LESSONS LEARNED (4.4.1.4.4.1)

(TBD)

3.4.1.4.4.2 Alternate independent braking.

Separate and independent braking shall be provided with the capability to (TBS 1) with (TBS 2) failures.

REQUIREMENT RATIONALE (3.4.1.4.4.2)

This requirement is necessary to establish performance requirements for the alternate braking system. An alternate braking system is nearly always required. Experience indicates that an alternate system is essential to provide adequate safety and reliability.

REQUIREMENT GUIDANCE (3.4.1.4.4.2)

TBS 1 should be filled in with the level of performance expected. Normally, the stopping performance should be equal to that provided by the normal system. Differential control of braking is a desirable feature to permit the pilot to use the brakes for directional control. Anti-skid control should be considered, but may be optional. There may be reason to have both a secondary and an emergency braking system that should be specified as follows: "A secondary braking system, separate and independent of the primary system, should be provided. The backup system should have braking capabilities equivalent to the primary system. An emergency braking system should be provided with sufficient capability to perform a maximum energy stop with pilot metered braking." Such a design concept may be needed to preclude any single failure causing loss of normal brake functions.

TBS 2 should define the number of non-structural failures.

To minimize the potential of a tire blowout, consideration should be given to a protection circuit or the pilot should receive indication of an incipient skid.

The design and marking of the alternate brake control should be coordinated with the crew system design group.

REQUIREMENT LESSONS LEARNED (3.4.1.4.4.2)

This is a reflection of the criteria previously stated in MIL-B-8584, AFSC DH 2-1, and AFSC DH 1-6. It reflects the lessons learned from World War II air vehicles and has been standard criteria for over 10 years. The only recent innovation has been the use of anti-skid control on emergency brake systems and the double redundancy of dual actuation lines for normal and emergency systems.

There are various approaches to emergency brake system design. During the 1950s, it was common practice to provide emergency braking from an auxiliary air bottle. These designs had limited capacity, utility, and effectiveness. They did not operate through the anti-skid control system, and there were often blown tires with the use of this type of emergency brake system. They also had separate lines to a shuttle valve at the brake. Since this was a different media than the normal system, extensive system bleeding was required after their use.

Another disadvantage of the air bottle emergency system is the limited capacity. If the pilot "pumps" the brakes, he will deplete the system and could have insufficient capacity to complete the stop.

Another recent design approach to emergency brake design is to provide dual lines to the brakes from different hydraulic systems. Each system has the capability to stop the air vehicle. The F-111, B-1, F-16, and F-35 utilize this approach.

Usually with pilot directed brake pressure, there is little or no sense of deceleration or "feel" for tire skidding. The problem is further aggravated by the pressure difference between the normal and emergency braking systems for the same pedal deflections. One successful method was a "foot thumper" which caused a small pin in the brake pedal to "thump" the pilot's foot when the tire started to skid, thus allowing the pilot to back off the pedals. This also assisted the pilot in metering the pressure up to the point of skidding, thus providing a means of achieving maximum deceleration without a blowout in emergency conditions.

Since the normal and emergency brake systems may not provide comparable pressure to the brakes for the same pedal position, it is desirable for the condition of the wheel to be indicated in the cockpit. This is necessary because in most air vehicles the pilot does not have a “feel” of locked wheels or air vehicle deceleration in the cockpit. A foot pulsar has been used in one case to fulfill this need.

4.4.1.4.4.2 Alternate independent braking.

Alternate braking shall be verified by flight test.

VERIFICATION RATIONALE (4.4.1.4.4.2)

The requirement is for a level of performance, thus, the only suitable test is of the total system.

VERIFICATION GUIDANCE (4.4.1.4.4.2)

The alternate brake performance should be verified by analysis and laboratory tests. System performance should then be substantiated during flight-testing.

VERIFICATION LESSONS LEARNED (4.4.1.4.4.2)

(TBD)

3.4.1.4.4.3 Skid control.

Skid control shall be tuned for optimum performance on a (TBS) surface, considering both braking and cornering forces throughout the control speed range.

REQUIREMENT RATIONALE (3.4.1.4.4.3)

There has been a tendency within industry to attempt to achieve a minimum stop distance on a dry runway and subsequently apply an assumed factor to predict wet stopping distances (FAA). However, the real need of the system is to have the skid control system be tuned on the surface where the greatest need exists. Therefore, every attempt should be made to tune the production adjustments or the anti-skid brake control system for a wet runway, where the performance is most critical. The brake and skid control system should provide differential braking control, locked wheel protection, touchdown protection, parking brake function, anti-spin on retraction, and hydroplaning protection. In addition, the brake and skid control system should permit holding the air vehicle at a full stop and locked wheel pivot turns.

REQUIREMENT GUIDANCE (3.4.1.4.4.3)

Stopping distance is not the only factor to be considered. Cornering power is equally important on runways experiencing adverse weather. Crosswinds may dictate that differential controls to assist steering are equally important to stopping performance. This should be considered equally in tuning the system.

TBS: The anti-skid system should operate satisfactorily under the following conditions:

a. Prevent tire flat-spotting and never permit a completely locked brake within the control speed range when the brake will respond to control.

b. From maximum ground operation speed to the lowest speed compatible with ground handling, not to exceed 10 knots.

c. Should not induce airframe dynamic instability, gear walking, and gear chatter.

d. Tuned for optimum performance on a wet runway, a dry runway, and combination of wet and dry surfaces. Should consider both braking and cornering forces throughout the control speed range.

e. At temperatures from -65 degrees F to +160 degrees F.

f. When conditions are imposed that duplicate the environment of seacoast regions.

g. Environmental conditions of 100 percent (100%) humidity, including conditions in which condensation occurs in the form of water or frost.

h. When subject to pressure variations associated with altitude ranging from 1,300 feet below sea level to the maximum operational altitude of the air vehicle.

i. Under conditions consisting of blowing sand and dust particles as encountered in desert areas.

j. Environmental conditions such as explosive atmosphere, translational accelerations, acoustics in the region where the hardware is mounted, vibrations, shock, and fungus.

REQUIREMENT LESSONS LEARNED (3.4.1.4.4.3)

This criterion is generally stated in MIL-B-8075. Difficulty has been encountered on numerous systems where the anti-skid control system components are adjusted to provide minimum stop distance on a dry concrete surface. Consequently, the wet runway performance is left to chance and is frequently less than optimum. The requirement for consideration of wet system adjustment was not introduced into specification language until 1971. Prior documentation reflected ancient state of the art design and evaluation. The anti-skid activation controls and location should be coordinated with the crew station group.

In tuning an anti-skid system or adjusting the response rates for production, there is significant risk in tailoring the system for dry runway performance. The available coefficient is relatively constant with a dry surface as compared with a wet surface. Therefore, system response or sensitivity can be improperly placed from dry runway testing. This usually is the direct result of establishing guaranteed stop distances on dry surfaces, but not requiring specific performance on wet. It is extremely difficult to define a wet surface and to control it in flight test for demonstration. It is dependent upon the surface (micro-texture), the runway construction, and the rate of water input.

Factors to be considered in anti-skid tuning and operation are features such as locked wheel protection and interaction if the brakes are paired, touchdown protection to prevent lock-up or flat spotting upon initial contact with the runway, and the degree of sophistication desired. Anti-skid systems vary in performance from anti-locked wheel devices to approaching automatic braking systems. Some commercial and T-43 brakes are automatically applied without pilot effort and function to a pre-selected deceleration rate.

There are several basic design approaches to anti-skid system in terms of hydraulic control. One is paired wheel control and another is individual wheel control, with various combinations of each. For single wheel gear air vehicle, such as used on fighters, more use has been made of paired wheel control. This decision is made primarily for dynamic stability and ground control reasons. If release and reapplication of brakes on one side of the air vehicle at a time can induce control problems, paired wheel control should be considered. However, individual wheel control is more efficient from a stopping efficiency point of view, because each braked wheel is producing all of the possible torque. With paired wheel control designs, caution should be used in valve selection to ensure retention of differential braking capability in crosswind situations. Some systems reduce both wheels to a common threshold pressure and offset the differential pressures that the pilot thinks he is applying. Other paired wheel control valves operate like individual wheel control systems.

4.4.1.4.4.3 Skid control.

Skid control shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.4.4.3)

Ultimately, the final production tuning should be done on the air vehicle, but there are various approaches to preliminary evaluation. These include computer simulation and working simulators. The verification should be tailored to reflect the economic coordinated method used for other systems.

VERIFICATION GUIDANCE (4.4.1.4.4.3)

TBS should include the following statement: “The brake and skid control system performance, including efficiency and compatibility with interfacing subsystems, shall be initially evaluated by computer simulation analysis; final verification shall be performed by air vehicle test subsequent to final production tuning. Tuning performance verification shall include operation on a wet runway and shall be accomplished with an instrumented air vehicle. The effects of system malfunction shall be evaluated by analysis and validated by computer simulation. The operating characteristics of the anti-skid system and design features of the system shall be verified by inspection.”

Verification of the anti-skid should include the following:

a. Freedom from air vehicle dynamic instability due to anti-skid brake control operation will be demonstrated on the air vehicle throughout the forecasted air vehicle operation spectrum.

b. Document all test conditions, test equipment, and test procedures for component preproduction tests.

c. Analysis of brake control system performance under various anti-skids, air vehicle (including wing lift), runway surface conditions, and brake system inputs should be considered.

d. Analysis of the effects of various system part failures should be considered. Those failures not adequately covered by analysis should be simulated by appropriate laboratory tests.

e. Operational checkout procedures should be developed to detect all failures.

VERIFICATION LESSONS LEARNED (4.4.1.4.4.3)

(TBD)

3.4.1.4.4.4 Skid control with power interruption.

During interruption of power to or malfunction of the skid control, the system shall (TBS).

REQUIREMENT RATIONALE (3.4.1.4.4.4)

It is the intent of this requirement to state how the system responds to circumstances of power interruption or system malfunction. It indicates the reaction that is most acceptable for system design.

REQUIREMENT GUIDANCE (3.4.1.4.4.4)

TBS should be filled by specifying an acceptable means for responding to power interruption or system malfunction. Examples include “return to pressure as metered, with adequate pilot notification,” or “metered brake pressure is dumped and the braked wheels are free rolling until the alternate brake system is activated.” There may be other logical choices of action for system power interruption or malfunction that should also be considered. No single failure shall cause loss in ability to control the air vehicle, loss of complete braking, or result in a locked wheel. System should handle common failures of weight on wheel switches: loss of electrical power, loss of hydraulic power, and loss of wheel speed sensor.

REQUIREMENT LESSONS LEARNED (3.4.1.4.4.4)

The source of this requirement is MIL-B-8075. A requirement similar to this has been in force since the anti-skid systems were introduced into USAF aircraft around 1954-55. The failure response mode has been questioned on numerous occasions and user preference appears to be the criteria that should be applied.

On fighter air vehicle or relatively simple gear with multiple tires, most systems revert to manual upon system failure with suitable notification to the pilot. On complex systems, such as the C-5A, the affected wheel and brake assembly is isolated and the remainder of the system continues to function with anti-skid control.

If the gear was not retracted on a touch-and-go, the anti-skid should be capable of resetting its touchdown protection circuit to provide touchdown protection for each subsequent landing regardless of gear cycling.

On one aircraft, the logic of the anti-skid allowed brake pressure only when both Main Landing Gear (MLG) and Weight On Wheels (WOW) switches indicated weight on (Touchdown Protection). This approach causes the anti-skid to go into touchdown protection mode when one of the MLG strut extended enough during turns to trip the WOW switch off, thus causing loss of braking.

4.4.1.4.4.4 Skid control with power interruption.

The effects of power interruption and system malfunctions shall be verified by: (TBS).

VERIFICATION RATIONALE (4.4.1.4.4.4)

There are numerous means to evaluate anti-skid system malfunction. These include failure mode analysis under the reliability program, simulator studies on the full-scale landing gear mock-up, and flight test evaluation. The flight test portion is normally on a routine monitoring.

VERIFICATION GUIDANCE (4.4.1.4.4.4)

TBS should specify that computer simulations and analysis, with the results being substantiated by on-aircraft demonstration and checkout of system switching logic parameters.

VERIFICATION LESSONS LEARNED (4.4.1.4.4.4)

Often test sets will not detect all types of failures and causes. Generally, the using activity observes the test set or warning light and, if functioning, will assume the unit is acceptable when in fact those lights only indicate failures of a specific type. Operation instructions, including failure modes and effects, are desirable.

3.4.1.4.4.5 Anti-skid engagement and disengagement.

A means shall be provided, if required, to engage or disengage the anti-skid.

REQUIREMENT RATIONALE (3.4.1.4.4.5)

This requirement is to provide a means for the pilot to override anti-skid system operation. It permits the pilot to select normal braking without anti-skid as an alternative to emergency braking. This is desirable if the emergency system has limited capacity or is difficult to control.

REQUIREMENT GUIDANCE (3.4.1.4.4.5)

The anti-skid override is usually accomplished by removing power from the anti-skid control box. The control for this can vary from a circuit breaker to a switch (stick or panel mounted) to a complex control and warning system (semi-automatic shutdown). The control should be as simple as possible. Braking force should be that commanded by the pilot. The pilot should be provided with a warning that the anti-skid has been disabled.

REQUIREMENT LESSONS LEARNED (3.4.1.4.4.5)

The criteria for pilot control is a restatement of requirements previously stated in specification MIL-B-8075 and AFSC DH 1-6.

In the past, it has frequently been desirable to shut off anti-skid during taxi to prevent unexpected brake release. The argument against the control is that it leads to inadvertent operation without anti-skid. Furthermore, if the pilot is given several alternatives, he may try all of them and overrun the runway (direct selection of an emergency system may provide a shorter total stop distance).

Many older air vehicles utilize an on-off switch for the anti-skid control system. Without anti-skid protection, it is much easier to flat spot or blow out the tire. The heavier the air vehicle the more likely the pilot will not know he is locking up a wheel until the tire blows. With digital technology, one can easily design two or more equivalent braking control systems that switch back and forth almost instantaneously without the loss of any braking performance. Therefore, strong consideration should be given to determine whether the pilot could operate without anti-skid. If not, then the requirement is to design a redundant braking system that switches automatically and notifies the pilot when it has switched.

4.4.1.4.4.5 Anti-skid engagement and disengagement.

The means to engage and disengage the anti-skid shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.4.4.5)

To ensure that the switching logic works appropriately for all the condition that the system is engaged and disengaged.

VERIFICATION GUIDANCE (4.4.1.4.4.5)

TBS should reflect verification by computer simulations and the results substantiated by on air vehicle checkouts and flight-testing. The anti-skid control and switching logic should be modeled on the computer and applied to a laboratory simulator.

VERIFICATION LESSONS LEARNED (4.4.1.4.4.5)

(TBD)

3.4.1.4.5 Nose wheel steering

4.4.1.4.5 Nose wheel steering

3.4.1.4.5.1 Steering characteristics.

Nose wheel steering shall have the following characteristics: (TBS).

REQUIREMENT RATIONALE (3.4.1.4.5.1)

Usually some form of nose gear steering will be required to provide adequate directional control. If this should be the case, it may be desirable to specify some characteristics. This is required to standardize controls and ensure that aircrew procedures are similar to previous air vehicles to minimize aircrew transition training.

REQUIREMENT GUIDANCE (3.4.1.4.5.1)

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

a. Steering control force

b. Steering rate

c. Ability to track a straight line

d. Steering deadband

e. Method of control (rudder pedals or wheel)

f. Indicators (strut marking, warning lights)

g. Self-test provisions

h. Shimmy damping. Shimmy damping should be provided at all times, including with or without steering engaged, and during power system failures. Shimmy damping should be maintainable without dependency on replacement of normally wearing parts.

i. 360-degree swivel. Nose gear should be capable of providing 360-degree full swivel to aid in towing and maneuvering the aircraft in hangers. While a design that allows full range without disconnection is preferable, disconnection of torque arms is acceptable to prevent damage to any air vehicle component.

j. Power recovery of the nose landing gear wheel to the commanded position should be possible from any wheel angle within the powered steering range.

k. System stability should be controlled to the commanded position without hunting, chatter, or instability under all conditions when installed and operating on the air vehicle.

l. Positive trail should be provided to allow recovery to neutral from any powered steering angle when the system is disengaged during taxi.

m. Nose wheel centering should be automatically provided when the nose wheel is airborne.

n. Static nose wheel steering should be provided to give sufficient torque to turn through the full steering range statically at the maximum weight with brakes applied on dry pavement, on unprepared site of some specified CBR, and with tires initially frozen to the ground.

The activation and location of the steering controls should be coordinated with the crew station group.

REQUIREMENT LESSONS LEARNED (3.4.1.4.5.1)

This requirement is to provide a method of including specific design characteristics that have previously been directed by MIL-S-8812, MIL-STD-203, and AFSC DH 2-1. System rate and response characteristics have not been quantitatively stated in the past, but rather have been controlled by test pilot consensus. In the future, it may be desirable to establish quantified requirements to permit more orderly development of the system. The type of control (rudder pedal or wheel) has been dictated in the past by MIL-STD-203. Steering indication systems and built-in tests have been given little consideration in the past.

Past air vehicles have generally been designed to the following criteria:

a. The steering system should be designed with sufficient output torque to permit the turning of the steered wheels through the full range without the aid of motion or the air vehicle or engine thrust or auxiliary power. The steering capability should be available throughout the design temperature range of the air vehicle and with the most critical combination of weight and center of gravity at engine idle thrust and a design friction coefficient of 0.80 at the tire ground interface. The tires should be inflated in accordance with applicable servicing instructions, and all brakes may be assumed to be released unless normal engine idle thrust is sufficiently high to cause motion.

b. Testing has indicated that the actual maximum tire to ground friction coefficient may be less than 0.8. Air vehicles that have little or no capability to turn the nose gear when the air vehicle is static have generally been unacceptable and required redesign to increase steering torque.

c. Flight and laboratory tests indicate that excessive nose gear steer angle during takeoff and landing, particularly on slippery surfaces, is likely to result in over control by the pilot. If excessive steering angle is used, the turning force may be less than the maximum available. This has caused several air vehicle accidents. Consideration should be given to restriction of steer angle during takeoff and landing to preclude this problem.

d. Development of suitable steering rate and control force have been problem areas on several recent air vehicle developments (C-141 and F-15). Frequently, the problem involves excessive deadband in the control, control hysteresis, or poor pedal geometry. Careful analysis of initial flight test results is recommended to ensure timely detection and correction of problems. Quantitative control criteria to avoid problems by good design are desirable but not available.

e. Deflection of cables, pulleys, pulley mounts, and pulley mount back up structure are a frequent cause of poor response in systems with mechanical control.

f. MIL-STD-203 required use of hand wheel steering in cargo air vehicles. This is desired because it permits smoother operation during taxi, therefore providing a better ride for passengers. Recent work with prototype air vehicles indicates that perhaps the advantages of the steering wheel are not clear-cut for tactical cargo air vehicles. Presently, it is probably best to leave the type of steering control unspecified.

g. Some air vehicle steering systems have a method to show the pilot the nose gear steering angle. One evaluation reveals that such indicators are seldom used and may be of little value. On some air vehicles, it may be desirable to indicate that landing gears are not centered. Indicators on the landing gear showing steering angle are useful for rigging of the steering system.

h. The caster axis for wheel swivel or rotation should be vertical.

i. The freeplay, friction, and steering load path should be stable.

Damping should be provided to preclude shimmy through the speed range for wheel ground contact.

Damping provisions should be in accordance with MIL-S-8812.

Unless otherwise specified in the detail specification, nose wheel steering should be provided in accordance with MIL-S-8812.

If possible, avoid putting the steering actuator on top of the strut. Try to keep the steering power as close to the torque arms as possible. This minimizes the effect of freeplay, wear, and friction in the shimmy tendency of the gear.

See the structure section on shimmy to keep the trail distance between 1-5 inches for better chance of a stable design.

Avoid designs where the gear has to be rotated to be stored.

Avoid designs where unequal or unsymmetrical loading goes into the gear.

For designs that exhibit shimmy, it has been found that hanging a mass damper on the strut, particularly forward of the gear, has been able to move the shimmy onset speed to a level higher than air vehicle rotational speed.

4.4.1.4.5.1 Steering characteristics.

Steering characteristics shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.4.5.1)

Performance of the steering system is the result of the complex interaction of air vehicle subsystems and geometry. Flight test of the complete air vehicle is considered the only valid verification method. Usually, this can be accomplished concurrently with flight performance testing. However, it may be necessary to augment testing by formal test or demonstration of the adverse steering conditions. Engineering analysis during development is desirable to ensure successful testing. However, it is not required for verification.

VERIFICATION GUIDANCE (4.4.1.4.5.1)

TBS: Steering characteristics should be verified by an analysis, flight test, and a formal demonstration of the steering system operation with the static air vehicle. The demonstration should be accomplished to determine compliance with factors that cannot be verified by flight test. Configuration design requirements should be verified by inspection of engineering drawings and hardware.

The verification should cover at least the following: Compliance with system performance and control requirements, including power recovery, torque output, and control stability, should be verified by analysis and ground test. Adequate positive trail and 360-degree swivel should be verified by demonstration on the air vehicle. Configuration design requirements, including centering, should be verified by inspection of drawings and hardware and demonstration on the air vehicle (on jacks). The effects of system failure should be verified by analysis.

VERIFICATION LESSONS LEARNED (4.4.1.4.5.1)

(TBD)

3.4.1.4.5.2 Response to nose wheel steering failure.

No single or multiple failures of the nose wheel steering control, including hydraulic or electrical power, shall cause the air vehicle to depart the runway.

REQUIREMENT RATIONALE (3.4.1.4.5.2)

This requirement is to influence the contractor in selection of the type of steering system to be used and the degree of redundancy to be provided when there is loss of the steering function. It should be tailored to recognize the importance of steering to the particular air vehicle.

REQUIREMENT GUIDANCE (3.4.1.4.5.2)

In the event of nose wheel steering failure, including power system failure, the steering system should provide for automatic or manual switching to a backup system or deselection to a free caster mode in sufficient time to avoid departing the runway.

The following should be considered:

a. Maneuverability of the air vehicle without steering
b. Operating environment
c. Performance of similar air vehicle

REQUIREMENT LESSONS LEARNED (3.4.1.4.5.2)

This item reflects criteria previously identified in MIL-S-8812. Requirements on failure mode and effect were introduced into this document in 1975 and they represent input from industry.

Some air vehicles incorporate dual sources of steering power. This should be considered for air vehicles that must have operable steering to maintain control for takeoff and landing. It may also be desirable for air vehicles that cannot be taxied by use of differential brakes and thrust. Secondary systems should be pilot selectable after the air vehicle is on the ground and should not degrade braking performance.

4.4.1.4.5.2 Response to nose wheel steering failure.

Adequate response to nose wheel steering failure shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.4.5.2)

This requirement usually will be such a low rate of occurrence that demonstration by flight test is not practical. Verification should be by use of a failure mode analysis combined with historical failure rates of similar equipment. In some cases, it may be difficult or impossible to determine the result of some component failures.

The effects of such failures should be investigated by simulation on a laboratory simulation of the system or on the air vehicle.

VERIFICATION GUIDANCE (4.4.1.4.5.2)

TBS should be filled in with analysis, computer simulations, systems checkout, and demonstrations on the air vehicle to ensure proper system response to failures of the nose wheel steering system and power supply.

VERIFICATION LESSONS LEARNED (4.4.1.4.5.2)

(TBD)

3.4.1.4.5.3 Emergency steering.

In the event of failure of primary nose wheel steering, emergency nose wheel steering, if required, shall be provided with the following characteristics: (TBS).

REQUIREMENT RATIONALE (3.4.1.4.5.3)

If a nose wheel steering system is required to provide adequate directional control, consideration should be given to directional control in the event of system failure.

REQUIREMENT GUIDANCE (3.4.1.4.5.3)

TBS should define unique requirements. Possible characteristics include pilot or automatic selection of an alternate power system, indication or primary failure, and type and amount of steering to be accomplished. Emergency steering should not degrade normal or emergency brake system performance.

REQUIREMENT LESSONS LEARNED (3.4.1.4.5.3)

A requirement for emergency steering capability has been a requirement of MIL-S-8812 since 1969. However, most military air vehicles achieve emergency directional control with differential brakes or rudder control.

a. Emergency systems that operate by providing a second source of hydraulic pressure should be designed with care to prevent creation of additional critical failure modes. Emergency steering should be designed so that it does not degrade normal or emergency braking.

b. The question of automatic or pilot selected emergency steering should be carefully considered. Automatic selection reduces pilot workload and provides minimum transfer time. Pilot selection, on the other hand, reduces the possibility of depletion of the emergency system before the critical operating period. All hydraulic selector valves should be designed so that fracture of the valve body will not result in loss of both steering systems.

c. Steering systems that use two sources of power for normal operation have been used to fulfill this requirement. Consideration should be given to whether operation with one failed system will provide sufficient steering torque for emergency operation.

d. Use of differential braking for directional control is often considered a suitable substitute for an emergency steering system. This may not be a suitable approach for air vehicles with complex landing gear arrangements, narrow landing gear tread, or unpaved airfield operating requirements.

4.4.1.4.5.3 Emergency steering.

Emergency steering shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.4.5.3)

Performance of the emergency steering system is the result of a complex interaction of air vehicle subsystems and configuration. Suitability can be determined only by test of the complete air vehicle.

VERIFICATION GUIDANCE (4.4.1.4.5.3)

TBS should be filled in with analysis and a flight test. Adequacy of the emergency steering system should be verified by analysis and tested on the air vehicle.

VERIFICATION LESSONS LEARNED (4.4.1.4.5.3)

(TBD)

3.4.1.5 Actuation control.

4.4.1.5 Actuation control.

3.4.1.5.1 Retraction and extension actuation interface.

A means shall be provided to actuate retraction and extension of the landing gear.

REQUIREMENT RATIONALE (3.4.1.5.1)

The intent of this requirement is to identify the technique required for landing gear actuation.

REQUIREMENT GUIDANCE (3.4.1.5.1)

Normally the gear actuation should be accomplished by actuation of a standard gear handle. This requirement should be coordinated with crew systems.

REQUIREMENT LESSONS LEARNED (3.4.1.5.1)

(TBD)

4.4.1.5.1 Retraction and extension actuation interface.

Retraction and extension actuation interface shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.5.1)

Normally, suitability of the design and location and operation of the landing gear control can be evaluated by inspection of engineering drawings, crew station mock-ups, or actual hardware. Unusual designs may require pilot evaluation during flight test or formal demonstration to verify suitability.

VERIFICATION GUIDANCE (4.4.1.5.1)

TBS should be filled with inspection of drawings.

VERIFICATION LESSONS LEARNED (4.4.1.5.1)

(TBD)

3.4.1.5.2 Gear door actuation and locking.

If required, fairing door actuation and locking shall be (TBS).

REQUIREMENT RATIONALE (3.4.1.5.2)

The objective of the requirement is to establish the relationship and mechanical interface of the gear and door actuation and locking system. Usually, this statement will be completed by the phrase: "automatically sequenced with the landing gear actuation." The intent here is to minimize aircrew workload and to standardize aircrew procedures. In some special cases, however, it may be desirable to provide controls for separate operation of the fairing doors. An example would be to open doors that are normally closed for ground operation.

REQUIREMENT GUIDANCE (3.4.1.5.2)

TBS should be filled with "automatically sequenced with the landing gear actuation. Retraction or extension of any single landing gear shall not depend on satisfactory operation of any other landing gear."

REQUIREMENT LESSONS LEARNED (3.4.1.5.2)

This item was previously contained in AFSC DH 2-1 and AFSC DH 1-6. The requirement dates back to ARDCM 80-1 or HIAD in the 1955 period. The following lessons learned provided additional guidance:

a. Landing gear and door sequencing is frequently a major source of problems in development of a new air vehicle. The best approach is to minimize or eliminate sequencing by elimination of landing gear fairing doors or by connecting the doors directly to the landing gear. Serious consideration should be given to statement of this design approach as a part of this requirement.

b. Current air vehicles use one or more of the three basic types of sequencing: mechanical, hydraulic, or electrical. Mechanical consists of use of links, bellcranks, and torque tubes to transfer landing gear motion to door drive motion. Hydraulic includes use of priority valves, actuator internal porting, or mechanically actuated valves to operate door actuators at a proper time in the landing gear operation. Electrical consists of detection of landing gear and door positions by electrical switches to enable control of relays or solenoid operated hydraulic valves to apply power in the proper sequence.

c. F-5, F-15, and T-38 type aircraft include separate door controls so that doors can be opened for ground maintenance. This introduces several design problems. The first is that it may present operational problems if doors are not returned to proper position before flight. The actuation sequence and in-flight performance should not be degraded by this maintenance error. As an alternative, the error should be correctable by the pilot while the air vehicle is in flight. Separate operation of doors also results in a need for door ground locks to prevent inadvertent ground operation while personnel are in the wheel wells. Control switches should be located so that the operator is clear of the door operation, but so that he can readily determine that all personnel are clear of the doors.

d. Proper operation of some sequencing methods is very dependent upon hydraulic pressure, hydraulic flow, dynamic loads, and aerodynamic loads. It is essential that it be possible to check the system for proper operation with the air vehicle on jacks. Ground checkout set up and test procedures should be developed that adequately simulate the in-flight operation. If this is not possible with the proposed design, the design should be changed to provide a practical operational air vehicle.

e. Proper timing of landing gear door locks to the door drive system is a frequent problem area. Usually, some type of time delay is used to ensure door unlocking is complete before doors are powered open. Time delay systems are not fail-safe and sometimes will not perform properly at extreme temperatures. Door unlock detection systems avoid these problems but add significantly to control circuit complexity.

f. The effect of landing gear and door actuation dynamics on proper sequencing of door locks is frequently overlooked. Rebound of the door from the closed position may prevent proper locking. Oscillations may combine with control circuit characteristics to cause buzz or chatter of doors and locks. This can be avoided by decelerating the door near the closed position and by use of a time delay to ensure that door closed and locked force is maintained for seven to ten seconds after initial indication of locking.

g. Nose door has locks on the door as the result of a late design change to an aft retracting nose gear configuration. Low observability requirements led to more locks than on other air vehicles. Compounding the rigging problem is the flexibility of the composite door.

h. When loads are high on all doors, a very tight rigging requirement is required for the doors. Unfortunately, the adjustments are made on the connecting rods, which have threads that are too coarse for the required levels of accuracy. High loadings on the hooks and rollers led to galling problems, which were addressed by changing the coatings on the surfaces.

4.4.1.5.2 Gear door actuation and locking.

Landing gear door actuation and locking shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.5.2)

Proper operation of the landing gear and doors is the result of a complex interaction of air vehicle subsystems and dynamic and aerodynamic loading. It can be evaluated only by flight test of the air vehicle. Preliminary verification by analysis, laboratory test of a simulated system and with the air vehicle on jacks, is highly recommended to minimize flight test time and cost.

VERIFICATION GUIDANCE (4.4.1.5.2)

TBS should be filled with inspection of drawing and hardware followed with demonstration on the air vehicle during checkouts and in flight-testing.

VERIFICATION LESSONS LEARNED (4.4.1.5.2)

(TBD)

3.4.1.5.3 Single failure criteria.

No single point nonstructural failure, including power interruption or unmated connector, shall prevent gear extension or cause mis-sequencing.

REQUIREMENT RATIONALE (3.4.1.5.3)

This requirement is needed to ensure that the landing gear will extend and lock with a single point nonstructural failure, including power interruption or unmated connector.

REQUIREMENT GUIDANCE (3.4.1.5.3)

The design should be such that there is no single failure in the power and electrical portion of the actuation system that will prevent the extension of the landing gear.

REQUIREMENT LESSONS LEARNED (3.4.1.5.3)

The past approach was to specify a general level of redundancy and to prohibit or require certain design features. Requirements were contained in AFSC DH 2-1.

Consideration should be given to the fact that air vehicles with multiple landing gears may be able to land with one landing gear retracted. This may require modification of this requirement statement. Landing with one assembly retracted will impose some weight limit and may require special techniques. Operating limits should be evaluated by analysis to ensure that they provide a useful emergency capability. Flight-test to evaluate technique should be accomplished. This approach was successfully used in development of the C-5A aircraft.

4.4.1.5.3 Single failure criteria.

It shall be verified that no single point nonstructural failure, including power interruption or unmated connector, shall prevent gear extension or cause mis-sequencing by (TBS).

VERIFICATION RATIONALE (4.4.1.5.3)

The acceptable level of failure is normally so low that verification by test is not practical. The requirement should be verified by failure mode and effects analysis of the extension system combined with historical failure rate data for similar components. In some cases, it may be necessary to accomplish laboratory testing to verify failure modes and effects and to establish failure rate data for new design components.

VERIFICATION GUIDANCE (4.4.1.5.3)

TBS should be filled in with inspection of drawing, design logic, and schematics to eliminate single failure points. Extension with failures induced should be verified by demonstration, either on the air vehicle or on a simulator if available.

VERIFICATION LESSONS LEARNED (4.4.1.5.3)

(TBD)

3.4.1.5.4 Actuation reversal.

Reversal of the landing gear control during actuation shall result in the landing gear going to the last position selected.

REQUIREMENT RATIONALE (3.4.1.5.4)

This requirement is to ensure that consideration is given to system operation if the command is changed before the system completes an earlier command. In some cases, however, it may be necessary to use some other scheme to avoid system design problems. Then the requirement should be changed accordingly.

REQUIREMENT GUIDANCE (3.4.1.5.4)

This requirement is to ensure that the landing gear actuation system will not “hang-up” under any motion of the control handle and prevent the gear from finally going to the last commanded position.

REQUIREMENT LESSONS LEARNED (3.4.1.5.4)

This requirement is from the AFSC DH 2-1.

It may not be possible to meet this requirement with a system fairing door actuation. F-15 experience indicates that this is the case for a design that requires that fairing doors be closed after extension of the landing gear.

All systems should be analyzed in the design stage to determine if there are any critical periods in which a control reversal will create a problem. Consideration of dynamic loads and time delay functions of the system may be required for an accurate analysis.

Control reversal characteristics after single component failures in complex electrical control and indication systems should also be reviewed. Failure of a single switch may not only give an indication that the landing gear is not in the position selected, but also disrupt normal sequencing.

It may be proposed that this requirement be modified to establish a time limit on reversal or that the landing gear immediately go to the last position selected. The concern is that a landing gear that must go fully to the first position selected will take excessive time to reach the last position. Modification of the requirement in this form should be resisted because it may complicate the design and increase cost excessively.

4.4.1.5.4 Actuation reversal.

The ability of the landing gear to go to the last commanded position during actuation shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.5.4)

Control reversal characteristics of the actuation system may be very dependent upon system dynamic, hydraulic supply characteristics, and aerodynamic loads. Verification of the characteristics should, therefore, be accomplished by flight test of the air vehicle.

VERIFICATION GUIDANCE (4.4.1.5.4)

TBS should be filled in with landing gear simulator and demonstrated on the first air vehicle prior to first flight. Usually, this is accomplished as a part of the subsystem functional test after initial assembly. A retest of control reversal characteristics should also be accomplished with the air vehicle on jacks whenever test air vehicle are modified by components that affect the retraction or extension sequence.

VERIFICATION LESSONS LEARNED (4.4.1.5.4)

(TBD)

3.4.1.5.5 Airspeed operational criteria.

4.4.1.5.5 Airspeed operational criteria.

3.4.1.5.5.1 Retraction.

Retractable landing gear shall retract into an aerodynamically faired enclosure and the fairing doors, if used, shall close and lock without damage at all airspeeds up to (TBS 1) for flight at (TBS 2) within a time no greater than (TBS 3) .

REQUIREMENT RATIONALE (3.4.1.5.5.1)

This requirement is to establish the range of airspeed for retraction of the landing gear and to define the flight conditions at which the limits apply. Usually, minimum airspeed for retraction is not a problem. Landing gears usually retract with the air vehicle static on jacks. In special cases, such as use of an air turbine to power gear retraction, it may be desirable to specify a minimum airspeed for operation. A possible selection is “minimum flying speed.” The maximum airspeed is frequently a design driver in sizing of retraction or door closing actuators. The value selected usually will depend upon the type and performance or the air vehicle. It may also be established indirectly to be compatible with landing gear extended limit speed or landing gear extension limit speed. A possible approach is to specify that the maximum airspeed must be compatible with air vehicle performance and mission requirements. In some cases, the using command may specify a minimum value based on operational experience. Conditions for application of limit speeds should be defined. This should include temperature (usually 59 degrees F), altitude (usually sea level), air vehicle attitude (sideslip, yaw, pitch, and roll), and possibly configuration.

A time limit should be put on retraction to reduce drag for take-off and minimize the transition time between clean and dirty.

REQUIREMENT GUIDANCE (3.4.1.5.5.1)

TBS 1 should reflect the maximum air speed required for operation.

TBS 2 should define the environmental conditions and the air vehicle maneuvering limits for the operation of the actuation system.

TBS 3 should be filled in with a time compatible with air vehicle performance, but no greater than ten seconds.

REQUIREMENT LESSONS LEARNED (3.4.1.5.5.1)

Aerodynamic loads on the landing gear and doors are frequently difficult to predict. Errors to 100 percent (100%) have been experienced. This may result in severe restrictions of the landing gear limit speed compared to the planned value. The retraction system should be instrumented for load and air load surveys accomplished early in the flight test program.

External stores on some air vehicle may significantly change aerodynamic loads on landing gear doors. Performance should be evaluated with various external stores configurations.

Retractable landing gear should be designed to ensure proper wheel alignment during retraction and stowage.

For large air vehicles where feasible, a clear vision panel or a positive mechanical indicator should be provided that may be used to verify the gear position as indicated on the gear indicator panel.

Hydraulic linear actuators should be preferred over hydraulic rotary actuators for landing gear and door actuation.

When electronic proximity switches are used, the larger model proximity switch should be preferred over the smaller model.

Landing gear door lock actuators should be mounted on the airframe and the lock stirrup should be mounted on the gear doors, and not vice versa.

A solid-state automatic gear sequencing control system should be used only if it has adequately built-in test equipment to check out the principal components of the control system. Indicator lights on the control box should also indicate the progress of the gear actuation sequence from retract to extend and vice versa. Frequently, low temperature severely degrades operating time due to increased viscosity of hydraulic fluid and lubricants. Rotary drive systems seem more susceptible to this problem than linear actuators. Examination of system performance after cold soaking is very important because maximum air vehicle take-off performance occurs at low temperature.

Loss of an engine or hydraulic system may severely degrade operating time. This should be examined by analysis and flight test to confirm that it does not create a hazardous flight condition.

Very short operating time usually results in severe dynamic loads on the actuation mechanism and points of attachment to the landing gear and doors. Mechanism acceleration and deceleration loads may greatly exceed aerodynamic and inertia loads determined by analysis. Failure to consider this fact has resulted in early failure of mechanisms on flight-test air vehicle. Strain gage instrumentation of the mechanism during initial checkout and flight-test is recommended to confirm that dynamic loading is acceptable.

4.4.1.5.5.1 Retraction.

Retraction requirement shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.5.5.1)

Normally, the suitability of the retraction system to function properly can be determined by direct observation of flight test results. Loads instrumentation may reveal, however, that although the function is proper, retraction mechanism stresses are too high for reliable operation.

VERIFICATION GUIDANCE (4.4.1.5.5.1)

TBS should be filled in with analysis and by flight test.

Initial design should be supported by air loads analysis. The results should then be substantiated by flight-testing that include the establishing of maneuvering limits at the specified air speed.

VERIFICATION LESSONS LEARNED (4.4.1.5.5.1)

It has been found in several cases that the air loads seen on the air vehicle differ significantly from that calculated. This has often required the air vehicle to do certain series of yaw movements to get gears down and locked.

It has also been seen that for high accelerating air vehicles that they can exceed the operational limits speed of gear retractions during a max performance takeoff. Thus in determining the maximum operational limit of the actuation system will take into account air vehicle acceleration speeds after liftoff and allow a pad if retraction time is compromised (longer than expected).

3.4.1.5.5.2 Extension.

Retractable landing gears shall extend and lock, and the fairing doors, if used, shall be positioned as required for landing without damage at all airspeeds from (TBS 1) to (TBS 2) for flight within a time no greater than (TBS 3) .

REQUIREMENT RATIONALE (3.4.1.5.5.2)

This requirement is to establish the minimum acceptable range of airspeeds for extension of the landing gear and to define the flight conditions at which the limits apply.

Previous requirements were based on structural design criteria of MIL-A-8862. This contained four conditions to be considered to determine actuation speed for the landing gear. Usually, this was discussed with the contractors prior to contract award and a general agreement reached on a specific airspeed for design. Frequently, the actual basis for the design criteria was comparison with similar type of air vehicle or previous experience of the contractor.

A time limit should be put on extension to minimize the time necessary for return to base and between clean and dirty.

REQUIREMENT GUIDANCE (3.4.1.5.5.2)

TBS 1 should be filled with the minimum air speed, which should usually be “0” to avoid excessive design reliance on air loads to extend the landing gear. This also enables checkout of the landing gear with the air vehicle on jacks. From a practical operational limit, this block could also state, “minimum flying speed.”

TBS 2 should be filled with the maximum airspeed for landing gear extension and should be the minimum acceptable to perform the required mission.

This block should be completed as necessary to define the flight condition at which the limit speed applies. This should include temperature (usually 59 degrees F), altitude (usually sea level), and possibly flight attitude (roll, pitch, yaw).

TBS 3 should be filled in with a time compatible with air vehicle performance, but no greater than 15 seconds.

Retractable landing gear should be designed to ensure proper wheel alignment during and after extension.

REQUIREMENT LESSONS LEARNED (3.4.1.5.5.2)

Application of the criteria contained in MIL-A-8862 may not result in adequate or reasonable landing gear limit speeds.

Although it is desirable to have the landing gear operate in a direction that enables the air load to assist extension, normal and emergency extension should not depend on this air load for proper operation. Use of a landing gear that requires some minimum airspeed for operation should be avoided because it presents maintenance difficulties (hard to functional test and adjust) and may be sensitive to lubrication, wear, and air vehicle maneuvering.

Many factors other than normal landing gear operation may be significant in selection of the maximum landing gear limit speed. Examples include use of the landing gear as a high-speed air brake and air traffic control rules for operation near airports. The limit should be set only after careful analysis of the total mission of the new system.

Frequently, low temperature severely degrades operating time due to increased viscosity of hydraulic fluid and lubricants. Rotary drive systems seem more susceptible to this problem than linear actuators. Examination of system performance after cold soaking is very important because maximum air vehicle take-off performance occurs at low temperature.

Loss of an engine or hydraulic system may severely degrade operating time. This should be examined by analysis and flight-test to confirm that it does not create a hazardous flight condition.

Very short operating time usually results in severe dynamic loads on the actuation mechanism and points of attachment to the landing gear and doors. Mechanism acceleration and deceleration loads may greatly exceed aerodynamic and inertia loads determined by analysis. Failure to consider this fact has resulted in early failure of mechanisms on flight-test air vehicle. Strain gage instrumentation of the mechanism during initial checkout and flight test is recommended to confirm that dynamic loading is acceptable.

4.4.1.5.5.2 Extension.

Extension requirement shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.5.5.2)

This requirement can be verified only by flight-test because proper operation is the result of complex interaction of the air vehicle aerodynamics, dynamics, and system design.

VERIFICATION GUIDANCE (4.4.1.5.5.2)

TBS: Landing gear extension should be verified by analysis. Flight-testing should test to the calculated speed limits. The results of these tests should be compared to the analysis, and the analysis should be corrected accordingly.

VERIFICATION LESSONS LEARNED (4.4.1.5.5.2)

(TBD)

3.4.1.5.6 Operation with loss of door.

Loss of any landing gear fairing door used shall not result in (TBS).

REQUIREMENT RATIONALE (3.4.1.5.6)

This requirement is to ensure that the design approach minimizes the effect of losing a fairing door. The primary intent here is to discourage routing of hydraulic lines and wires on the doors. Alternate design approaches that have been used include use of hydraulic fuses on lines that are routed on doors. Expansion of the requirement statement to include consideration of door loss detection may be desirable.

REQUIREMENT GUIDANCE (3.4.1.5.6)

TBS should be filled with the phrase: “loss of the actuation power system.”

REQUIREMENT LESSONS LEARNED (3.4.1.5.6)

Routing of hydraulic lines and electrical wires on fairing doors can cause severe problems with the landing gear operation if the doors are lost in flight. Usually the landing gear extension capability remains operable after a door loss if power to the actuators and controllers are maintained. Problems were experienced during flight test of C-5A air vehicles because both electrical and hydraulic lines are mounted on the landing gear doors.

Mechanical linkages and cables should not be located on fairing doors because they are subject to binding due to deflections of the door caused by aerodynamic and inertia loading. Rigging of door locks with complex mechanisms mounted on the doors may be very difficult because the in-flight dimensions cannot be duplicated on the ground. Problems with door-mounted mechanisms were encountered on the B-57 air vehicles.

Control logic with the lost door should be reviewed to confirm that it does not prevent landing gear extension. Normal extension is preferred, however, emergency extension after door loss is acceptable.

4.4.1.5.6 Operation with loss of door.

Operation with loss of door shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.5.6)

If a door-loss operating requirement is imposed, it should be verified by analysis. The intent is to ensure consideration of safety aspects rather than positive demonstration of a mission capability. Flight demonstration is not worthwhile because of the many possibilities of the mode of door loss. In some cases, it may be desirable to cycle the landing gear with the air vehicle on jacks and the doors removed or disconnected to confirm proper control logic.

VERIFICATION GUIDANCE (4.4.1.5.6)

TBS should be filled with an analysis of gear operation with loss of door and an analysis of the effects of inflight loss of gear doors.

VERIFICATION LESSONS LEARNED (4.4.1.5.6)

(TBD)

3.4.1.5.7 Emergency extension.

A separate emergency extension system shall be provided with the capability to (TBS 1). It should extend the landing gear in not more than (TBS 2) seconds at all airspeeds from (TBS 3) to (TBS 4).

REQUIREMENT RATIONALE (3.4.1.5.7)

The intent of this requirement is to indicate that an emergency extension system is required and to define characteristics of the system.

REQUIREMENT GUIDANCE (3.4.1.5.7)

TBS 1 should state, “be independent of the normal system except for components stressed by ground loads.”

TBS 2 should specify the time required to get the gear down and locked with the emergency system.

TBS 3 should specify the minimum airspeed at which the emergency system should function successfully. This is usually 0 to accommodate on jacks operation.

TBS 4 should reflect the maximum air speed that the emergency extension system will need to operate. This value needs to allow enough speed to have safe control of the air vehicle in all phases of landing.

The time and speeds are not usually the same as those required for normal gear extension.

System and linkage design details, lock designs, method of emergency extension, and redundancy of system with power sources influence this requirement. This item reflects the criteria previously stated in AFSC DH 1-6 and AFSC DH 2-1. It has been a standard input for over 20 years.

When a strut compressing mechanism is used, means should be provided in the wheel well to preclude jamming of the gear in case of compressing mechanism failure.

A direct mechanical linkage should be provided to release the uplocks for emergency gear extension unless otherwise specified in the detail specification. It should not be necessary for the crewmembers to have a physical hold of the emergency extension control in the actuated position. Where possible, interior fuselage and compartment doors should be provided to permit direct in-flight access to gear uplocks by a crewmember.

REQUIREMENT LESSONS LEARNED (3.4.1.5.7)

The limit airspeed for emergency extension should be the same as the normal extension limit speed to simplify emergency procedures. During a C-5A air vehicle accident, the landing gear did not fully extend because the emergency extension gear limit speed was exceeded. At the time, the C-5A emergency extension limit speed was significantly lower than the present limit.

Experience indicates that the most desirable design is one that provides for free fall of the landing gear after manual release of the uplocks and door locks. Frequently, this approach cannot be used due to the geometry of the landing gear and doors. Alternate power systems of various types are in current use but all have some inherent problems as discussed below.

The emergency landing gear control should be located near the normal control unless specific approval is granted for an integral control. Whenever cockpit space is at a minimum, consideration should be given to integrating the emergency landing gear control with the normal control. The design should preclude interaction between normal and emergency operation. Failure of the normal landing gear control should not preclude subsequent successful actuation of the emergency landing gear subsystem. The emergency landing gear control should be as specified in MIL-STD-203.

Manual uplock release - free fall systems. A major problem with these systems is degradation of performance due to inadequate lubrication and corrosion. It should be possible to conduct a functional test of such systems on the ground. As in the case of normal system operation, excessive reliance should not be placed on assisting air loads. Actuation forces should be carefully considered to ensure that they remain within capability of the aircrew. Proper rigging and resetting of the system after use frequently presents a maintenance problem. Complex resetting procedure may seem acceptable for use after real emergencies but normally become intolerable because of the need for periodic checkout of the system. Consideration should be given to the effect of normal retraction after use of the emergency extension system.

Typical actuation endurance testing with 10 percent (10%) of the extensions being emergency extensions may drive the design of system components unnecessarily. The life of a typical bomber could see less than 100 emergency cycles. Some extend by having the tires knock the doors out of the way. With composite doors, 500 impacts versus 100 impacts can cause a considerable weight difference and strength difference. Consider the appropriate number of emergency extension cycles for endurance, instead of arbitrarily assigning 10 percent (10%) of the cycles.

The actual time for emergency extension of the landing gear includes the time required to confirm that the landing gear is down and locked. Air vehicle accidents have occurred because aircrew spent long periods trying to confirm whether the emergency system operated properly.

Operating time for manual emergency extension systems that include a set of controls for each landing gear assembly should be based on the assumption that landing gear will be extended in sequence (one at a time) rather than simultaneously.

Emergency extension system operating time may be significantly degraded by operation at low temperature. Performance at low temperature, including cold soak of the mechanism, should be investigated.

Performance of emergency extension systems is sometimes severely degraded by certain hydraulic system configurations. Measurements should be made using hydraulic return pressures and hydraulic porting typical of that expected for actual emergencies. Do not assume that the normal hydraulic actuation system is devoid of fluid. Many landing gear emergency extensions are accomplished as a precautionary measure rather than in response to a confirmed fluid loss failure in the landing gear hydraulic system.

4.4.1.5.7 Emergency extension.

Emergency extension shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.5.7)

Verification of emergency extension system characteristics should be accomplished during flight because air loads and the interface with other air vehicle systems cannot be accurately simulated.

VERIFICATION GUIDANCE (4.4.1.5.7)

TBS: The verification of the emergency extension system should include an air load analysis that is supported by simulator testing and flight-testing. If simulator testing is too expensive, adequate means should be used to test the air vehicle emergency extension system both on the ground and in the air.

VERIFICATION LESSONS LEARNED (4.4.1.5.7)

On some air vehicles, additional flight hardware was added to block the normal extension system so the emergency system was the only operating system. Additional flight hardware may be added to ensure that the gear would be extended if the emergency system failed the extension testing or did not have the hydraulic power to get the gear down, especially if the gear has to extend into the air stream.

Providing correct air loads on simulators have not been very successful. They have often been in the wrong direction and the max loads have often been at the wrong gear position and door position.

The flight test used to verify performance of the emergency extension system should accurately reflect the most critical probable failure conditions. For example, depressurization of the hydraulic system may not accurately simulate failure of a landing gear sequence valve. Hydraulic flow with a blocked valve may cause much higher extension loads than experienced with a depressurized hydraulic system. Critical failure modes should be accurately simulated.

3.4.1.5.8 Actuation indication.

4.4.1.5.8 Actuation indication.

3.4.1.5.8.1 Gear position status indications.

An indication shall be provided to show gear position.

REQUIREMENT RATIONALE (3.4.1.5.8.1)

This requirement is to provide an indication of the position and status of the landing gear. This is required on air vehicle with retractable landing gear to enable the pilot to know that the landing gear is in the position required for the intended operation. In addition, the system may warn the pilot of unsafe conditions and permit him to select the proper corrective action.

REQUIREMENT GUIDANCE (3.4.1.5.8.1)

A means to indicate normal gear position, disagreement between the gear control and the gear position, and gear unsafe conditions should be provided. See Crew Systems Specification Guide, JSSG-2010, for position indicators and standard lighting configurations.

REQUIREMENT LESSONS LEARNED (3.4.1.5.8.1)

This requirement was formerly contained in AFSC DH 1-6. MIL-STD-203 also contained a requirement that stated that the indicator(s) should be located on the instrument panel or adjacent to the landing gear control lever visible to the pilot(s) in his (their) normal position(s). The following lessons learned provide additional detail:

a. The general requirement for an indicator has existed in some form for at least 25 years.
    1. Normally, an indicator should be provided for each separate landing gear assembly. The pilot usually needs to know which landing gear is not in the position selected to plan the corrective action properly.
    2. The gear indicating system should not indicate a “safe-gear-locked-position” prior to actual locking or positive engagement of uplock or downlock mechanism. Landing gear indicators are usually lights or electromechanical devices. Usually a green light is used for each landing gear to indicate that it is down and locked. Red lights are sometimes used to indicate that landing gear or doors are not up and locked. In some cases, no indicator is provided for up and locked. However, unsafe uplock condition is indicated by the warning system (red light in gear handle plus an aural warning). Electromechanical indicators have been used in many air vehicles. These usually show green wheels for gear down, a barber pole design for in-transit, and “up” for landing gear up and locked.
    3. Indicator systems that use lights should include two bulbs in each indicator with a

light test function either as an integral part of the indicator or as a part of the air vehicle lighting system. When two bulbs are used, be sure that it is possible to detect that one bulb is burned out. F-15 air vehicle experience indicates that bulbs should be separated under the common lens to ensure that failed bulbs can be detected.

4. Indicator lights and panel lighting should be designed with replaceable bulbs. A sealed lighting system used on the C-5A air vehicle proved troublesome. Bulb replacement required removal of the entire landing gear control. Replacement of the landing gear control required a complete functional check of the landing gear retraction system. The functional check required that the air vehicle be jacked. What seemed like a good idea at the component level had a major impact on system maintenance man-hours. Landing gear indicator panel lighting should be accomplished with easily accessible bulbs or light emitting elements that will permit easy replacement without removal of the panel or removal and disassembly of the panel. This requirement should stand regardless of the alleged guaranteed life of the bulbs.

5. Switches used to indicate an uplock or downlock position of the gear should be activated directly by the locking means.

6. Indicators should function from a positive signal rather than lack of a signal. Negative logic, for example, can result in a broken wire giving a false down and locked indication.

7. Landing gear control circuits, indicator circuits, and electrical and magnetic proximity sensors should be separated insofar as possible. This minimizes the possibility of sensor-to-sensor inductive interference that will not only prevent landing gear operation but could also give false indications of the malfunction. When gear geometry does not allow sensor separation, interference properties should be investigated to determine if sensor isolators are needed. Furthermore, separation of the circuits usually prevents compromise of emergency circuits. Use of common components would result in simultaneous deactivation of the indication systems.

8. Indicator operation after a single failure of the nominal extension system should be carefully considered. An incident was experienced on the initial F-15 design wherein a single failure resulted in a down and locked indication when the landing gear was up and locked. A switch failed causing the landing gear to try to extend while still uplocked. Deflection caused by the force against the uplock caused an indicator switch to make contact. The combination of failed switch plus the false actuation of the second switch resulted in a false indication.

9. If possible, some type of backup system of indication should be provided. Usually viewing windows can be provided on cargo air vehicle so that uplocks and downlocks can be inspected directly. Some type of simple marking system should be used for the downlock locked indication. Frequently, a diagram of proper position is placed near the viewing window so that the aircrew can quickly judge the position. On some air vehicles, it is also desirable to mark the downlock so that it can be observed from a chase air vehicle. Other devices such as mechanical indicators and mirrors have been used on air vehicles to permit the pilot to check

gear position if he suspects indicator system malfunction. The use of fiber optic scopes to inspect the position of the landing gear in flight has been unsatisfactory to date.

10. The original nose landing gear position indicator used on C-141A air vehicle was actuated by a switch in the over center drag brace link. Slight movement of the landing gear in the retracted position could result in a false indication that the landing gear was extended and locked. This feature resulted in an air vehicle accident. The deficiency was eliminated by installation of a switch to detect that the landing gear is extended.
11. All switches should be designed and installed so that they are readily accessible, easily adjusted or rigged, and removed and replaced. Switch mounting and installation should be adequate to ensure proper switch actuation under all landing gear loads and deflection. Proximity switches have proven to be highly reliable, easy to troubleshoot, and do not require the frequent rigging and adjustments associated with mechanical switches as long as the initial design locates the switches and targets in stable areas of the landing gear linkages. Mechanical switches should have a high-force actuator return spring or be provided with a direct double-acting mechanical linkage. This prevents mechanical switches from sticking in one position due to contamination or friction.
12. For certain locations on the gear, it may be desirable to install connectors on the proximity switches. This would reduce maintenance time if chafing or wire bundle failures are a problem. Note: if connectors are used on the switches, ensure they are designed to be compatible with the EMC/EMI requirements.
13. The squat switch should be located and should be of such a design that the "weight-off" condition is not indicated until the wheel is off the ground.

b. The following detailed requirements have been applied to most current air vehicles. The results are generally satisfactory. Use of a similar requirement and approach aids aircrew transition to a new air vehicle design.

1. Provide a Type MA-1 audio warning signal (refer to MIL-DTL-9320) that automatically actuates when the following conditions exist simultaneously:
   (a.) The air vehicle is below a preset altitude.
   (b.) The indicated air speed (IAS) of the air vehicle is less than a preset value.
   (c.) In turbine engine air vehicles, the throttle is less than a predetermined power setting. In reciprocating engine air vehicle, the throttle is less than normal cruise position.
   (d.) The landing gear is not down and locked.
2. Provide a radially mounted wheel-shaped landing-gear control knob. Ensure that the internal red warning light automatically lights when any gear is not exactly consistent with the position selected for the landing-gear control or if any of the gear is retracted. Additionally, ensure that this light illuminates when the audio signal occurs. Install the red warning light on an automatic dimming circuit. Provide a test

switch that tests the landing-gear audio and warning light circuit.

Recently, difficulty was experienced with the F-105 control handle. The detent had worn to such a state that adequate warning was not provided. This indicated that periodic inspection is required.

4.4.1.5.8.1 Gear position status indications.

Gear position status indications shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.5.8.1)

Proper operation and suitability of the indicator system can best be determined by normal use during the flight test program. In some cases, it may be desirable to perform a specific demonstration of operation when specific malfunctions to the landing gear are simulated. If a landing gear retraction simulator is available, it is highly recommended that the various failure modes be investigated on the simulator.

VERIFICATION GUIDANCE (4.4.1.5.8.1)

TBS: The verification of the landing gear indication should be by inspection of drawing and logic schematics. The verification of operation should be demonstrated on the air vehicle, both on jacks during checkouts and in flight-testing.

VERIFICATION LESSONS LEARNED (4.4.1.5.8.1)

Consideration should be given to conducting an icing test where the landing gear subsystem will successfully operate after there is an ice build-up and freezing of the hydraulic locks. The gear should successfully retract and extend. Consideration should be given to ice build-up on door or locks to verify that the ice will not prevent extension.

Conduct simulator testing to verify that the braking inertia loads encountered while stopping the wheel from spinning during retraction are not exceeding the design limits and concur with the analysis.

Conduct simulator testing to determine minimum accumulator pressure needed to extend and lock the gears successfully under all conditions.

It is significantly more difficult to verify operation at -65 degrees F than it is at -40 degrees F.

3.4.1.5.9 Landing gear position restraint.

4.4.1.5.9 Landing gear position restraint.

3.4.1.5.9.1 Gear position restraint.

A means shall be provided to maintain each landing gear in the selected position.

REQUIREMENT RATIONALE (3.4.1.5.9.1)

The intent of this requirement is to ensure that the gear will stay in the final selected position without any power for all air vehicle operations within its mission profiles.

REQUIREMENT GUIDANCE (3.4.1.5.9.1)

The objective of the requirement should be to establish performance for gear positioning. “Locks” should be considered for maintaining each landing gear in the selected position.

Where doors are used in conjunction with landing gear, the method used to restrain the landing gear in the selected position should not result in extension of the landing gear due to gapping or loss of a landing gear door.

REQUIREMENT LESSONS LEARNED (3.4.1.5.9.1)

AFSC DHs 1-6 and 2-1 formerly stated the requirement for automatic operating positive mechanical locks. These requirements were based on ARDCM 80-1 (HIAD) that were generated primarily from lessons learned.

a. Use of actuation force or blocking of the actuation pressure to retain the landing gear in the retracted or extended position is considered an unacceptable approach. Such designs are subject to failure due to power failure, leakage, or excessive deflection. Inadvertent gear extension at high speed has caused major air vehicle accidents. This requirement should specify that positive mechanical locks be used to maintain the landing gear in the extended or retracted position.

b. Landing gear and door locks should be designed for proper rigging while on the ground. Rigging of up locks and down locks should be by simple adjustment and not require devices with close tolerance adjustments. Some designs have been used in the past that require compensation for the fact that alignments of parts of the lock are dependent upon the amount of air load applied. These designs require considerable flight test effort to develop suitable rigging procedures. Frequently, the problem is not recognized and severe flight test delays result. In most cases, the problem can be avoided by mounting major lock components on fixed structure and providing guides to direct moving parts to the proper position.

c. Landing gear up locks should not be mounted in a manner that requires that the shock absorber be properly serviced for the lock to operate correctly. A recent incident with a fighter air vehicle revealed that not only will the lock not lock but also the lock parts may jam and prevent landing gear extension.

d. Landing gear down locks should be designed so that ground loads do not stress them. Down locks subjected to ground loads are exposed to a severe fatigue stress environment that may be highly dependent upon lock rigging. Durability testing on a single landing gear may not accurately reflect operational design life. If the design dictates that the down lock must carry ground loads, it is recommended that the lock be non-adjustable.

e. Hydraulic pressure variations due to surges or thermal expansion have caused locks to unlock. Locks sometimes work properly for normal operation but malfunction when used for emergency extension because subjecting both sides of the actuator to return pressure results in a tendency to unlock. The actuators should be installed so that if both sides of the piston are pressurized, the resultant force tends to lock the actuator towards the commanded position. In designs where pressure works on both sides of the actuator, time delays and system logic should be ensured to cause the gears or doors to lock in the commanded position. The use of landing gear simulators is strongly recommended in proving the logic and capability of such a system.

f. Locks should be designed so that if actuation force is applied with the lock engaged, the lock does not unlock and neither the lock nor the actuating mechanism is damaged.

g. Some ground load conditions may result in deflections that tend to unlock down locks. An analysis should be performed to determine if limit load conditions will result in excessive deflection. The analysis should include unusual loading conditions such as extreme landing attitudes and reverse braking.

h. Electrically operated locks should be designed so that no single electrical failure will result in the lock unlocking.

i. Locks should be designed with no water traps. Ice build-up should not prevent operation. Testing may be required to verify that actuator force or icebreaker design is adequate.

j. Up locks should be designed so that flight inertia loads of the landing gear do not load the actuation mechanism.

k. Landing gear subsystems should be designed so that small errors in servicing will not cause gear malfunctions.

l. The use of shims for adjustments between any switch, brackets, and gear structure decreases the reliability and maintainability of the landing gear subsystem.

m. The up locks should hold the individual gears in the up and locked position independent of door locks.

n. Failure of door locking linkages or extension devices should not preclude emergency unlocking and extension of the landing gear.

Slight 5 to 7 percent (5-7%) over inflation of the F-111 gear struts will prevent the main gear from locking in the retract position.

The F-111 landing gear strut servicing procedure used air pressure in conjunction with strut extension for proper inflation of the shock struts. The strut extension is measured in one-eighth inch increments and the air pressure is held to plus or minus 25 pounds per square inch. The gage used for this procedure has a range of 0-4000 pounds, and the dial face is marked in 100-pound increments, which makes accurate air servicing very difficult and almost impossible to meet the plus or minus 25-pound requirement.

Do not use air for inflation, for under certain conditions an explosive mixture can be formed, resulting in a “dieseling” effect. Nitrogen will prevent this potential problem.

This requirement should not prohibit use of systems that depend on the landing gear up locks to keep doors closed. These systems have been used on fighter air vehicles, F-4 for example, with considerable success. An inherent disadvantage of this approach is that door linkage must be rigged to provide proper preload of the door. The preload should be enough to prevent door gaping due to air loads but not so high as to cause structural damage. The major advantage of this approach is that it simplifies the actuation sequence and mechanism.

The number of actuators required to operate door and landing gear locks should be minimized. Failure of an actuator normally disables the actuation system and may cause severe damage. Only electrical or hydraulic interlocks can avoid this. Experience has indicated that these interlocks frequently cause more failures and maintenance problems than the basic system. Use of a small number of actuators often results in a complex mechanism. Once developed, however, such systems provide better operational service.

4.4.1.5.9.1 Gear position restraint.

The means to maintain gear in the selected position shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.5.9.1)

Suitability of the lock system should be evaluated by flight test. Evaluation of performance under extreme conditions such as load or low temperature may require that a laboratory test be performed. In some cases, design analysis may be sufficient to show that the lock performance is not adversely affected by the specified conditions.

VERIFICATION GUIDANCE (4.4.1.5.9.1)

TBS should be filled with analysis, laboratory tests (simulators), taxi and flight-testing, and failure modes and effect analysis.

VERIFICATION LESSONS LEARNED (4.4.1.5.9.1)

(TBD)

3.4.1.5.10 Ground safety restraint.

Ground safety provisions shall be provided to prevent retraction without damage to the air vehicle or ground safety provisions under any of the following conditions: (TBS).

REQUIREMENT RATIONALE (3.4.1.5.10)

There have been numerous incidents of inadvertent or uncoordinated gear retractions during landing gear maintenance, which have resulted in personnel injury. Therefore, operational needs exist to provide a design that precludes this characteristic.

REQUIREMENT GUIDANCE (3.4.1.5.10)

TBS should be filled with the following: Inadvertent gear handle actuation, transient, taxi, take-off, landing, hydraulic or electrical signals, EMI, physical impact of gear linkages, or other should be included in the blank.

Unique landing gear ground locks should be stowable on the air vehicle.

REQUIREMENT LESSONS LEARNED (3.4.1.5.10)

Previously, ground lock requirements were contained in AFSC DHs 2-1 and 1-6. These documents identified the need for inclusion of such a device in the design but they did not attempt to identify the conditions under which the lock would continue to provide safety. This will be a new requirement.

a. Landing gear lock should be designed so that they may be installed and removed regardless of the load on the landing gear. This is required so that locks can be used for normal operation to maximum weight and with the air vehicle on jacks.

b. Doors that are power activated for ground maintenance access should be provided with separate ground locks for installation with doors open. It may not be necessary to use these locks for normal flight operations.

c. Pins used to hold a ground lock in place should be permanently attached to the lock to minimize the possibility of the pin being improperly installed.

4.4.1.5.10 Ground safety restraint.

The effectiveness and adequacy of the ground safety locks shall be verified during flight-test.

VERIFICATION RATIONALE (4.4.1.5.10)

Design aspects of the ground lock can be evaluated by inspection of the hardware. Functional suitability can be evaluated as a part of the overall flight test evaluation of the air vehicle.

VERIFICATION GUIDANCE (4.4.1.5.10)

During ground operation in flight-testing the use of ground safety restraints should be demonstrated and proved to be adequate.

VERIFICATION LESSONS LEARNED (4.4.1.5.10)

(TBD)

3.4.1.6 Ground operation interface.

The landing gear shall be capable of providing flotation, high frequency ground roughness accommodation, frictional drag at the ground for stopping, stopping energy absorption, a side load at the ground as a function of yaw angle, and low friction drag for takeoff and landing.

REQUIREMENT RATIONALE (3.4.1.6)

The objective is to provide a capability compatible with the air vehicle operation and performance for all taxi, turns, takeoff, and landing operations at the critical gross weights and velocities that do not exceed air vehicle structural or operational limits. Emergency conditions should also be considered, such as aborted takeoffs and maximum weight landings. If aerodynamic heating exceeds 160 degrees F during flight, this should be considered.

REQUIREMENT GUIDANCE (3.4.1.6)

Performance parameters:

a. Air vehicle configuration.
b. Flotation.
c. Load - This parameter will be dependent upon 3.4.1.3.
d. Growth allowances.
e. Runway considerations.
f. Speed - maximum ground speed, rotation speed, brake application speeds.
g. Taxi distances and turning requirements.
h. Environmental heating - Aerodynamic heating level, time at high speed, equipment mass and air flow may be significant parameters for the design. This may dictate high temperature compounding.
i. Temperature.
j. Air vehicle design weights.

The environment developed by the wheel-brake-tire combination should be accounted for in the design conditions of the wheels.

See sections 3.4.1.11 and 4.4.1.11 for component information if tires, wheels, and brakes are used.

REQUIREMENT LESSONS LEARNED (3.4.1.6)

This requirement reflects the concept generated in MIL-PRF-5041, AFSC DH 2-1, and AFSC DH 1-6. This is an industry-accepted practice for military and commercial tire development.

4.4.1.6 Ground operation interface.

Ground operation interface shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.6)

This is to ensure that the ground operation interface requirement is verified.

VERIFICATION GUIDANCE (4.4.1.6)

TBS should be filled in with analysis and ground and flight-test as appropriate.

This should take into account the static and dynamic loads as well as speeds and time at loads for worst-case operational conditions and normal operating conditions.

VERIFICATION LESSONS LEARNED (4.4.1.6)

If tires are used, the use of a laboratory dynamometer to evaluate tire, wheel, and brake performance characteristics permits evaluation to the limits of the tire, wheel, and brakes capability with low risk. The design conditions are carefully controlled and are repeatable. Industry has always utilized this method of evaluation prior to installation on an air vehicle to determine performance limits and to establish safety of flight. It is more profitable than any other verification method. The tire, wheel, and brakes will also be observed and evaluated during the routine flight-test program.

3.4.1.7 Restraint capability.

The landing gear shall provide restraining force to hold the air vehicle static on a dry paved surface during application of (TBS).

REQUIREMENT RATIONALE (3.4.1.7)

This establishes the need to hold the air vehicle static for functions such as engine run-up.

REQUIREMENT GUIDANCE (3.4.1.7)

TBS should reflect the thrust level of engine run-up during which the air vehicle is required to remain static, such as 100 percent (100%) military power.

REQUIREMENT LESSONS LEARNED (3.4.1.7)

Depending upon using command practices, this requirement may vary. Most jet air vehicles do not generally park with brakes locked and run-up all engines to military power. However, the requirement should be tailored for the Command requirements.

The ability to meet these requirements is a function of the size and design of the rolling components selected. If there is not enough tire contact area, holding the brakes locked will still result in skidding the tires. The ability to develop a tire drag force is a function of the applied load and the tire to ground coefficient of friction. The contact patch may have some effect, but that should be included in the assumptions used to select the coefficient of friction.

Depending on the type of brake used on the design, the brakes may or may not remain locked at full actuation pressure. With steel brakes, the static coefficient of friction between the brake disks is much higher than that generated during braking, and holding the wheel locked is relatively easy. With carbon brake disks and friction material, the static and dynamic coefficients of friction are very close to one another and more effort would be required to keep the disks from rotating.

It is not clear whether it is best practice to let the operational practice drive the hardware design or whether the hardware design should drive the operational practice. This should be a joint engineering/using command decision.

4.4.1.7 Restraint capability.

Total air vehicle stopping performance and the ability to hold the air vehicle static during engine run-up shall be evaluated by air vehicle test as follows: (TBS).

VERIFICATION RATIONALE (4.4.1.7)

Even though the static coefficients of the brake are evaluated in the laboratory during development testing, it is best to evaluate the system performance on the air vehicle.

VERIFICATION GUIDANCE (4.4.1.7)

TBS should reflect a demonstration on the air vehicle. On some air vehicle, the thrust is sufficient to move the air vehicle even with the wheel locked up. This is not a failure of the brake system as long as the brakes can keep the tires from rotating. It would be prudent to release brake once the air vehicle begins to move to prevent flat spotting the tires.

VERIFICATION LESSONS LEARNED (4.4.1.7)

A number of air vehicles start to move toward the end of the runway when the throttles are advanced and before they get to 100 percent (100%) power. In these cases, the pilot should release the brakes and begin the takeoff roll. This should not be considered a failure of the braking system as long as the wheel did not begin to rotate first.

3.4.1.8 Auxiliary deceleration devices

4.4.1.8 Auxiliary deceleration devices

3.4.1.8.1 Arresting hook systems

4.4.1.8.1 Arresting hook systems

3.4.1.8.1.1 Air vehicle arrestment performance

The arresting hook system shall be capable of decelerating (TBS 1) air vehicle to a stop by engaging (TBS 2) arrestment system at (TBS 3).

REQUIREMENT RATIONALE (3.4.1.8.1.1)

This is a performance statement for the arresting hook system. The legacy arresting hook specification MIL-A-83136 can provide additional guidance.

REQUIREMENT GUIDANCE (3.4.1.8.1.1)

TBS 1 should define air vehicle’s maximum weight or configuration to be arrested.

TBS 2 should list the intended arresting system. If specific arresting system is not known, use the BAK-12ER.

TBS 3 should list the speed of engagement in the blank and define the energy to be absorbed. If the total energy of the system exceeds the barrier capability, the limit speed at the design gross weight selected should be used.

The arresting system and air vehicle should withstand engagement loads with all tires contacting the ground (i.e., the aircraft in a three-point roll) and with brakes off as aircraft traverses the cable. The minimum requirement should occur with the tires’ deflection and landing gear shock absorbers’ stroke at static levels for a landplane landing design weight and approach speed. A maximum requirement would be with a flat nose tire and flat nose gear to represent worst case.

Barrier system design and limits hook compatibility, air vehicle configuration, and engaging speeds control this requirement.

The verification aspects are defined in AFSC DH 2-1. The original emergency tail hooks were in accordance with MIL-A-18717, which was used to establish criteria. Through the efforts and cooperation of industry, MIL-A-83136 was published in August 1968. Recently, errors were found in the load data used for design compatibility with the BAK-12 barrier system, and efforts were being made to update the criteria.

REQUIREMENT LESSONS LEARNED (3.4.1.8.1.1)

The spring-type hook shanks have exhibited numerous problems during both testing and operation in the field. If a spring tube shank is used, consideration should be given to its bending mode after contacting a protrusion on the runway or at barrier engagement, as missed engagements are common place because of hook bounce when the vertical load at the attach point is very high.

4.4.1.8.1.1 Air vehicle arrestment performance.

Performance limits for arresting hook systems shall be evaluated by air vehicle test with the specified arrestment system.

VERIFICATION RATIONALE (4.4.1.8.1.1)

Since the performance is basically a function of interface and compatibility with the arrestment system, the most logical demonstration is on the air vehicle with the intended barrier system. Much of the performance is a dimensional and dynamic response as a system.

VERIFICATION GUIDANCE (4.4.1.8.1.1)

The design and structural capability should be verified by analysis and laboratory testing. On air vehicle testing should verify overall system performance capability.

VERIFICATION LESSONS LEARNED (4.4.1.8.1.1)

A number of engagements should be performed on the air vehicle during flight-testing to ensure there is no damage due to cable dynamics and that the loads are within the design envelopes.

3.4.1.8.1.2 Fly-in engagement criteria.

Arresting hook system and attachment shall withstand loads of <u>(TBS)</u> fly-in engagement.

REQUIREMENT RATIONALE (3.4.1.8.1.2)

If the using command intends to arrest the air vehicle during emergency by fly-in engagement, this statement should reflect the requirement. If the user does not intend to operate in this manner, the requirement should be deleted. The blank should show the gross weight condition for fly-in engagement.

REQUIREMENT GUIDANCE (3.4.1.8.1.2)

TBS should list the approach speeds expected for this type of engagement and still maintain control of the air vehicle.

Barrier system energy capacity, hook design loads, hook point design, air vehicle configuration, and weight affect and control meeting this operational need.

Most Air Force aircraft do not have this as a requirement to avoid the steep approaches and high sink rates needed for precise touchdown location. The landing gear and air vehicle is subjected much lower loads and therefore considerable weight savings is achieved. In addition, the arresting gear barriers at Air Force installations are placed approximately at the 2,000 ft point from both the approach and departure ends of the runway. However, this requirement establishes performance for such a maneuver, since the user needs this option in case of an emergency. If fly-in engagements are required, MIL-STD-18717 provides a comprehensive set of requirements to ensure safe capture of the barrier.

REQUIREMENT LESSONS LEARNED (3.4.1.8.1.2)

The fly-in engagement loads are significantly higher than those encountered when taxiing into the barrier. Therefore, the weight of the air vehicle that can be recovered within the design load envelope is reduced. The cable dynamic reactions increase in severity, as well as the impact of higher loads due to higher energy transmission. It would be anticipated that local damage to the underside of the air vehicle could be expected due to fly-in engagement.

4.4.1.8.1.2 Fly-in engagement criteria.

Performance limits for emergency arresting hook systems shall be evaluated by air vehicle flight test with the specified arrestment system.

VERIFICATION RATIONALE (4.4.1.8.1.2)

Since the performance is a function of interface and compatibility with the arrestment system, the most logical demonstration is on the air vehicle with the intended barrier system. The dynamic effects play a major part in the ability to arrest the intended air vehicle.

VERIFICATION GUIDANCE (4.4.1.8.1.2)

The fly-in engagement should be verified by air vehicle testing with the required arrestment systems.

VERIFICATION LESSONS LEARNED (4.4.1.8.1.2)

(TBD)

3.4.1.8.1.3 Probability of successful engagement.

The probability of successful engagement of the arresting system shall be not less than (TBS) for all air vehicle-landing attitudes. The arresting hook system shall provide sufficient hook hold-down force and damping to minimize hook bounce and prevent further loss of contact with the runway for all-landing configurations and attitudes.

REQUIREMENT RATIONALE (3.4.1.8.1.3)

This requirement is to establish an acceptable level of reliability of the arresting hook system. It is primarily intended to ensure consideration of proper positioning of the hook and prevention of hook bounce.

REQUIREMENT GUIDANCE (3.4.1.8.1.3)

TBS should be filled with an appropriate value based on operational experience with existing systems on air vehicles with similar mission requirements. In some cases, it may be desirable to further define the conditions applicable to this success probability. This could include such factors as type of runway surface, type of arrestment system, and maximum lateral or angular misalignment of the air vehicle and arrestment cable.

Runway roughness, damping characteristics, discrete bump characteristics, hold-down force, main landing gear track, and hook toe position are parameters influencing the ability to meet this requirement.

Design criteria were previously furnished in legacy documents MIL-A-83136 and AFSC DH 2-1.

REQUIREMENT LESSONS LEARNED (3.4.1.8.1.3)

Prevention of hook bounce prior to arrestment cable engagement is a major factor in the probability of success. Previously, it was specified that hook bounce should not exceed 2.25 inches before arrestment. This has been found to be one way to improve the probability of success and should be strongly considered by the designer. Hook bounce is limited by using a damper.

A hydraulic or mechanical damping device usually provides damping. In most cases, the worst-case condition is when the nose tire is flat and the nose gear strut is flat. However, with the viper, it is when the nose tire just touches the runway, because the main gears are still extended due to wing lift. Essentially, with the aircraft in a 3-point landing condition with all the gears extended, the hook will sail over the cable. Arresting gear design should successfully engage under this condition also.

The distance between main landing tires and hook is a significant factor. As the main tires cross the cable, a wave is created which can force the cable close to the ground. If the hook toe is too close to the main tires, the hook can skip over the top of the cable, thus preventing engagement. The hook toe should be positioned to allow the cable to return to the undeflected height, which increases probability of a successful engagement.

4.4.1.8.1.3 Probability of successful engagement.

The probability of successful engagement shall be determined by analysis of flight test results.

VERIFICATION RATIONALE (4.4.1.8.1.3)

The requirement should be verified by analysis because the high probability of success would require too much testing to establish a significant sample size. Arrestment failures experienced during flight test should be considered. If the design or procedures that caused the arrestment failure is not corrected, probability of the condition reoccurring should be considered in the analysis.

VERIFICATION GUIDANCE (4.4.1.8.1.3)

Arresting hook dynamics and adequacy of the hold-down force should be determined by computer analysis and should be demonstrated on the air vehicle.

VERIFICATION LESSONS LEARNED (4.4.1.8.1.3)

(TBD)

3.4.1.8.1.4 Lateral freedom of hook.

Hook installation shall have lateral freedom for (TBS).

REQUIREMENT RATIONALE (3.4.1.8.1.4)

Frequently, the air vehicle will contact the runway off-center and in a drift-landing attitude, which would make engagement other than straight into the center of the cable span. Therefore, limits on off-center and alignment engagement should be established for operational requirements. In the past, 20 percent (20%) off-center and 20-degree misalignment have been selected for design purposes.

REQUIREMENT GUIDANCE (3.4.1.8.1.4)

TBS should be filled with "…20% off-center and 20-degree misalignment at engagement with respect to the center of the cable span."

Lateral hook loads, centering forces, barrier characteristics, crosswind, direction, and velocity are characteristics impacted by this requirement.

This requirement was previously stated in MIL-A-83136. A portion was in the performance section, and a portion was previously in the verification/quality assurance section. It is expected that this requirement originally stemmed from the Navy requirement as expressed in MIL-STD-18717.

REQUIREMENT LESSONS LEARNED (3.4.1.8.1.4)

Since many of the previous requirements on Air Force arresting hook design stemmed from Navy experience, most of the lessons learned are from this operational regime.

The biggest problems associated with off-center engagement are eccentric loads, control, and air vehicle clearance. If there are any protuberances within the envelope of arresting hook movement, they are in jeopardy of damage due to hook contact. The bottom of the air vehicle should be clear in the envelope of hook movement. A suitable protected fairing is needed for most arresting hook installations.

The attachment of the hook should be designed to take off-center loading to the limit of the design envelope. Cable bounce and dynamics are as important a consideration as the hook movement itself. Therefore, knowledge of anticipated cable dynamics is an important task of proper design and installation.

Most hook installations have had difficulty in maintaining directional control during barrier runout. This is particularly true for off-center misaligned engagements. On the F-111 and F-5, it was best to maintain control with the use of rudder rather than steering. Rollback after completion of the runout is also a problem. If the brakes are applied too abruptly, air vehicle with aft center of gravity situations will sit back on the tail and suffer structural damage. Each air vehicle should develop the proper design technique for steering and handling of rollback. Another problem with rollback is catching the hook point on runway irregularities. This can accentuate the tendency to tip back.

A method should be provided to keep the shank on the air vehicle centerline prior to engagement but permit movement after engagement.

4.4.1.8.1.4 Lateral freedom of hook.

Performance limits for arresting hook systems shall be evaluated by air vehicle flight test with the specified arrestment systems. The dynamic and design characteristics shall be evaluated by analysis and inspection.

VERIFICATION RATIONALE (4.4.1.8.1.4)

The air vehicle with the intended system best demonstrates compatibility with the arrestment system. Dynamic response of the system can be predicted to a limited degree, but the final proof is an actual demonstration.

VERIFICATION GUIDANCE (4.4.1.8.1.4)

Appropriate dynamic analysis and laboratory testing may be needed to determine the performance envelope for the arrestment system. The results of the analysis should be supported by on air vehicle tests and demonstrations.

VERIFICATION LESSONS LEARNED (4.4.1.8.1.4)

(TBD)

3.4.1.8.1.5 Hook retracted criteria.

The retracted hook shall preclude (TBS).

REQUIREMENT RATIONALE (3.4.1.8.1.5)

The objective of this requirement is to establish a safety requirement for landings where hook engagement is not desired.

REQUIREMENT GUIDANCE (3.4.1.8.1.5)

TBS should be filled with "…the inadvertent engagement of the arresting system for all air vehicle landing attitudes, including the effects of compressed tires and struts, and rebound of the cable due to the tires running over it."

Rather than define a prescribed ground clearance at maximum tail down attitude, including compressed tires and struts, this requirement states that the stowed hook should not inadvertently engage the barrier or arresting system while in the most critical condition.

Physical details of the hook design, aft fuselage detail design, and high angle of attack flying characteristic affect meeting this design requirement.

This requirement was previously contained in MIL-A-83136.

REQUIREMENT LESSONS LEARNED (3.4.1.8.1.5)

Generally, tail hooks have provided a minimum ground clearance of 14 inches in the stowed position at maximum tail down attitude. This rule of thumb is to ensure ground clearance for the cable that is rebounding from the main tires running over it. Although conservative, it represents lessons learned by the Navy after years of experience in arresting hook design and installation.

If such clearance cannot be provided, a fairing can provide suitable protection to preclude inadvertent hook-cable engagement. Considerable damage to the fairing was experienced on the F-111 during category II testing at Edwards AFB. This occurred on routine engagement after the hook picked up the cable and rebounded against the bottom of the air vehicle. Fairing design should be inexpensive or easily replaceable or both.

4.4.1.8.1.5 Hook retracted criteria.

The dynamic and design characteristics shall be evaluated by inspection.

VERIFICATION RATIONALE (4.4.1.8.1.5)

No special tests can be conceived to evaluate inadvertent hook engagement on routine landings. This will become readily apparent by observation.

VERIFICATION GUIDANCE (4.4.1.8.1.5)

Inadvertent engagements should be evaluated by analysis and inspection of drawings and the installation.

VERIFICATION LESSONS LEARNED (4.4.1.8.1.5)

(TBD)

3.4.1.8.1.6 Position indication.

Current position of the hook shall be (TBS).

REQUIREMENT RATIONALE (3.4.1.8.1.6)

In order for the pilot to maintain control of the air vehicle in emergency or normal operation, it is vital to be able to know whether the hook has been deliberately or inadvertently extended and whether the hook has in fact been extended when such action was initiated. Therefore, indication is deemed necessary to provide this status information to the pilot.

REQUIREMENT GUIDANCE (3.4.1.8.1.6)

TBS should reflect the need for indicating the current extended/retracted position of the hook. Indication should be provided to the crew whenever the hook position is inconsistent with the control position.

Cockpit designs, arresting hook position display, position-sensing circuit, redundancy of circuit, power sources, and switch design and location affect the ability to meet this operational need.

This is a new requirement not previously contained in prior documentation.

REQUIREMENT LESSONS LEARNED (3.4.1.8.1.6)

Experience on recent air vehicle indicates that location of the arresting hook release lever is important. On the F-111A and the F-15A, the arresting hook release handle is located in the near proximity to the parking brake control handle. In each case, the handle shapes are similar, and there have been incidents with each air vehicle where the wrong handle has been inadvertently actuated. The direct result has been blown tires and a missed barrier. Fortunately, no serious damage resulted in either occurrence.

Therefore, judicious placement of the release handle and some method of position indication are reasonable expectations for new designs.

4.4.1.8.1.6 Position indication.

Position indication shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.8.1.6)

Observations from drawings, mock-up, or actual air vehicle confirm the adequacy of the arresting hook controls.

VERIFICATION GUIDANCE (4.4.1.8.1.6)

TBS should be filled with inspection of drawings and on air vehicle demonstrations. The air vehicle demonstrations should check both correct position indications and incorrect position indications.

VERIFICATION LESSONS LEARNED (4.4.1.8.1.6)

(TBD)

3.4.1.8.1.7 Maintenance and installation criteria.

For maintenance activity, the hook installation shall (TBS).

REQUIREMENT RATIONALE (3.4.1.8.1.7)

Numerous features are available for arresting hook system designs. Each adds complexity and are cost drivers. If the intended user desires such features, this requirement should reflect such choice.

REQUIREMENT GUIDANCE (3.4.1.8.1.7)

TBS should reflect the need for provisions to secure the hook in the extended and retracted positions to prevent inadvertent retraction or extension.

This requirement influences detail hook design, user’s needs, and maintenance procedures. This requirement contains some previous requirements of MIL-A-83136 and has the potential of adding new requirements. The retraction and extension features were previously defined. AFSC DH 1-6 also contained a discussion of this item.

REQUIREMENT LESSONS LEARNED (3.4.1.8.1.7)

If the arresting hook extension is designed to be used only under emergency conditions, no retracting mechanism was required in the past. However, a positive latching device, which prevents inadvertent extension in flight or on the ground, should be provided. If the system is electrically actuated, the controls from the cockpit to the up lock release mechanism should be totally redundant. In the past, extension time has been limited to two seconds or less. With electrically actuated release mechanisms, the ground safety pin should interrupt the electrical power to the release mechanism. This will prevent release mechanism damage if the cockpit switch is actuated with the ground safety pin installed. In the interest of personnel safety, the release mechanism should prevent installation or removal of the ground safety pin with the arresting hook in any position other than fully up and locked.

4.4.1.8.1.7 Maintenance and installation criteria.

Maintenance of the hook system shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.8.1.7)

Design features are best reviewed by inspection of drawings and actual air vehicle installations.

VERIFICATION GUIDANCE (4.4.1.8.1.7)

TBS should be filled with inspection and on air vehicle demonstrations.

VERIFICATION LESSONS LEARNED (4.4.1.8.1.7)

(TBD)

3.4.1.8.1.8 Hook actuation criteria.

The hook shall be positioned by the following action (TBS).

REQUIREMENT RATIONALE (3.4.1.8.1.8)

This requirement is to establish the design and performance requirements for the arresting hook control.

REQUIREMENT GUIDANCE (3.4.1.8.1.8)

TBS should reflect the hook actuation control method in accordance with the crew station specification. If required, the following statement may be added, “The air vehicle shall be able to disengage from the arresting cable without external assistance and then be able to taxi over the cable without reengagement.”

Factors include location, actuation, and design of the control switch. The following has been specified in the past by MIL-STD-203:

a. (Normal system operation) Single pilot, tandem pilot, operable by pilot: Actuation -

Direction of motion should correspond to hook movement. Design - when an indicator light is used, it should be located in the control handle and should be "ON" when the arresting hook is inconsistent with control position.

b. Emergency arresting hook control (ground use only). Single pilot, tandem pilot, side-by-side pilot: Location - Accessible to the pilot's shaped switch—down or aft for hook "down." Design - A recessed, guarded push button switch or a guarded hook-shaped, coded toggle switch.

Type of arresting hook (normal of emergency), type of air vehicle, and number of crew influence this requirement.

This requirement was formerly included in MIL-STD-203.

REQUIREMENT LESSONS LEARNED (3.4.1.8.1.8)

(TBD)

4.4.1.8.1.8 Hook actuation criteria.

Hook actuations shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.8.1.8)

The characteristics established by this requirement can usually be determined by review of the hardware and engineering drawings. Formal demonstrations or tests may be necessary for some complex control systems such as automatic deployment. Revise the verification requirement to be compatible with the design requirements.

VERIFICATION GUIDANCE (4.4.1.8.1.8)

TBS should be filled with inspection of drawings and demonstration on the air vehicle.

VERIFICATION LESSONS LEARNED (4.4.1.8.1.8)

(TBD)

3.4.1.8.2 Drag chutes.

4.4.1.8.2 Drag chutes.

3.4.1.8.2.1 Air vehicle drag chute performance.

Drag chute performance requirements shall be (TBS).

REQUIREMENT RATIONALE (3.4.1.8.2.1)

Drag chutes should follow standard drag or drogue chute design practices as typically found in JSSG-2010, which provide the performance capability of drag chutes. The main performance requirements are aircraft deceleration rates required or, from a performance base approach, required stopping distances, environmental conditions (e.g., icy runway), and deployment envelope speeds. Other considerations include capability to release parachute by aircrew and provide fuse link to prevent overloading structure.

REQUIREMENT GUIDANCE (3.4.1.8.2.1)

TBS should refer to the latest parachute design guide or specification as needed.

REQUIREMENT LESSONS LEARNED (3.4.1.8.2.1)

(TBD)

4.4.1.8.2.1 Air vehicle drag chute performance.

VERIFICATION RATIONALE (4.4.1.8.2.1)

The drag chute performance shall be by (TBS).

VERIFICATION GUIDANCE (4.4.1.8.2.1)

Analysis and flight-testing are the primary means of verifying the performance of the drag chute system. Wind tunnel testing may also be beneficial to increase understanding of airflow characteristics to ensure reliable chute deployment.

VERIFICATION LESSONS LEARNED (4.4.1.8.2.1)

With the advances in wheel braking capabilities, drag chute usage is limited. Drag chutes are incorporated to meet stopping distances on very short and icy runways. There are limited facilities where the aircraft performance can be verified. For Air Force aircraft, the testing is conducted at Eielson AFB in Alaska. This testing requires preplanning and coordination with the base. Since this is an operational base and test conditions are weather dependent, there can be long delays in achieving the number of test points needed.

3.4.1.9 Shipboard compatibility.

Landing gear for shipboard compatibility shall include features for (TBS).

REQUIREMENT RATIONALE (3.4.1.9)

(TBD)

REQUIREMENT GUIDANCE (3.4.1.9)

TBS should be filled in with catapulting, arrested landings, deck operations, ski jumps, and parking brakes.

REQUIREMENT LESSONS LEARNED (3.4.1.9)

(TBD)

4.4.1.9 Shipboard compatibility.

(TBD)

VERIFICATION RATIONALE (4.4.1.9)

(TBD)

VERIFICATION GUIDANCE (4.4.1.9)

(TBD)

VERIFICATION LESSONS LEARNED (4.4.1.9)

(TBD)

3.4.1.9.1 Landing gear catapult compatibility.

Air vehicles with ship-based landing gear shall be compatible with catapult systems by (TBS).

REQUIREMENT RATIONALE (3.4.1.9.1)

Catapult systems provide additional power necessary for an air vehicle to take off from an aircraft carrier.

REQUIREMENT GUIDANCE (3.4.1.9.1)

TBS should be filled in with consideration given to the following: Provisions for catapulting should be in accordance with MIL-L-22589.

The air vehicle deck clearance should not be less than six inches. This clearance should also be maintained under the following conditions: during all catapulting operations with the air vehicle in all critical off-center positions, aircraft rolled to an attitude commensurate with a 25-knot cross wind, and the main gear fully compressed and tire flat on the wing-low side.

Landing gears of ship-based air vehicles should include provision to prevent damage due to repeated sudden extension of the landing gear as the wheels pass over the deck edge subsequent to catapulting, a bolter, or a touch and go.

For ship-based air vehicles, tire selection should be based on the dynamic reaction resulting from catapulting whereby tires should not be fully deflected to a bottomed condition.

On ship-based air vehicles, if the shock absorber is of the stored-energy type, the energy stored in the shock absorber during the catapult stroke should be sufficient to provide rotation of the air vehicle to flight attitude at the end of the deck run in the event that one or both nose gear tires have failed during the catapult run. The stored energy should not cause pulsating loads that would jeopardize safe operation of the air vehicle.

When catapulting, means should be provided for automatic retraction of the bumper wheel or skid, if used.

A “park-on” cockpit warning system or an automatic park brake release system should be provided to preclude “brakes-on” during catapulting.

The landing gear retraction time should be compatible with the air vehicle flight performance and should not exceed 10 seconds.

The center of the nose wheel axle of ship-based air vehicle should clear the deck by no less than 6 ½ inches when the tire(s) is (are) flat.

REQUIREMENT LESSONS LEARNED (3.4.1.9.1)

(TBD)

4.4.1.9.1 Landing gear catapult compatibility.

Landing gear catapult compatibility shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.9.1)

Verification will ensure that air vehicles can take off safely and successfully from aircraft carriers.

VERIFICATION GUIDANCE (4.4.1.9.1)

(TBD)

VERIFICATION LESSONS LEARNED (4.4.1.9.1)

(TBD)

3.4.1.9.2 Arrested landings compatibility.

Landing gear for shipboard conventional takeoff and landing air vehicles shall be capable of arrested landing.

REQUIREMENT RATIONALE (3.4.1.9.2)

Ship-based air vehicles should be capable of landing on ships at high speeds, which requires the use of arresting gear so that the plane does not roll beyond the carrier deck edge.

REQUIREMENT GUIDANCE (3.4.1.9.2)

When designing tires, consideration should be given to dynamic impact loads, especially when traversing a 1⅝ inch diameter arresting cable.

For ship-based air vehicles, the restraint system should withstand the following ultimate load factors: 20 forward static, 10 lateral static, 7.5 aft static, 20 down static, and 5 up static.

The fuselage aft of landing gear struts on ship-based air vehicles should be designed to prevent or shield external projections that might engage the arresting wires.

Provisions should be made to retain the nose wheel in the centered position until landed, and remain centered during roll back from arrested landings.

The landing gear installation of ship-based air vehicles should not contain features such as sharp projections or edges that would be conducive to failure of the barricade in the event of a barricade engagement.

In any position of the foot, there should not be a tendency for the pilot to apply brake effort unintentionally during the normal use of the rudder pedals or during arrested landings.

Wheel diameter should be selected to prevent the arresting cable from riding overtop the wheel when the tires are flat. The recommended dimension of the wheel radius is greater than 6.5 inches.

The tire pressure for ship operating design pressure should not exceed 1.3 times the static pressure at the rated load or 350 psi and 32 percent (32%) deflection.

REQUIREMENT LESSONS LEARNED (3.4.1.9.2)

4.4.1.9.2 Arrested landings compatibility.

Arrested landing compatibility shall be verified by <u>(TBS).</u>

VERIFICATION RATIONALE (4.4.1.9.2)

Verification will ensure that air vehicles can safely and securely land on aircraft carriers.

VERIFICATION GUIDANCE (4.4.1.9.2)

TBS should be filled in with analysis and test to ensure arrested landings can be safely executed.

VERIFICATION LESSONS LEARNED (4.4.1.9.2)

(TBD)

3.4.1.9.3 Deck operations.

Deck spotting of ship-based air vehicles shall be provisioned by <u>(TBS).</u>

REQUIREMENT RATIONALE (3.4.1.9.3)

Air vehicles should be operable in a confined area on a carrier. These operations should include but not be limited to taxiing, towing, and spotting.

REQUIREMENT GUIDANCE (3.4.1.9.3)

TBS: The wheel brake hydraulic system should be capable of providing adequate braking for deck handling without engine operation of external power packages. In addition, the wheel brake hydraulic system should perform at least 10 applications of the normal brake before a hand pump or other means would be utilized to repressurize the brake system. A pressure indicator should be provided in the pilot’s cockpit.

A minimum tire section width of six inches should be provided for ship-based air vehicles.

REQUIREMENT LESSONS LEARNED (3.4.1.9.3)

(TBD)

4.4.1.9.3 Deck operations.

Deck spotting for carrier air vehicles shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.9.3)

Maneuverability on air vehicles carrier decks is limited. Therefore, it is necessary to ensure air vehicles are capable of operation as well as being stowed to maximize space on the carrier.

VERIFICATION GUIDANCE (4.4.1.9.3)

(TBD)

VERIFICATION LESSONS LEARNED (4.4.1.9.3)

(TBD)

3.4.1.9.4 Ski jumps.

Air vehicles with ski jump capability shall have (TBS).

REQUIREMENT RATIONALE (3.4.1.9.4)

The objective of the requirement is to establish gear performance for ski jump operations.

REQUIREMENT GUIDANCE (3.4.1.9.4)

(TBD)

REQUIREMENT LESSONS LEARNED (3.4.1.9.4)

(TBD)

4.4.1.9.4 Ski jumps.

(TBD)

VERIFICATION RATIONALE (4.4.1.9.4)

(TBD)

VERIFICATION GUIDANCE (4.4.1.9.4)

(TBD)

VERIFICATION LESSONS LEARNED (4.4.1.9.4)

(TBD)

3.4.1.9.5 Parking brake.

All shipboard air vehicles shall have a parking brake.

REQUIREMENT RATIONALE (3.4.1.9.5)

Shipboard air vehicles need a parking brake for ready alert status, rough sea conditions, and catapult spotting. Parking brakes reduce pilot workload while aircraft is undergoing operational checkouts and preparations for takeoff.

REQUIREMENT GUIDANCE (3.4.1.9.5)

VTOL air vehicles with wheeled-type landing gear should be able to set parking brakes prior to landing.

REQUIREMENT LESSONS LEARNED (3.4.1.9.5)

(TBD)

4.4.1.9.5 Parking brake.

Parking brake holding power and functionality shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.9.5)

A ground demonstration is needed to validate whether the parking brake can hold the aircraft in position under the required engine thrust levels. The operational logic must be checked to prevent locking of brakes while aircraft is in motion.

VERIFICATION GUIDANCE (4.4.1.9.5)

The torque capability is verified by a combination of analysis, component level testing, and ground demonstration. Brake qualification testing quantitatively determines the amount of torque produced under various conditions (wet and operating temperatures). Aircraft demonstration verifies system capability to hold aircraft under the required conditions and also validates functionality of operating modes to ensure parking brake releases and provides protection from inadvertent application to cause brakes on at touchdown.

VERIFICATION LESSONS LEARNED (4.4.1.9.5)

(TBD)

3.4.1.10 Specialized subsystems.

The air vehicle shall have specialized subsystems or landing gear characteristics as follows: (TBS).

REQUIREMENT RATIONALE (3.4.1.10)

This requirement is to cover those specialized subsystem requirements not normally covered under landing gear subsystem.

The requirement describes landing gear other than nose wheel, main wheel, or tail wheel. Examples could be outrigger or skid-type landing gear. Unique air vehicle design or operational characteristics may drive the need for this gear.

REQUIREMENT GUIDANCE (3.4.1.10)

TBS is filled with the name and requirements of any specialized subsystems to meet mission requirements. Examples of specialized subsystems are skis, crosswind positioning systems, kneeling systems, and inflator-deflations systems.

Towing and ground handling of air vehicles with skid-type landing gear should be possible with the airplane loaded to maximum gross weight.

REQUIREMENT LESSONS LEARNED (3.4.1.10)

The C-5 has forward and aft kneeling systems and an aft steerable gear to account for cross wind landings. It also had onboard inflation and deflation systems.

4.4.1.10 Specialized subsystems.

The specialized subsystem shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.10)

Each type of specialized subsystem will have its own particular verification methods and needs.

VERIFICATION GUIDANCE (4.4.1.10)

TBS: Most subsystems should require system analysis, laboratory testing, on air vehicle demonstration, possibility pass, and fail criteria.

VERIFICATION LESSONS LEARNED (4.4.1.10)

(TBD)

3.4.1.10.1 Floatation gear.

When an air vehicle is equipped with floatation gear, the gear shall facilitate safe takeoff, landing, taxiing, towing, and mooring of the air vehicle on the water's surface.

REQUIREMENT RATIONALE (3.4.1.10.1)

Flotation gear has been used successfully on rotorcraft and other air vehicles, but specialized landing gear setups have unique performance requirements.

REQUIREMENT GUIDANCE (3.4.1.10.1)

Flotation gear is either fixed position or deployable. Deployable flotation gear should take into account, but are not limited to the following:

a. Water buoyancy.
b. Drop characteristics.
c. Stability and control characteristics at various sea states.
d. Stability and control with rotors turning and at rest.
e. Weight and balance limitations.
f. Effects on aerodynamic performance and aeroelastic qualities.
g. Water taxi capabilities.
h. Takeoff and landing characteristics with the subsystem installed.
i. Validation of adequate clearance for rotors or propellers at various centers of gravity and various sea states.

The effects of in-flight deployment should be investigated. The effects on egress should also be investigated.

REQUIREMENT LESSONS LEARNED (3.4.1.10.1)

(TBD)

4.4.1.10.1 Floatation gear.

The operational characteristics of the floatation gear shall be verified by analysis and tests.

VERIFICATION RATIONALE (4.4.1.10.1)

Some aspects of the floatation gear's behavior can be verified by analysis (weight and balance limitations, water buoyancy, and adequate propeller or rotor clearance), but other aspects should be demonstrated by actual testing (stability and control characteristics and takeoff and landing characteristics).

VERIFICATION GUIDANCE (4.4.1.10.1)

Typical qualification test objectives and measurements should validate the following:

a. Water buoyancy.
b. Drop characteristics.
c. Stability and control characteristics at various sea states.
d. Stability and control with rotors turning and at rest.
e. Weight and balance limitations.
f. Effects on aerodynamic performance and aeroelastic qualities.
g. Water taxi capabilities.
h. Takeoff and landing characteristics with the subsystem installed.
i. Validation of adequate clearance for rotors or propellers at various centers of gravity and various sea states.

- j. Maintainability.
- k. Electromagnetic compatibility if the flotation gear is squib activated.

The effects of in-flight deployment should be investigated. The effects on egress should also be investigated. Typically, strain gages should be used to evaluate structural adequacy of points of attachment. Typical measurements are weight, buoyancy, drag characteristics, clearance, required power, voltage, stress at attachment points, and vibration characteristics.

VERIFICATION LESSONS LEARNED (4.4.1.10.1)

(TBD)

3.4.1.10.2 Snow ski gear.

When an air vehicle is equipped with snow skis, the gear shall facilitate safe takeoff, landing, taxiing, towing, and mooring of the air vehicle on snow.

REQUIREMENT RATIONALE (3.4.1.10.2)

Snow ski gear have been used successfully on rotorcraft and other air vehicles, but specialized landing gear setups have unique performance requirements.

REQUIREMENT GUIDANCE (3.4.1.10.2)

Considerations to take into account include, but are not limited to the following:

- a. Buoyancy in snow.
- b. Stability and control characteristics at various wind conditions.
- c. Visibility in snow with rotors turning.
- d. Weight and balance limitations.
- e. Effects of aerodynamic performance.
- f. Taxi capabilities under various snow conditions.
- g. Takeoff and landing characteristics with the subsystem installed.
- h. Validation of adequate clearance for rotors or propellers at various centers of gravity positions.
- i. Effects on in-flight performance.

REQUIREMENT LESSONS LEARNED (3.4.1.10.2)

(TBD)

4.4.1.10.2 Snow ski gear.

The operational characteristics of the snow ski gear shall be verified by analysis and tests.

VERIFICATION RATIONALE (4.4.1.10.2)

Some aspects of the snow ski gear's behavior can be verified by analysis (footprint areas, buoyancy in snow, and weight and balance limitations), but other aspects should be demonstrated by actual testing (stability and control characteristics, takeoff and landing characteristics, and visibility in snow with rotors turning).

VERIFICATION GUIDANCE (4.4.1.10.2)

Typical qualification test objectives and measurements should validate the following:

a. Footprint areas.
b. Buoyancy in snow.
c. Stability and control characteristics at various wind conditions.
d. Visibility in snow with rotors turning.
e. Weight and balance limitations.
f. Effects of aerodynamic performance and aeroelastic qualities.
g. Taxi capabilities under various snow conditions.
h. Takeoff and landing characteristics with the subsystem installed.
i. Validation of adequate clearance for rotors or propellers at various centers of gravity positions.
j. Maintainability.
k. Effects on in-flight performance.

Typically, measurements should include weight, footprint area, structural adequacy of attachment points, vibration characteristics, ground and snow clearances, step height, and aerodynamic and aeroelastic characteristics.

VERIFICATION LESSONS LEARNED (4.4.1.10.2)

(TBD)

3.4.1.11 Components.

4.4.1.11 Components.

3.4.1.11.1 Tires.

4.4.1.11.1 Tires.

3.4.1.11.1.1 Air vehicle tire performance.

The tires shall be capable of performing on the air vehicle for the following: (TBS).

REQUIREMENT RATIONALE (3.4.1.11.1.1)

The objective is to provide a tire capability compatible with the air vehicle operation and performance for all taxi, turns, takeoff, and landing operations at the critical gross weights and velocities that do not exceed air vehicle structural or operational limits. The blank should be filled with an all-inclusive performance requirement, such as conditions of maximum air vehicle takeoff and landing, including all ground maneuvering before and after takeoff and landing. Emergency conditions should also be considered, such as aborted takeoffs and maximum landings. If aerodynamic heating exceeds 160 degrees F during flight, this should be considered.

REQUIREMENT GUIDANCE (3.4.1.11.1.1)

TBS should as a minimum, have the following air vehicle performance parameters defined:

a. Tire sizing parameters

1. Air vehicle configuration - This will tend to dictate the gear geometry and possibly the decision for a small number of large diameter tires or a large number of small diameter tires.
2. Flotation - This requirement will tend to dictate tire pressure and gear configuration and may drive the design of the air vehicle fuselage. If flotation does drive the design, tire service life problems typically will be low.
3. Tire load - This requirement will be dependent upon parameters 1 and 2 above.
4. Growth allowances - This requirement will tend to dictate tire size, if not established by flotation.
5. Runway considerations - Maximum tire pressure is limited to 300 psi; minimum footprint area is to be equal to or greater than 50 square inches.

b. Tire design parameters

1. Velocity - This requirement will dictate the tread thickness and, therefore, wear life.
2. Taxi distances and turning requirements - These requirements will tend to design the tire carcass, bead step-off area, and the shoulder area due to internal heating from the flexing of the tire.
3. Environmental heating - Aerodynamic heating level, time at high speed, equipment mass and air flow may be significant parameters for the design. This may dictate high temperature compounding.
4. Tire slippage - Wheel and tire interface should be designed to present slippage that could cause loss of air with damage to the tire, tube, valve, or wheel.
5. Low temperature - Unless otherwise specified, the low temperature requirement for the tire compounds should be −65 degrees F.
6. Burst pressure - Tires normally are designed to withstand a burst pressure equal to 3.5 times the maximum operating (rated) inflation pressure. A factor of 4.0 is sometimes used for low-pressure (less than 150 psi) tires.

This requirement reflects the concept generated in MIL-PRF-5041, AFSC DH 2-1, and AFSC DH 1-6. This is an industry-accepted practice for military and commercial tire development.

Unless otherwise specified in the detail specification, tires should be tubeless. When specified, inner tubes should be in accordance with SAE AS50141.

The tire land based operating pressure should be equivalent to the rated pressure at a tire static load with a 32 percent (32%) tire deflection for bias-ply and up to 36 percent (36%) for radial.

A tire contour should be selected that provides an aspect ratio above 72 (that is, tire section height to tire section width) unless exception is authorized by the detail specification.

Nose wheel tire size selection should account for maximum dynamic braking loads in addition to the maximum air vehicle static load.

REQUIREMENT LESSONS LEARNED (3.4.1.11.1.1)

Historically, except for the B-52, tires operated at velocities at or above 250 mph and 250 psi have relatively poor service life, less than 25 landings per tire. Tires operated at or less than 225 mph and 200 psi have good service life, over 100 landings per tire. Tires inflated at 250 psi and greater are more susceptible to cuts due to the high stress in the tread compared to a 200-psi tire. Higher inflation pressure also tends to accelerate groove cracking, resulting in tread failure such as chunking or stripping a tread.

As the speed rating increases, the tread thickness decreases which results in less wear life and greater susceptibility to cut removal. The cut depth is much more critical as the velocity increases.

Therefore, when establishing tire operational parameters, strive to limit the adverse effects of high rotational velocities and high pressures. Flotation and growth requirements will aid in a good solution to this problem. This requirement should not dictate design of a high performance air vehicle, such as fighter or interceptor types.

The use of air to inflate main wheel tires, where thermal fuse plugs are used, is not recommended. Release of the fuse plug will result in discharge of the air on to the hot brake increasing the probability of fire. Nitrogen is used to inflate most commercial and military air vehicle tires.

It is sometimes desirable to mold a ridge in the tire sidewall to deflect water spray or other debris thrown up by the tire. This ridge is known as a “chine,” and such tires are usually called “chine tires.” The primary use has been to prevent water spray from entering engine inlets. Chine tires are presently used on F-111 and C-9 air vehicle nose landing gears. Chine tires should be tailored for each application. Flight-testing is necessary to confirm suitability of design.

In the past, the maximum allowable braking dynamic load factor were 1.4 and 1.35 for low-pressure type III tires and for extra high-pressure type VII tires, respectively.

4.4.1.11.1.1 Air vehicle tire performance.

Takeoff, landing, and taxi performance shall be verified by: (TBS).

VERIFICATION RATIONALE (4.4.1.11.1.1)

The use of a laboratory dynamometer to evaluate the tire performance characteristics permits evaluation to the limits of the tire capability with risk. The design conditions are carefully controlled and are repeatable. The industry has always utilized this method of evaluation prior to installation on an air vehicle to determine performance limits and to establish safety of flight. It is significantly more efficient than any other verification method. The tire will also be observed and evaluated during the routine flight test program.

VERIFICATION GUIDANCE (4.4.1.11.1.1)

TBS should be filled with the air vehicle performance requirements that need to be meet. This should take into account static and dynamic loads as well as speeds and time at loads for worst-case operating conditions and normal operating conditions.

VERIFICATION LESSONS LEARNED (4.4.1.11.1.1)

(TBD)

3.4.1.11.1.2 Tire Service life.

Tires shall have a service life, due to tread wear only, of not less than (TBS 1) landings. This shall apply during operation of the air vehicle as follows: (TBS 2).

REQUIREMENT RATIONALE (3.4.1.11.1.2)

Tire life will be one of the largest sustainment costs over the life of the aircraft. Specifying tire life is difficult because the many aircraft characteristics, outside of the tire manufacturer's control, will drive tire wear. The objective is to provide a satisfactory life. Historically, tires of a conventional design, Types III, VII, and VIII, should provide 50 to 300 cycles (one takeoff and one landing equals one cycle), dependent on diameter and velocity requirements.

REQUIREMENT GUIDANCE (3.4.1.11.1.2)

TBS 1 should be filled with a reference to tire design load-speed-time figure for the air vehicle application, showing the number of air vehicle cycles required for a given tire diameter and speed rating range.

TBS 2 should describe the operation during which the life requirement is applied. The following are the performance parameters controlling service life:

a. Tire diameter establishes thickness.
b. Velocity rating of tread.
c. Tire pressure due to load - stress in tread rubber.
d. Installation.

The source of these criteria is MIL-PRF-5041, supplemented by the AFSC-Ogden ALC Life Cycle Cost Program. A similar arrangement is a worthy candidate for future programs.

Tire mold skid depth (tread wear prior to removal) should be compatible with current state of the art for the particular tire size selected.

REQUIREMENT LESSONS LEARNED (3.4.1.11.1.2)

The air vehicle installation frequently affects tire life. If there is excessive camber or yaw, abnormal tread wear can be generated. Early F-15 air vehicles are an example of this problem. Obviously, the tire design cannot be held accountable for this performance.

If the landing gear is designed or modified to cause excessive camber or yaw angle, excessive tire wear may result.

The need for venting (drilling of vent holes in the side wall of the tire) high performance tires exists, regardless of type of construction, to prevent blistering and buildup of nitrogen pressure between the cord layers within the tire.

4.4.1.11.1.2 Tire Service life.

The service life shall be evaluated on the air vehicle during (TBS).

VERIFICATION RATIONALE (4.4.1.11.1.2)

The primary factor in tire service is tread wear. In the past, no standardized laboratory testing for tire wear could adequately represent the actual wear experienced out in the field. Flight demonstration is typically the chosen method of verification so that requirement compliance can be verified in a reasonable period. Testing for Air Force aircraft at Edwards AFB can cause unrealistic wear because the long taxi distances, high temperatures, and flight test conditions wear tires more than normal field use. Contractors and government personnel must define an acceptable tire test spectrum for this method to be used.

Laboratory testing for wear has made significant progress in recent years with the use of an internal drum dynamometer, which allows controlled conditions and replicates actual runway surface textures. Again, agreement of test spectrum is critical. The other limitation is many tire manufacturers do not have internal drum dynamometers but test can be performed on dynamometer at Wright-Patterson Air Force Base.

VERIFICATION GUIDANCE (4.4.1.11.1.2)

Achieving a desired tire life for a new aircraft acquisition program is a challenge, especially for fighter aircraft. Air vehicle specifications rarely address tire life requirements due to the inability to determine wear characteristics early in the design process. Tire life could not be verified until the aircraft went into flight-testing. Verification of tire life during flight-testing may not provide realistic results because of long taxi distances, high ambient temperatures, and the very nature of flight-testing. This has been historically true for Air Force air vehicles because flight-testing is conducted at Edwards AFB. For some aircraft, the initial tire life has been as low as 2 to 20 landings. This results in high sustainment costs in man-hours, replacement and disposal. New missionized test methods using internal drum dynamometers offer the capability to compare wear effects due to different design constructions in advance of flight-testing. There are limited test facilities that has this capability, but the Air Force landing gear test facility does have a 168-inch internal drum dynamometer. Establishing tire service life requirements can reduce life cycle costs.

The customer and the manufacturer need to agree on the specific operational service spectrum flown by the air vehicle. Otherwise, a Life-Cycle-Cost program will have to be established to verify the life of the tire.

VERIFICATION LESSONS LEARNED (4.4.1.11.1.2)

(TBD)

3.4.1.11.1.3 Retread and carcass performance.

The tire carcass shall be capable of (TBS) retreads without degradation of tire structure performance.

REQUIREMENT RATIONALE (3.4.1.11.1.3)

The objective is to provide a tire construction that can be retreaded. This has proven to be cost effective in the Air Force and particularly on commercial air vehicle where they have retreaded a single tire as many as nine times.

REQUIREMENT GUIDANCE (3.4.1.11.1.3)

TBS should be filled with a number for repeated retreads that would be compatible with the tire performance and life. If the tire life is relatively long on a large diameter slow speed tire, the aging life of the carcass may limit it to one retread. If the tire is medium in diameter, 34-40 inches, and rated in the 225 mph range, it could be retreaded four or five times. A high-speed fighter tire of a 28-34 inch diameter could also be retreaded five times, providing the carcass could not be subjected to high working stress due to inflation pressure of 250 psi or greater. In this case, only one retread may be cost effective. Performance parameters controlling retreadability include the following:

a. Tire velocity rating.
b. Tire pressure rating.
c. Tire construction (special requirements):
    1. Environmental heating
    2. Excessive deflection
    3. Exotic designs
    4. Age limitations
    5. Balancing

This is a new requirement not currently defined in any general defense specification. It reflects the current state of the art and has been used on all recent systems in the interest of Life Cycle Cost.

REQUIREMENT LESSONS LEARNED (3.4.1.11.1.3)

Reliable retreading is dependent on a sound carcass and sufficient material on the crown of the tire to prepare the surface properly for a new tread. Providing a sound carcass is dependent on testing the initial construction through repeated life test on the dynamometer, stripping the tread and retreading between cycles, and a good inspection of a used carcass prior to retreading.

4.4.1.11.1.3 Retread and carcass performance.

Retreading capability shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.11.1.3)

The retread capability of the carcass can be verified by requiring the tire to complete all the dynamic tests of the "air vehicle tire performance" in this specification guide, followed by buffing the tread and repeating the cycle without the heat soak rising above 300 degrees F for one hour.

VERIFICATION GUIDANCE (4.4.1.11.1.3)

TBS: The tire should be tested to the operational requirements of the original tire to ensure compatible performance for all air vehicle operational missions.

VERIFICATION LESSONS LEARNED (4.4.1.11.1.3)

(TBD)

3.4.1.11.1.4 Growth within tire.

In selecting tire sizes, an allowance shall be made for (TBS) growth in air vehicle maximum design weight within the same size tire.

REQUIREMENT RATIONALE (3.4.1.11.1.4)

The objective is to provide a tire with growth potential within the original clearance envelope. Historically, even in the 1970's era, aircraft continued to grow in gross weight that would overload original tire capabilities. Whereas, by adding plies, the tire can easily be changed to carry the extra load within the same envelope.

REQUIREMENT GUIDANCE (3.4.1.11.1.4)

TBS should be filled with 25 percent (25%) based on experience. Performance parameters controlling growth are as follows:

a. Burst pressure.
b. Bulk modulus.
c. Taxi distances, velocity, and temperature.

This requirement was contained in AFSC DH 1-6 and AFSC DH 2-1. In the mid-1950s, this requirement was generated based on lessons learned with aircraft growth. Since change in tire size impacts stowage area and airframe sizing, it is considered to be an important concern. A tire ply rating that is at least two-ply ratings less than the maximum recommended ply rating for any particular tire size should be selected.

REQUIREMENT LESSONS LEARNED (3.4.1.11.1.4)

Most aircraft developed in the last 25 years have grown in gross weight from 10 to 40 percent (10 to 40%). In many of these instances, the landing gears cannot grow accordingly and, therefore, are operated as less than "0" margin. Tires readily lend themselves to easy growth potential within the original designed envelope by increasing the number of plies. This has been a very effective method of providing sufficient tire growth on aircraft developed in the late 1960s and early 1970s.

4.4.1.11.1.4 Growth within tire.

An analysis shall be performed to show growth potential in the selected tire sizes.

VERIFICATION RATIONALE (4.4.1.11.1.4)

The requirement for tire growth can be verified by analysis of actual plies to ply rating, to maximum number of plies, and to maximum ply rating allowed.

VERIFICATION GUIDANCE (4.4.1.11.1.4)

A load analysis using an increased ply rating should be conducted to show that the tire can handle the specified increase in air vehicle gross weight without having to change tire size.

VERIFICATION LESSONS LEARNED (4.4.1.11.1.4)

(TBD)

3.4.1.11.1.5 Multiple tire operation with failures.

For multiple tire gear designs, capacity shall be provided to accommodate (TBS 1) tire failure(s) without additional tire failure when operating at all gross weights under the following conditions: (TBS 2).

REQUIREMENT RATIONALE (3.4.1.11.1.5)

The objective is to provide tires with the dynamic load carrying capability to withstand an overload for a short period and not cause a catastrophic failure. Should a tire fail during taxi at maximum gross weight, the other tire(s) on that strut should have the capability to support the additional dynamic load while taxiing back to an apron or repair area. On takeoff, the remaining tire(s) should have the capability to support the dynamic load for either aborting or completion of takeoff, followed by a landing at landplane landing gross weight.

REQUIREMENT GUIDANCE (3.4.1.11.1.5)

TBS 1 should be filled with a statement such as “one” or “fifty percent (50%) of assembly.”

TBS 2 should describe the minimum operation with the failed tire(s).

Performance parameters include the following:

a. Load rating.
b. Ply rating.
c. Air vehicle gross weight.
d. Center of gravity locations.
e. Tire construction.
f. Operating spectrum.

Criteria for overload capability factors in tire capacity were previously documented in AFSC DH 2-1. The requirement, as expressed, is a new requirement defining the conditions of overload from which the remaining tires are expected to continue to operate. This will allow the airframe manufacturer to properly develop and demonstrate this overload capability.

REQUIREMENT LESSONS LEARNED (3.4.1.11.1.5)

Present specifications do not require testing tires to dynamic loads greater than the rated static load. Nose tires are rated with dynamic load factors ranging from 135 percent (135%) to 150 percent (150%) of the static load rating. The dynamic loads usually are not verified by test.

Development of a tire to withstand a sustained overload, such as excess load due to a mating flat tire, requires a tire test program simulating this condition. For example, if a tire is required to operate safely after a mating tire has failed, at least investigate the following:

a. Failure of a tire during taxi out for takeoff will result in an overload on the mating tire(s). The mating tire should have the capability to endure the excess load for taxiing back to a repair area.

b. Tire failure during takeoff run. The mating tire should have the capability to endure the excess load for an aborted stop.

4.4.1.11.1.5 Multiple tire operation with failures.

Overload capability shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.11.1.5)

Laboratory dynamometer tests provide the opportunity to conduct a controlled test to the required limits without risk to air vehicle or personnel. It is the economic approach from a cost and schedule viewpoint.

VERIFICATION GUIDANCE (4.4.1.11.1.5)

TBS should be filled with analysis and tests.

VERIFICATION LESSONS LEARNED (4.4.1.11.1.5)

(TBD)

3.4.1.11.2 Wheels.

4.4.1.11.2 Wheels.

3.4.1.11.2.1 Air vehicle wheel performance.

The wheel assemblies shall be capable of performing on the air vehicle for the following: (TBS).

REQUIREMENT RATIONALE (3.4.1.11.2.1)

The purpose of this requirement is to identify the operating conditions that will establish the design envelope for the main, nose, and auxiliary wheel equipment.

REQUIREMENT GUIDANCE (3.4.1.11.2.1)

The conditions should account for maximum gross weight usage (taxi and takeoff), design mission takeoff, landing, and taxi. A spectrum should be generated to simulate the anticipated load distribution to give the required life. If high brake temperatures are typically encountered with main wheels, the design spectrum should include this condition. Eccentric loads induced by installation on the air vehicle or operational usage should be suitably reflected in the requirements. These will not be known until the design of the installation is complete, but provisions for such eventualities should be included in the basic requirements. Examples might be high frequency pivot, cambered roll, or yawed roll.

TBS should include all ground operation of the air vehicle, in particular, worst-case conditions covering both static and dynamic requirements.

Velocity, wheel material and processing, vertical versus side load, fatigue characteristics, sustained stress levels, and tire-wheel-axle interfaces have an impact on the ability of the wheel to meet the required performance requirements. This requirement summarizes the various load discussions previously stated in legacy documents MIL-W-5013, AFSC DH 1-6, and AFSC DH 2-1. This is the very backbone of the wheel design requirements. It establishes the static strength and fatigue requirements for the wheel assemblies.

REQUIREMENT LESSONS LEARNED (3.4.1.11.2.1)

In the past, the static load capability was established by arbitrary criteria, and the design conditions were not necessarily associated with actual operating conditions. An example of problems associated with arbitrary criteria in lieu of rational criteria is the C-141A main wheel. It was designed and tested to maximum-load military specification criteria with an arbitrary cambered roll fatigue requirement. On the airplane, with 80 degrees steering available to the pilot, the landing gear was experiencing numerous full pivots during routine taxi usage. The result was over 75 wheel flange failures in service. The wheel was redesigned to accommodate this specific condition of pivot turn. Since the revised wheel has been put into service (approximately 1970), there have been no further wheel flange failures.

Use of arbitrary criteria does not always drive the designs to structural inadequacy. A recent example has been the use of 0.5g turn for yawed roll criteria in design. This particular condition has produced numerous laboratory failures that drove redesign of the wheel hub area. There has never been evidence of field difficulties in this area with the wheels involved. It is suspected that the criteria is quite conservative and is resulting in heavy hub wheels.

Another aspect that is of some concern is the aspect of corrosion effects in the field as compared with development testing. Corrosion has a significant impact on inventory life, but painting technique improvements will potentially diminish this disparity.

Corrosion effects that occur in the field are not adequately covered during development testing. Thus, design considerations should be given to improve corrosion protection procedures for the wheels. Specifically, ensure the wheel bearing seal will protect the bearings from the environment. A metal-to-metal interface on the seal is inadequate for this purpose, as discovered on the B-1 wheel.

Corrosion is one of the main reasons for retiring aluminum wheel halves. Fatigue cracks start from corrosion pits in most of the cases. The tire beads wear off the corrosion protection on the wheel rims.

4.4.1.11.2.1 Air vehicle wheel performance.

Laboratory tests shall be conducted to evaluate takeoff, landing, and taxi performance requirements.

VERIFICATION RATIONALE (4.4.1.11.2.1)

Laboratory tests are recommended because of the versatility in evaluating performance and the schedule required for development. The laboratory can explore the load envelope and provide timely answers to the designers and evaluators.

VERIFICATION GUIDANCE (4.4.1.11.2.1)

The wheel should be subject to the operational loading that it would experience on the air vehicle to ensure all mission requirements can be met.

VERIFICATION LESSONS LEARNED (4.4.1.11.2.1)

(TBD)

3.4.1.11.2.2 Wheel Service life.

The wheel service life shall be (TBS).

REQUIREMENT RATIONALE (3.4.1.11.2.2)

From a logistic consideration, an arbitrary average service life should be established for wheels, consistent with operational needs.

REQUIREMENT GUIDANCE (3.4.1.11.2.2)

In the past, an arbitrary laboratory life of 1500, 2000, or 2500 miles at rated load or 110 percent (110%) of air vehicle design limit load on the wheel was selected for design, and the service life achieved was accepted. However, the requirement should reflect actually service life, so an average field service life should be specified. The number selected is a function of the type of air vehicle on which it will be installed and the overall logistic plan. Some air vehicles place premium on lightweight, and the wheel criteria should knowingly reflect this priority. Weight and life are directly related. Ten thousand service miles for a cargo air vehicle are consistent with airline criteria. Two thousand service miles for high-performance air vehicle wheels seem to reflect the primary concept of design.

Current airline wheels are designed for 50,000 miles or greater service life.

TBS should reflect an accelerated life performance of 2,000 or 2,500 mile at 110 percent (110%) of maximum rated load. This allows a reasonable test program and produces a limited life wheel.

Maintenance procedures, air vehicle usage, wheel material, and operating technique are major factors in achieving service life. Wheel fatigue life requirements were contained in MIL-W-5013. Generally, the roll life requirements were straight roll at an arbitrarily established rated load. About 15 years ago, commercial and military development requirements were modified to include typical service abnormalities. This has resulted in improved service performance. In most cases where frequent service failures occur, the cause can be traced to service induced conditions that were not accounted for in the development criteria and evaluation. Therefore, duplication of operating environment in development evaluation is a paramount consideration.

REQUIREMENT LESSONS LEARNED (3.4.1.11.2.2)

Actual wheel service life is difficult to determine. Ogden Life Cycle Management Center (LCMC) is attempting to initiate a system to track wheel forging by serial number. Commercial wheels are traced and tracked. Each major forging is warranted for a given life.

Maintenance has a major role in extending or shortening wheel service life. Bearing and axle nut installation, handling during tire changes, and tire-wheel inflation technique and diligence contribute to wheel life.

Being able to predict a realistic usage spectrum and qualifying to this criterion represents a major factor in achieving long service life. However, if a wheel qualified to the above accelerated life spectrum gives a 10 year life expectance, only 2-3 shipsets of wheels are needed for the life of the air vehicle, which can be easier and cheaper to maintain than trying to test the wheel to a long and drawn-out test program.

Wheel flanges are the most frequent source of service failure. Extra attention should be placed on this portion of the design.

Air vehicle wheels qualified with one type of tire may not be compatible with other types. This incompatibility may not be limited to radial versus bias construction, but may occur on bias-to-bias or radial-to-radial from different vendors. When qualifying different types of tires for the same application (bias versus radial), it is strongly recommended that both a strain survey and a roll test be performed on both types of tires. When an alternate tire supplier is qualifying for the same application, a strain survey should be performed to determine if further roll testing is needed.

A-10, F-15, F-16 wheels were qualified with one type of tire, when the other type of tire was later qualified to the same tire requirements, it was found that there was a significant reduction in the wheel fatigue life. Analysis should only be used for design and to obtain confidence that the component will pass the test.

4.4.1.11.2.2 Wheel Service life.

Service life of wheels shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.11.2.2)

Dynamometer roll test is the most economical and reasonable means of demonstrating service life. The loads and environment are carefully controlled and permit a more formal analysis of results.

VERIFICATION GUIDANCE (4.4.1.11.2.2)

TBS should show verification by analysis and laboratory testing.

VERIFICATION LESSONS LEARNED (4.4.1.11.2.2)

When a second source for tires is qualified, the requirement for additional strain and roll testing is not the tire manufacturer responsibility. Responsibility belongs to the prime airframer or government's responsibility; the procurement contracts should reflect this.

The latest wheel roll tests include combined load roll tests with the side load inputted by a yawed roll. Cambered roll does not produce a side load on a dynamometer.

Service life can best be determined by a properly structured experimental stress analysis using strain gages.

3.4.1.11.2.3 Brake overheat capability.

Protection from brake heat shall be provided to the wheel to prevent (TBS 1) after exposure to (TBS 2) energy.

REQUIREMENT RATIONALE (3.4.1.11.2.3)

The purpose of this requirement is to establish performance requirements for heat dissipation.

REQUIREMENT GUIDANCE (3.4.1.11.2.3)

The potential detrimental effects to wheels and tires include wheel or tire explosion due to degradation in strength of either unit or increase in tire pressure causing overstress. Solutions to these problems include wheel heat shields and wheel fuse plugs.

TBS 1 should reflect no destructive degradation of the wheel.

TBS 2 should reflect the emergency energy level associated with maximum landing weight landing, which is the highest energy from which you could expect a serviceable assembly.

Peak brake heat sink temperature, thermal conductivity properties of material, effectiveness of heat shields, and fuse plug eutectic are parameters affecting this requirement. Performance requirements similar to this statement on heat dissipation are contained in legacy documents MIL-W-5013, AFSC DH 1-6, and AFSC DH 2-1. Direct requirements for fuse plugs are contained in MIL-W-5013. The requirement reflects design approaches originally developed for commercial air vehicle but currently accepted as standard design practice for the military brake industry. The first fuse plugs were introduced around 1957.

REQUIREMENT LESSONS LEARNED (3.4.1.11.2.3)

Caution should be taken in designing the fuse plug installation to minimize stress risers. If the plug is screwed into the wheel well, extra precautions should be taken with the threads.

The fuse plugs should be located directly within the heat path from the brake to ensure an environment similar to that being seen at the tire bead seat. Since this is the area that suffers degradation due to heat, the fuse plug should accurately reflect the environment.

Upon installation, heat shields can cause structural damage to the wheel forging by inflicting a scratch. Care should be taken to ensure relatively simple installation. Heat shield retention has been a difficult problem to solve on many wheel designs.

All sharp edges should be eliminated from heat shields.

4.4.1.11.2.3 Brake overheat capability.

Wheel overheat capability shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.11.2.3)

The laboratory provides the opportunity to explore the total design envelope. Under laboratory conditions, the energy input and other important factors can be controlled and will generally provide a better evaluation than on the air vehicle. Of course, flight test observations will also contribute to the overall assessment of design adequacy for the assembly.

VERIFICATION GUIDANCE (4.4.1.11.2.3)

TBS should be filled with analysis and laboratory testing.

VERIFICATION LESSONS LEARNED (4.4.1.11.2.3)

(TBD)

3.4.1.11.2.4 Nonfrangability criteria (flat tire operation).

Each wheel, with a flat tire, shall be (TBS).

REQUIREMENT RATIONALE (3.4.1.11.2.4)

This requirement is to provide a wheel that can roll on its rim without coming apart and damaging the air vehicle. This capability is called non-frangibility.

The roll-on-rim requirement of TSO C26c all but eliminated the flange failure mode on commercial airliners. This area should be carefully investigated in the development stage using strain gage techniques. Flange fatigue lives should be several times that of the area selected as the failure point. Failure point is normally selected for its non-explosive pressure release when a through crack develops.

REQUIREMENT GUIDANCE (3.4.1.11.2.4)

TBS should be filled with “capable of performing one maximum weight landing touchdown and rollout without failure; reuse of the wheel is not required.”

REQUIREMENT LESSONS LEARNED (3.4.1.11.2.4)

(TBD)

4.4.1.11.2.4 Nonfrangability criteria (flat tire operation).

Flat Tire operation shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.11.2.4)

The verification of the non-frangibility of the wheel is usually demonstrated during laboratory testing and is usually one of the last tests since the wheel is unusable after the test.

VERIFICATION GUIDANCE (4.4.1.11.2.4)

TBS should be filled in with analysis and laboratory testing to the required load-time curves. The wheel should not come apart and fragment in any way.

VERIFICATION LESSONS LEARNED (4.4.1.11.2.4)

Consider the TSO C26c roll-on-rim test method. This method does not use a tire, for a tire will likely scatter the results over an unacceptable range.

3.4.1.11.2.5 Bias and radial tire compatibility.

Wheels shall be compatible with (TBS).

REQUIREMENT RATIONALE (3.4.1.11.2.5)

This requirement is to ensure that wheel life and strength is not lessoned or less than what is required for mission operation when radial, bias tires, different bearings, or brake manufacturers are used.

REQUIREMENT GUIDANCE (3.4.1.11.2.5)

TBS should be filled with "…bias and radial ply tire designs, brakes, bearings, and axles with respect to life, loads, corrosion, lubrication, sealing, and thermal protection."

REQUIREMENT LESSONS LEARNED (3.4.1.11.2.5)

Wheels that have been qualified with either bias or radial tire designs only have consistently shown shorter service life when the other tire type is used on it. Thus, the need exists to qualify both tire types if both type of tires are being used on the air vehicle.

4.4.1.11.2.5 Bias and radial tire compatibility.

Bias and radial tire compatibility shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.11.2.5)

The life capability of the wheel will be determined by analysis, wheel stress testing, and roll testing with all qualified parts intended to be used in air vehicle operations will determine the life capability of the wheel.

VERIFICATION GUIDANCE (4.4.1.11.2.5)

TBS should be filled with "… analysis and laboratory wheel and tire qualification testing." The testing and analysis should reflect the use of both types of tires if the program intends to allow both types of tires. If different bearings or brakes are to be used, the same sets of analysis and testing should be accomplished.

VERIFICATION LESSONS LEARNED (4.4.1.11.2.5)

(TBD)

3.4.1.11.2.6 Pressure release criteria.

Braked wheels shall have (TBS).

REQUIREMENT RATIONALE (3.4.1.11.2.6)

This requirement is to provide protection from wheel and tire explosions due to over-pressurization and overheat protection. The device(s) should release tire pressure before critical failure conditions occur.

REQUIREMENT GUIDANCE (3.4.1.11.2.6)

TBS should be filled with protection to prevent wheel or tire explosion due to high pressure or high temperature conditions. Braked wheel should provide a safe method of automatically releasing tire pressure whenever brake energies exceed maximum landing stop conditions. The device should not release at any time during or after a maximum design energy stop as specified for mission operations regardless of brake wear state. The device should not release during any Rejected Takeoff (RTO) stop, but may release after the air vehicle has come to a stop. However, it should release before the wheel and tire strength is compromised.

REQUIREMENT LESSONS LEARNED (3.4.1.11.2.6)

There has been loss of life from wheel and tire failures where protection was either not provided or malfunctioned.

4.4.1.11.2.6 Pressure-release criteria.

The pressure release capability shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.11.2.6)

The verification effort should show that the pressure release devices would release the pressure both before any dangerous over-pressurization occurs and when the strength of the wheel is compromised by over heat due to brake energy inputs.

VERIFICATION GUIDANCE (4.4.1.11.2.6)

TBS should be filled in with “analysis and laboratory testing.” The analysis should take into account both thermal as well as strength considerations. The analysis should be compatible with the testing accomplished on the wheel, brake, and tire assembly.

VERIFICATION LESSONS LEARNED (4.4.1.11.2.6)

Temperature release devices come in only incremental values; thus, the location and shielding of the devices are critical to ensure that they will release before the wheel softens enough to fail.

Usually several high-energy stops must be performed to determine the suitability of the particular release device and location thereof. Since heat rises, normally several of these devices are needed on the wheel. Thus, the upper portion of the wheel will have a higher temperature sooner. Therefore, one of the devices needs to be in the upper region at all times.

3.4.1.11.3 Brakes.

4.4.1.11.3 Brakes.

3.4.1.11.3.1 Air vehicle stopping and turn-around performance.

Brake assemblies used to provide any portion of the air vehicle stopping performance shall have the following characteristics: <u>(TBS).</u>

REQUIREMENT RATIONALE (3.4.1.11.3.1)

This requirement is to define acceptable performance of conventional brake assemblies should the contractor elect to use this approach to provide stopping performance. Requirements should be in the form of success criteria that are unique to the brake assembly and its installation when the brake is used to provide any part of the stopping performance.

REQUIREMENT GUIDANCE (3.4.1.11.3.1)

TBS should be filled in with the expected air vehicle stopping performance needed to satisfy the missions.

The requirement will usually be complex in that several aspects of “success” should be considered. Brake performance criteria may be different for the different stopping conditions specified in air vehicle specification. Requirements should be selected from the following performance parameters and modified as necessary to clearly indicate the applicable stopping performance.

The following success criteria should be considered in completion of this requirement:

a. There should be no structural failure of the brake assembly during any single stop within the design envelope. This condition does not apply for abuse or usage outside of recommended operating limits.

b. The required stopping performance should be provided at any time during the specified operational life of the brake.

c. After initial installation, it should not be necessary to perform manual adjustment of the brake to permit the required stopping performance.

d. Brakes should not squeal, chatter, or cause any vibration during the stop that results in malfunction or reduces the life of any air vehicle component.

e. Brakes should not cause heating of any air vehicle component that causes component malfunction prior to attainment of required life.

f. Brakes should release upon release of the normal brake control during and after the stop.

g. No damage to the air vehicle, including rolling components, except wear of brake friction surfaces and ground-contacting elements should result from stopping.

h. Prevention of structural overload due to braking should not be dependent upon pilot proficiency.

i. Overheating of brake assemblies due to malfunction or abuse should be indicated by a brake temperature monitoring system.

j. The wheel brakes should be adequate for a rapid “turn around” or “park” time of no greater than the time required for refueling operation or no greater than 15 minutes.

Most of the suggested brake criteria were stated or implied in MIL-W-5013.

REQUIREMENT LESSONS LEARNED (3.4.1.11.3.1)

A very large percentage of these failures were brake disc failures. Generally, these failures are not necessarily design failures, but they are induced by improper production processing. Another potential cause of brake disc failure is excessive heat input. If dragging or some other operational input abuses a brake, the structural integrity can be compromised. However, design assessment under controlled conditions should give some measure of capability and potentially a measure of tolerable abuse.

Brake chatter is the frictional or mechanical excitation of the landing gear fore and aft vibrational mode. It is generally caused by negative damping from the friction pair and usually has a critical speed range.

Brake chatter should be defined as brake vibration in the 50 to 100 Hz range. Since gear walk is normally in the 5 to 15 Hz range, brake chatter does not cause gear walk. Gear walk is much more complicated than implied by this section. Brake squeal is defined as greater than 100 Hz. Gear walk is a complicated interaction of the airframe structure, brake control system, and dynamic characteristics of all concerned.

Brake housing designs should avoid using a direst part of the housing as a dynamic grease seal rub surface unless it is adequately hardened or protected against wear.

Brake squeal is the induced vibration of the stationary parts of the brake assembly and its mounting. It generally has a natural frequency of several hundred cps, as compared to chatter frequency of 6-25 cps.

Brake chatter has been so severe that the gear walk was induced on the F-101 and F-105 air vehicles. There are numerous design changes within the brake that can control this compatibility. The most effective change is with the lining rubbing surface materials. The stiffness of some of the structural members controls the response to squeal. Squeal has been so intense on brakes that it has resulted in structural failure. Extensive flight-testing was required on the B-52, KC-135, F-100, and F-101 to evaluate the gear vibration. Recent designs have been "tailored" to the application by establishing response characteristics of the system prior to finalized hardware design. Testing has been modified to evaluate the brake mounting compatibility prior to installation on the air vehicle.

Peaks in brake torque are generally experienced as a result of various loading conditions. For instance, with steel brakes there is a high probability of brake chatter and peak torque at the low speed end of a normal energy stop. This is particularly true with a brake that is substantially worn. Peak torques are also experienced with very high-energy stops as the lining material reaches a point of maximum heat and wear. Most steel brakes produce very high torque, with maximum pressure applied from 30 to 0 knots. This occurs whether the assembly is cold or hot. It is experienced during taxi-out and taxi-in.

Temperature distribution within the brake and to the surrounding structure is a major factor in the success of a given brake design. Improper balance can produce hot spots in the hydraulic actuation section and contribute to seal deterioration and ultimately to leaks. It can produce excessive disk warpage. It can produce damage to the tire bead through the wheel assembly. Ventilation and elimination of conductive and convective heat is a major concern for assembly design. The problem of distribution is significantly increased with introduction of carbon brake discs. They may be lighter, but they do operate at a significantly higher temperature. Beryllium brake discs operate at significantly lower temperatures than steel or carbon brakes.

Overheating of brake assemblies may be encountered in operational use due to malfunction or abuse. A combination of low energy stops or a dragging brake may result in gradual temperature buildup that will negate normal safety devices or cause fires. To minimize damage caused by inadvertent overheating of the brake assembly, consideration should be given to detection of this condition and to design. Several methods of temperature detection have been conceived and tried without overwhelming success. Maintenance personnel place "Temp Sticks," heat sensitive devices that melt at a prescribed value, in direct contact with the hot brake to try to ascertain current temperatures. They read reliably, but it is dangerous to place personnel in such close proximity to an overheated brake. The use of "Temp Sticks" on carbon has proven to serve as an oxidation catalyst on the F-16 carbon pressure plated when applied. Temp Sticks should not be used on carbon heatsinks.

Brake temperature sensors and indicators have been used on some air vehicles. Sensors may be mounted either directly in the brake assembly or in the wheel well. Reliability and maintainability problems may be severe due to the severe operating environment. Current use of this system in Air Force air vehicles is limited to the B-1 and C-9A. A system was installed on C-133 air vehicles, but it was removed in operational use due to a maintainability problem. Brake temperature monitoring systems have been developed and used in several commercial air vehicles.

Life of adjacent components can be severely degraded due to high operating temperatures or to reduction in material strength due to long-term heat exposure. This softening effect has led to early removal of components from service. The requirements should establish the temperature limits of surrounding components that are not to be exceeded during normal operation of the braking system.

Load deflection characteristics have an impact on design and service performance. If the assembly is too flexible, the torque radius drops, and uneven wear and higher operating pressure result. Excessive deflection can also introduce eccentric or non-uniform loading into the brake structural members. The potential results of this can be premature failure in the field.

Often the source of yield failure is warpage and dimensional instability. Slots open up or close depending on the type service experienced or the temperature-time history of the part. This is why the development cycle should contain as many evaluations of actual service as possible.

Carbon brake discs have a much lower tolerance to abnormal loading. For example, they are incapable of supporting axial loads inadvertently transmitted through wheel deflections. The torsional loads should be properly directed to avoid localized structural failure. Axial deflections of the heat sink should be minimized to prevent degradation since the individual discs have low rigidity in response to loads in that direction.

Performance of some wheel brake systems with anti-skid control is severely degraded as the brake wears. This is because of the increase in volume of brake actuation fluid that must be moved for each skid cycle. Manual adjustment can be used to compensate for brake wear. However, most present-day high performance air vehicles use automatic brake adjusters.

Present tires, wheels, and brakes are subject to damage when subjected to greater than maximum design landing energy. It is an accepted practice to replace these components after refused takeoffs stop with greater than maximum landing energy. Replacement of other landing gear components after any refused takeoff stop (up to design RTO energy) is unacceptable due to the high cost of components.

Normally the landing gear is designed to withstand a limit drag load resulting from an effective peak brake coefficient of 0.8. In some cases, particularly in growth versions of an air vehicle, this coefficient is reduced. If less than 0.8 is used, a test should be accomplished to verify that peak brake torque does not result in excessive drag load. It may be necessary to limit brake torque to provide a compatible landing gear subsystem. If maximum torque is limited, refused takeoff stopping performance is degraded.

The maximum wheel static load and the tire static loaded radius should be associated at maximum wheel static load if the 0.8 wheel drag force is to be used to calculate peak-to-peak torque requirement. The 0.8 is not a brake coefficient, but a tire to ground coefficient of friction.

4.4.1.11.3.1 Air vehicle stopping and turn-around performance.

Brake durability, operating characteristics, and compatibility with interfacing subsystem such as

(TBS 1) shall be evaluated by (TBS 2).

VERIFICATION RATIONALE (4.4.1.11.3.1)

Brake evaluation will normally consist of laboratory and flight-testing. In so far as possible, verification should be by air vehicle stopping tests. Performance will most likely depend upon characteristics of the air vehicle and environment that are difficult to simulate simultaneously in the laboratory. Some extreme conditions such as maximum and minimum temperature can be duplicated only in the laboratory. Some extreme operating conditions may also be too hazardous for air vehicle test. The verification requirement should clearly indicate the characteristics that the air vehicle test should evaluate because flight-testing can be a significant cost and schedule driver due to damage and component replacement from high energy testing.

VERIFICATION GUIDANCE (4.4.1.11.3.1)

TBS 1 should reflect the various subsystems that are to be tested together to verify the stopping performance of the air vehicle.

TBS 2 should be filled with “analysis, laboratory, and air vehicle testing.” The laboratory testing is to evaluate maximum performance envelops. Flight-testing should verify that the analysis and laboratory test accurately demonstrated the stopping performance of the air vehicle as published in the flight handbooks.

VERIFICATION LESSONS LEARNED (4.4.1.11.3.1)

Brake failure modes experienced in the laboratory may have little correlation with failure modes on the air vehicle because of poor simulation of air vehicle operation. Modification of the brake to eliminate laboratory failure modes may induce additional failure modes on the air vehicle. An example is that large drive key clearances may result in severe battering damage to brake disc keyways. Reduction of the clearance to eliminate the problem can lead to severe dragging brake problems on the air vehicle. This is primarily due to the actual loading cycle on the air vehicle, which is quite different from the accelerated life test usually used in the laboratory. Verification requirements should be structured to ensure that performance on the air vehicle is the final success criterion. Laboratory test failures should not be ignored. However, laboratory successes are of no value to the operational Air Force.

Consideration can be given to allow structural failure or gross deformation of the brake assembly during a RTO, if the stopping performance is satisfied.

3.4.1.11.3.2 Wear indicator and servicing criteria.

Means shall be provided to determine status of brake wear without disassembly or the use of special tools.

REQUIREMENT RATIONALE (3.4.1.11.3.2)

This is an expression of an operational need to be able to determine status of brake wear during a pre-flight inspection or after any given flight. Rather than dictate wear pins for measurement, the designer is free to develop any means that will provide this inspection capability, consistent with the overall maintainability plan.

REQUIREMENT GUIDANCE (3.4.1.11.3.2)

Mechanical design of the brake, friction wear characteristics of the discs or lining material, and maximum permissible wear have marked influence on the ability to accurately display current wear status of the brake assembly.

This item was expressed in MIL-W-5013, calling specifically for “brake lining wear indicators.” This requirement has been established from operational lessons learned and generally expresses the desires of most Using Commands.

REQUIREMENT LESSONS LEARNED (3.4.1.11.3.2)

The details of attachment of wear indicators generally control the adequacy of the design. The problems encountered include improper use of frictional mechanical devices, which do not “pull through” to give an accurate assessment of brake disk wear. Other mechanical designs have encountered eccentric loadings and resulted in broken parts. There have been designs that utilize the mechanism of the automatic brake loadings. Frequently, design reliability is low due to exposure to this hostile environment.

Wear indicators should be readily observed and generally simple in design to provide a reliable indication of wear. Little or no interpretation should be required to assess the state of disk wear. Some degree of protection should be provided if the indicator extends beyond a reading surface to prevent damage due to foreign object impact.

4.4.1.11.3.2 Wear indicator and servicing criteria.

Brake wear indications and servicing suitability shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.11.3.2)

Brake evaluation will normally consist of laboratory and flight-testing. Laboratory testing can subject the brakes to a large number of stops to verify wear characteristics. Flight-testing results should be used to correlate the laboratory findings. Flight-testing will verify the actual serviceability to operational usage and environments.

VERIFICATION GUIDANCE (4.4.1.11.3.2)

TBS should be filled with “laboratory testing and on air vehicle demonstration.”

VERIFICATION LESSONS LEARNED (4.4.1.11.3.2)

Brake failure modes experienced in the laboratory may have little correlation with failure modes on the air vehicle because of poor simulation of air vehicle operation. Modification of the brake to eliminate laboratory failure modes may induce additional failure modes on the air vehicle. For example, large drive key clearances may result in severe battering damage to brake disc keyways. Reduction of the clearance to eliminate the problem can lead to severe dragging brake problems on the air vehicle. This is primarily due to the fact that the actual loading cycle on the air vehicle is quite different than the accelerated life test usually used in the laboratory. Verification requirements should be structured to ensure that performance on the air vehicle is the final success criterion. Laboratory test failures should not be ignored; however, laboratory successes are of no value to the operational Air Force.

3.4.1.11.3.3 Structural failure criteria.

Structural failure of the brake during normal, emergency, or parking operation shall not result in (TBS).

REQUIREMENT RATIONALE (3.4.1.11.3.3)

The intention of the requirement is to define the unacceptable modes of failure for the brake assembly. If the design can tolerate minor discrepancies, strict adherence to no crack philosophy may be an unnecessary cost driver. Therefore, the air vehicle specification should define unacceptable results.

REQUIREMENT GUIDANCE (3.4.1.11.3.3)

TBS should reflect unacceptable consequences of failure, such as locking, piston overextension, pieces of disc inducing locked wheel or structural failure of the wheel, deformation of the piston, bushing, or housing due to high operating pressures when the brakes are hot.

Maximum surface and heat sink temperature, heat sink materials, lug loadings, peak torques, and running clearances provide technical influence in meeting this requirement.

MIL-W-5013 contains a very superficial discussion of brake disc failure in section 4, which is inadequate to evaluate performance in the field. Therefore, this requirement is a new requirement to reflect all the lessons learned in maintenance and safety.

REQUIREMENT LESSONS LEARNED (3.4.1.11.3.3)

Brake disintegration can be the cause of serious accidents and potential fires.

A design approach, which has been used successfully to prevent fires caused by brake disc failure, should use actuation piston stops. The stops prevent the pushing of the pistons from the housing and subsequent flooding of the brake with hydraulic fluid from the open ports.

Carbon disk brakes are more susceptible to disk disintegration than steel discs due to the lack of strength when loaded axially. Extra precaution should be taken with this type of design to ensure piston retention and fire prevention. Carbon brake discs generally are operated at higher temperatures than its steel brake counterparts are.

The wheel to brake interface (wheel keys and brake clips) is critical. A number of carbon discs have been broken or cracked because of interference or brake dynamics in this area. Insure sufficient clearance is maintained at all loadings and the interface design is a proven concept.

4.4.1.11.3.3 Structural failure criteria.

Structural capacity of brake components shall be evaluated by test and analysis and the wheel lock-up range at various speeds on different surfaces shall be evaluated by analysis.

VERIFICATION RATIONALE (4.4.1.11.3.3)

Theoretical response to numerous modes of failure can be considerably more comprehensive than that which could be evaluated by test. Limited testing can be used to evaluate and validate the failure mode analysis.

VERIFICATION GUIDANCE (4.4.1.11.3.3)

The analysis should look at all possible brake failure modes and ensure the air vehicle is not compromised and will not produce a catastrophic failure. The testing accomplished on the braking system should verify that the safety design features are working as expected and, where relief devices are used, they release as designed. Piston retention features should be demonstrated.

VERIFICATION LESSONS LEARNED (4.4.1.11.3.3)

Numerous brake fires have been experienced due to expansion and deformation of brake components such as bushings, pistons, and housings from the high temperatures of the brakes. The result is leaking hydraulic fluid on the hot brake stack. Therefore, the verification should demonstrate that the brake assemblies are protected from the heat, or the components should operate normally without failure within the heat environment experienced throughout the air vehicle operating range.

3.4.1.11.3.4 Secondary braking capability (fail-safe).

(TBS) failure of the brake control system shall not result in a total loss of air vehicle braking capability.

REQUIREMENT RATIONALE (3.4.1.11.3.4)

The objective is to define whether single or dual failures will be permitted before loss of control. If the redundancy of dual failure concepts is a significant cost driver, the program management will have to determine what level of risk they are willing to take. The Using Command should clearly define the requirement parameters. The blank should indicate “single” or “dual.”

REQUIREMENT GUIDANCE (3.4.1.11.3.4)

TBS should list the number of failures that can occur without losing air vehicle braking. It should also indicate whether 100 percent (100%) braking capability of alternate braking systems is available.

Brake system design, redundancy, and reliability are key words in arriving at a decision for this requirement.

This requirement was previously contained in AFSC DH 2-1, and the intent is to clarify what is or is not acceptable performance for the brake system. It establishes the degree of redundancy, which is required. There is an obvious price to pay for double redundancy, but if the Using Command desires such features, the airframe manufacturer should be notified in advance so that the requirement is clear to all competitors during source selection.

The AFSC DH 2-1 contains a requirement just for single failure, but this “tailorable” requirement presents an option to increase the redundancy if the system needs the capability. Under no circumstances should a single failure in a hydraulic, electrical, or mechanical component of the normal braking system cause degradation of the emergency system capabilities.

REQUIREMENT LESSONS LEARNED (3.4.1.11.3.4)

The sources of failure that affect the ability of the system to maintain control are numerous. Failures may occur in the actuation system (hydraulic, pneumatic, or mechanical), the brake assembly, the pedal linkage, or the tire.

In one case, an electrical connector disconnected and caused both the normal and emergency system to become inoperable. Normal and emergency systems should not be routed through the same connectors.

4.4.1.11.3.4 Secondary braking capability (fail-safe).

The effect of component malfunctions shall be evaluated by (TBS).

VERIFICATION RATIONALE (4.4.1.11.3.4)

Options available for this verification include simulator demonstrations, flight test, or analysis. Depending on the complexity of the system, the availability of the simulator, and the experience level of the proposed contractors, the blank should be completed. It is also a function of economics, since each approach has associated costs. Technically, the simulator in conjunction with an analysis is most desirable because the interfaces can be evaluated, and the conditions can be controlled.

VERIFICATION GUIDANCE (4.4.1.11.3.4)

TBS should reflect analysis and laboratory simulations and brake control system testing.

VERIFICATION LESSONS LEARNED (4.4.1.11.3.4)

(TBD)

3.4.1.11.3.5 Fire prevention criteria.

Setting the parking or holding brake immediately after (TBS 1) stop conditions shall not cause damage to the brake, landing gear, or other air vehicle equipment. Brake fluid temperatures shall not exceed (TBS) degrees F at any time after any design-landing stop or up to fuse plug release conditions.

REQUIREMENT RATIONALE (3.4.1.11.3.5)

Due to the high temperatures that can occur within the brake, the rest of the brake, seals, and fluid should be protected from temperatures that would degrade the seals or cause fluid to escape on to the hot brake surfaces resulting in fire.

TBS 1 should reflect the highest energy stop condition that the brake system can experience in service (e.g.; maximum weight landing in which the parking brake can be used).

TBS 2 is the maximum operation temperatures for the hydraulic fluid and seals used in the system. Typically, the values is 275 degrees F. However, a number of fighters have raised the temperature limits up to 350 degrees F and higher, as long as tests prove that the brake assembly can successfully operate at these elevated temperatures without any system equipment degradations.

REQUIREMENT LESSONS LEARNED (3.4.1.11.3.5)

The F-16 brake system experienced a number of brake fires after the parking brake was set at the end of operational missions. They found that there was a direct heat flow path to the brake seals, which caused the brake seals to deteriorate and consequently allowed fluid to escape on the brake resulting in a self-feeding fire. Providing insulators between the piston and the brake stack solved this problem.

4.4.1.11.3.5 Fire prevention criteria.

Fire prevention shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.11.3.5)

The brake system design should consider the heat generated in the heat sink, determine the heat flow, and provide protection from over heat to those components not able to withstand the high heat.

VERIFICATION GUIDANCE (4.4.1.11.3.5)

TBS should be filled in with "...analysis and laboratory demonstration of the brake system at the design energies."

VERIFICATION LESSONS LEARNED (4.4.1.11.3.5)

(TBD)

3.4.1.11.3.6 Refurbishment criteria.

Provisions for the refurbishment of brake friction members or the use of spacers after initial stack wear out shall be incorporated to provide cost effective wear life extension. The refurbished brakes shall be capable of all requirements herein.

REQUIREMENT RATIONALE (3.4.1.11.3.6)

Some heat sink material is quite expensive, yet structurally sound, even though the stack has used its initial service life. It has been shown that the worn stack can be rebuilt either mechanically or by reprocessing to obtain nearly the initial life capability and meet all the performance requirements of the air vehicle for a fraction of the cost of a new brake heat stack.

REQUIREMENT GUIDANCE (3.4.1.11.3.6)

Cost effectiveness of using refurbished brakes or a spacer disc in the heat stack to extend brake wear life should be stated, so the initial design can consider this requirement. The cost of refurbishment or of an additional spacer has to be balanced against the expected air vehicle life and the number of landing and stopping cycles.

REQUIREMENT LESSONS LEARNED (3.4.1.11.3.6)

A number of air vehicles use spacers or have their brake heat sinks refurbished at a greater savings than buying new heat stacks.

The use of spacers and refurbished heat sinks should be carefully investigated for their effect on the new and worn brake RTO capability. Thermal constraints defined using the original equipment heat sink may not be appropriate for spacers or refurbished configurations.

4.4.1.11.3.6 Refurbishment criteria.

The use of refurbishment shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.11.3.6)

The spacer and or refurbished brake stack needs to be tested according to the initial design requirements to ensure that there is no compromise of air vehicle performance.

VERIFICATION GUIDANCE (4.4.1.11.3.6)

TBS should reflect all the testing that qualifies the airworthiness of the refurbished equipment to the original equipment testing.

VERIFICATION LESSONS LEARNED (4.4.1.11.3.6)

(TBD)

3.4.1.11.3.7 Temperature interface criteria.

Temperature interface between the brake heat sink and surrounding equipment shall be (TBS).

REQUIREMENT RATIONALE (3.4.1.11.3.7)

Typically, the material used in the equipment around carbon heat sinks have temperature-operating limits much lower than the capability of the heat sinks. None of the surrounding equipment should be degraded due to high heat and heat soak.

REQUIREMENT GUIDANCE (3.4.1.11.3.7)

TBS should be filled in with the temperature limits of each material temperature limits.

REQUIREMENT LESSONS LEARNED (3.4.1.11.3.7)

The tires, wheels, brake housing, and axles and wheel bearings should be able to operate without degradation for all normal brake operation up to RTO operations.

4.4.1.11.3.7 Temperature interface criteria.

The temperature interface limits shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.11.3.7)

The brake qualification testing at all energy levels should record equipment temperatures for all the test conditions. The temperature levels are not to exceed the capability of each item to continue to operate as designed, apart from the RTO energy level.

VERIFICATION GUIDANCE (4.4.1.11.3.7)

TBS should be filled in with laboratory testing at all the brake design energy levels.

VERIFICATION LESSONS LEARNED (4.4.1.11.3.7)

(TBD)

3.4.1.11.3.8 Service life and replacement criteria.

Service life of the arresting hook shall be (TBS 1) without replacement of components except (TBS 2).

REQUIREMENT RATIONALE (3.4.1.11.3.8)

This requirement is to establish the minimum service life of the arresting hook system. The requirement should recognize that the hook point or shoe is subject to severe wear and may need to be replaced at some interval less than the life of the system.

REQUIREMENT GUIDANCE (3.4.1.11.3.8)

TBS 1: Service life should be determined by analysis of the air vehicle mission and arrestment concepts. If no study results are available, it is suggested that the arresting hook system should have a service life of 1,000 landing engagements without replacement of components.

TBS 2: Ground-contacting elements may be replaced after each 15 landing engagements are used.

Hook point wear characteristics, attachment fatigue characteristics, shank design and load levels, and hook materials are parameters influencing the ability to meet this requirement.

This is a new requirement. MIL-A-83136 required a replaceable hook point.

REQUIREMENT LESSONS LEARNED (3.4.1.11.3.8)

“Weak link” theory should be considered in design of an arresting hook system. Inadvertent overload is a frequent possibility due to the hostile environment in which the hook is loaded. Frequently, the most severe loads are dynamically applied, and these are the most difficult to calculate. Therefore, attachment structure is extremely critical for capacity and life. Attachment is usually integral with the structure or bulkhead of the fuselage.

The hook life will be very low if the hook shank and hook point are integral. If a life greater than 15 landings is desired, the hook point should be separate from the shank to minimize replacement cost.

The F-111/FB-111 hook shank and point were integral. During category II testing, the average life for the FB-111 hook was 6 or 7 landings. The F-111A average life was 10-12 landings. These are considered economically high. The replacement hook cost was $3,200.00 in 1966.

4.4.1.11.3.8 Service life and replacement criteria.

Service life of the hook shall be evaluated by laboratory tests for fatigue life and by air vehicle tests for durability.

VERIFICATION RATIONALE (4.4.1.11.3.8)

The environment, load level, and load orientation can best be controlled in a laboratory. Therefore, lab tests with airplane certified loads produces the best combination for accurate verification. The cost of a laboratory test is significantly lower than airplane tests.

VERIFICATION GUIDANCE (4.4.1.11.3.8)

Service life of the hook system should be accomplished by analysis and laboratory testing.

VERIFICATION LESSONS LEARNED (4.4.1.11.3.8)

(TBD)

3.4.1.11.3.9 Drag chute service life.

Deceleration drag chutes shall (TBS).

REQUIREMENT RATIONALE (3.4.1.11.3.9)

The life of the drag chute should be depended on the number of expected operations and how often it should be replaced.

REQUIREMENT GUIDANCE (3.4.1.11.3.9)

TBS should reflect the life requirements for deceleration operations and environmental conditions.

REQUIREMENT LESSONS LEARNED (3.4.1.11.3.9)

(TBD)

4.4.1.11.3.9 Drag chute service life.

Drag chute service life shall be verified by (TBS).

VERIFICATION RATIONALE (4.4.1.11.3.9)

Life capability should be demonstrated and proven to last the required number of deployments.

VERIFICATION GUIDANCE (4.4.1.11.3.9)

TBS should specify the analysis, demonstrations, and air vehicle testing.

VERIFICATION LESSONS LEARNED (4.4.1.11.3.9)

(TBD)

5 PACKAGING

5.1 Packaging.

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

6. NOTES

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

6.1 Intended use.

The landing subsystem descriptions in this specification guide are intended for use in air vehicle systems developed to perform combat and combat-support missions in environments unique to military weapon systems.

6.2 Acquisition requirements.

Acquisition documents should specify the following:

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

6.3 Acronyms.

The following list contains the acronyms/abbreviations contained within this specification guide:

AGE	Aerospace Ground Equipment
AMST	Advanced Medium Short Take Off and Landing Transport
CAD/CAM	Computer Aided Design / Computer Aided Manufacturing
CBR	California Bearing Ratio
GVT	Ground Vibration Test
HIAD	Handbook of Information for Aircraft Designers
LCN	Load Classification Number
MLG	Main Landing Gear
RRR	Rapid Runway Repair
RTO	Rejected Takeoff
VTOL	Vertical Takeoff and Landing
WOW	Weight on Wheels

6.4 Subject term (key word) listing.

Actuation
Arresting hook
Brake
Drag chute
Fire prevention
Flotation gear
Nose wheel
Restraint
Ski jump
Skid
Steering
Tires
Wheel

6.5 International standardization agreement implementation.

This specification implements NATO STANDARD AASSEP-1, Aircraft Jacking; STANAG 3098, Aircraft Jacking; and STANAG 3278, Aircraft Towing Attachments and Devices. When amendment, revision, or cancellation of this specification is proposed, the preparing activity must coordinate the action with the U.S. National Point of Contact for the international standardization agreements, as identified in the ASSIST database at https://assist.dla.mil.

6.6 Responsible engineering office.

The office responsible for the development and technical maintenance of this specification guide is AFLCMC/EZFA, BLDG 28 RM 118, WPAFB OH 45433-7017; DSN 785-2023, COMMERCIAL (937) 255-2023; aflcmc.ezf.mailbox@us.af.mil.

Requests for additional information on this specification guide can be obtained from AFLCMC/EZSS, BLDG 28 RM 118, 2145 MONAHAN WAY, WPAFB OH 45433-7017; DSN 674-5476; COMMERCIAL (937) 904-5476; engineering.standards@us.af.mil.

6.7 Changes from previous issue.

Marginal notations are not used in this revision to identify changes with respect to the previous issue due to the extent of the changes.

CONCLUDING MATERIAL

Custodians:	Preparing activity:
Army – AV	Air Force – 11
Navy – AS	(Project 15GP-2018-004)
Air Force – 11	

Review activity:
Air Force – 70

NOTE: The activities listed above were interested in this document as of the date of this document. Since organizations and responsibilities can change, you should verify the currency of the information above using the ASSIST Online database at https://assist.dla.mil.