MIL-L-87139(USAF)
13 July 1979

MILITARY SPECIFICATION

LANDING GEAR SYSTEMS

This specification is approved for use by the Department of the Air Force, and is available for use by all Departments and Agencies of the Department of Defense.

1.0 Scope

1.1 Scope. This specification establishes the performance, development, compatibility and verification requirements for a conventional Landing Gear System and its components.

1.2 Applicability. The requirements and verifications contained in this specification apply to landing gear equipment developed for Air Force air vehicle and helicopters. Any paragraph marked "No" in this specification means that the subparagraph(s) is not applicable.

1.3 Use. This specification cannot be used for contractual purposes without supplemental information. The supplemental information relates to operational requirements of landing gear systems. The need for this information is identified by blanks within this document. The rationale for requirements, configuration interfaces and constraints, and component development requirements are provided in Appendix I, LANDING GEAR SYSTEMS HANDBOOK.

1.4 Deviation. Any projected design for a given application which will result in improvement of system performance, reduced life cycle cost or reduced development cost through deviation from this specification or where the requirements of this specification result in compromise in operational capability, the details shall be brought to the attention of the procuring activity for consideration of change.

2.0 Referenced documents

2.1 Issues of documents. The following documents, of the issue in effect on date of invitation for bids or request for proposal, are applicable to the extent specified herein.

STANDARDS

MILITARY

MIL-STD-1568	Materials and Processes for Corrosion Prevention and Control in Aerospace Weapon Systems
MIL-STD-1567	Materials and Process Requirements for Air Force Systems

Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: ASD/ENESS, Wright-Patterson AFB, OH 45433 by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

FSC 1620

3.0 Requirements

3.1 System description

3.1.1 Landing gear system. The Landing Gear System shall perform the allocated air vehicle functions and be compatible with overall air vehicle requirements. Landing gear system functions and hardware shall be allocated to the following categories for consideration in this specification.

3.1.2 Landing gear structure. This group shall consist of all equipment of the landing gear designed to provide structural support of the air vehicle in the ground environment.

3.1.3 Brake control. This group shall consist of landing-gear-related equipment which transmits the braking efforts and controls the braking output in terms of compatibility with the environment and hardware capabilities. It includes the hydraulic system, anti-skid control, and brake actuation mechanisms.

3.1.4 Rolling components. This group consists of wheel, brake, and tire equipment.

3.1.5 Directional control. This group consists of the landing gear hardware dedicated to accomplishing the function of directional control.

3.1.6 Gear and door actuation systems. This group consists of the hardware which is utilized in raising and lowering the gears, locks, doors, controls, indicators, and warning systems.

3.1.7 Auxiliary deceleration devices. This group encompasses the hardware associated with drag chutes and arresting hooks.

3.1.8 Ground handling. This group includes hardware associated with air vehicle ground handling functions such as tie-down, jacking, and towing.

3.1.9 Specialized subsystems. This group consists of equipment required for special functions, such as kneeling, crosswind positioning, skiing, tire pressure control, et cetera.

3.2 Operating requirements

3.2.1 Landing gear system

3.2.1.1 General.

a. With stated exceptions, the service life of the landing gear components shall be _________________________.

b. The landing gear shall have ground flotation capability to permit the air vehicle to ______________________.

c. The landing gear shall meet the requirements of this specification during and after operation of the air vehicle on surfaces with the following roughness characteristics: ________________.

3.2.1.2 Arrangement.

a. The landing gear shall be arranged so that the airframe structure will not contact the ground during a ground turn producing ________________ lateral acceleration at the most critical operational c.g. configuration.

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

3.2.1.3 Clearances.

a. Clearance shall be provided so that with the landing gear in the position for landing, and during any phase of air vehicle 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 or restrictions ________________.

b. Clearance 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: ________________.

c. _____ wheels shall be stopped from rotating during retraction or prevented from rotating in the retracted position.

d. In the event of flat tire and flat strut, the lowest part of the landing gear, door fairing, or air vehicle components, including external stores, shall not ___________________________.

3.2.1.4 Damping. All landing gears shall have natural or augmented damping so that the amplitude of any landing gear oscillations after ____________ cycles is reduced to ________ or less of the original disturbance, with the following exceptions: ____________. The damping requirement applies to all initial displacements of the landing gear under the following conditions: ______________________________.

3.2.2 Structure

3.2.2.1 General.

a. Landing gear structure shall be designed in accordance with ____________, except as modified by ________________.

b. Materials selection shall be made in accordance with MIL-STD-1587 and corrosion control shall be established in accordance with MIL-STD-1568, except as modified by ________________.

c. In the event of a flat tire or a depressurized shock absorber, the gear shall be capable of ____________ without structural damage to the gear or the air vehicle.

d. Where joints and wear surfaces are required, they shall have material for rework by ______________.

e. In the event of landing gear structural failure, no landing gear component shall __________________________.

3.2.2.2 Shock absorption. (Yes___, No___)

a. The landing gear system shall absorb sufficient energy of landing such that ______________ is not exceeded under the following conditions:__________ ________________.

b. The landing gear system shall provide a ride such that the vertical accelerations at the pilot's station shall not exceed _______ on a _________ runway under the following conditions: ________________.

c. The landing gear subsystem shall be designed for, and specify the use of, charging agents which will not cause corrosion nor support combustion.

d. The following types of shock absorber servicing shall be accomplished without removal of the shock absorber from the air vehicle or jacking of the complete air vehicle: __________________.

e. The shock absorber shall be capable of performing its required function within _________ after positioning for landing.

f. The shock absorber shall not prevent accomplishment of successive ________________ landings with _________ between landings.

g. Friction characteristics of the shock absorber shall not cause _________.

3.2.2.3 Tail bumpers. The tail bumper if used, shall incorporate the following features: _________________.

3.2.3 Brake system. (Yes___, No___)

3.2.3.1 General

a. The air vehicle shall be capable of stopping under the following conditions: __________________________.

b. The total system shall provide restraining force to hold the air vehicle static on a dry paved surface during application of _________.

c. ______________ failure of the brake control system shall not result in a total loss of air vehicle braking capability.

3.2.3.2 Brake actuation system.

a. A separate and independent emergency braking system shall be provided with the capability to _____ with ______ control.

b. brakes shall be applied by the following action: ________.

c. The brake control shall have the following force and travel characteristics: ____________.

d. A parking brake shall __________ to hold the air vehicle static under the following conditions: __________________.

3.2.3.3 Anti-skid brake control. (Yes___, No___)

a. The anti-skid brake control system shall be tuned for optimum performance on a _________ surface, considering both braking and cornering forces throughout the control speed range.

b. During air vehicle system power interruption or system malfunction, the system shall _________________.

c. The pilot shall be able to engage or disengage the anti-skid system by the following action: ___________.

3.2.4 Rolling components. (Yes___, No___)

3.2.4.1 Tires. (Yes___, No___)

a. The tires shall be capable of performing on the air vehicle for the following ___________________________________.

b. Tires shall have a service life, due to tread wear only, of not less than ______ landings. This shall apply during operation of the air vehicle as follows:__________________.

c. The tire carcass shall be capable of _______ retreads without degradation of tire structure performance.

d. The electrical conductivity characteristics of tires shall be such that the tire will not store a static charge which will be detrimental to any other air vehicle system or harmful to personnel.

e. In selecting tire sizes, make an allowance for _____ growth in air vehicle maximum design weight within the same size tire.

f. For multiple tire gear designs, capacity shall be provided to accommodate ___ tire failure without additional tire failure, when operating at all gross weights under the following conditions: _________________.

3.2.4.2 Wheels. (Yes___, No___)

a. The wheel assemblies shall be capable of performing on the air vehicle for the following: _______________________.

b. The wheel service life shall be ______________.

c. Protection shall be provided to the wheel from brake heat to prevent ________________ after exposure to ______________ energy.

3.2.4.3 Brakes

a. Brake assemblies used to provide any portion of the air vehicle stopping performance specified in 3.2.3.1a shall have the following characteristics: ____________________.

b. Brake assembly heat sink members shall be capable of producing ______________ operational landings and the brake structural members shall be capable of producing _____________ operational landings without failure or wear beyond limits. The spectrum of operational landings is defined as: ___.

c. Means shall be provided to determine current status of brake wear without disassembly or the use of special tools.

d. Structural failure of the brake heat sink shall not result in _______________.

3.2.5 Directional control system

3.2.5.1 General.

a. Directional control of the air vehicle for operation on the ground shall be provided as follows: ______________.

b. Ground directional control characteristics shall permit the pilot to precisely control the air vehicle under the following crosswind conditions: ____________________.

c. Emergency directional control shall be provided with the following characteristics: _______________________.

3.2.5.2 Nose gear steering system.

a. The steering system used to provide any portion of the directional control shall have the following characteristics: ___________________.

b. The probability of occurrence of a single failure that results in total loss of steering shall not exceed ______________ per mission.

c. The probability of occurrence of a single failure that results in "hardover" steering response shall not exceed _________ per mission.

d. In the event of failure of the primary steering system, emergency steering shall be provided with the following characteristics: ____________.

3.2.6 Landing gear actuation. (Yes___, No___)

3.2.6.1 Retraction-extension system.

a. The landing gear retraction and extension shall be actuated by crew members by ___________________.

b. If used, fairing door actuation and locking shall be ___________.

c. The probability of occurrence of a single failure that results in the failure of any landing gear assembly to extend and lock in the position for landing shall not exceed ________ per mission.

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

e. Retractable landing gears shall retract into an aerodynamically faired enclosure and the fairing doors, if used, shall close and lock without damage at all airspeeds from _____ to _____ for flight at _________.

f. 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 _______ to _______ for flight at _________.

g. Loss of any landing gear fairing door shall not result in _________ __________.

h. A separate emergency extension system shall be provided with the capability to _____________.

3.2.6.2 <u>Actuation system indication</u>.

a. An indicator shall be provided to show _____________.

b. A warning system shall be provided to _____________.

c. An override shall be provided for aural warning systems.

3.2.6.3 <u>Retraction-extension time</u>.

a. The time from selection of landing gear retraction or extension until all landing gear are retracted and locked and all fairing doors where used, are closed and locked or gear is extended and locked shall be compatible with air vehicle performance.

b. The time from selection of landing gear extension by the emergency actuation system until all landing gears are extended and locked and all necessary fairing doors are in position required for landing shall _________.

3.2.6.4 <u>Position restraint</u>

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

b. Where doors are used in conjunction with landing gear, the method used to retain the landing gear in the selected position shall have the following characteristics: _____________.

c. Ground safety provisions shall be provided to prevent retraction under the following conditions: ______________________. Provide indicators to alert ground crews to assure removal of safety devices prior to flight.

d. The air vehicle, actuation system, or ground safety provision shall not be damaged in the event that _____________.

3.2.7 Auxilary deceleration devices

3.2.7.1 Arresting hook systems. (Yes___, No___)

a. The arresting hook system shall be capable of decelerating __________ air vehicle to a stop by engaging __________ arrestment system at __________.

b. Arresting hook system and attachment shall withstand loads of __________ fly-in engagement.

c. The probability of successful engagement of the arresting system shall be not less than ____________ for all air vehicle landing attitudes.

d. Hook installation shall have lateral freedom for __________.

e. Service life of the arresting hook shall be _______________ without replacement of components except: ________________.

f. The retracted hook shall preclude _______________.

g. Current position of the hook shall be indicated in the cockpit.

h. For maintenance activity, the hook installation shall have ______________ _______________.

i. The hook shall be positioned by the following action: _________________ ____________________.

3.2.7.2 Drag chutes. For drag chute requirements, see MIL-___________.

3.2.8 Ground handling

3.2.8.1 Jacking.

a. Jacking provisions shall be provided by _______________.

b. The axle jacking system shall be capable of raising __________ weight air vehicle high enough to perform required maintenance while exposed to ________ crosswind from any direction.

c. The fuselage jacking system shall be capable of raising __________ weight air vehicle high enough to perform required maintenance while exposed to ___ crosswind from any direction.

3.2.8.2 Towing

a. The air vehicle shall be capable of being pushed or towed at ___________ gross weight up or down a __________ slope on a ____________ surface.

b. The main gear shall have the following provisions for emergency towing: _________.

c. The interface between the air vehicle and tow vehicle shall be as follows: _____________.

3.2.8.3 Mooring

a. The mooring arrangement shall be compatible with ________.

b. The mooring arrangement shall be capable of withstanding ________ with all surfaces locked, at ________ gross weight.

3.2.9 Specialized subsystems

3.2.9.1 General. Many air vehicles are equipped with specialized subsystems, which are associated with landing gear equipment. Examples of such systems include: skis, kneeling systems, crosswind positioning systems, and in-flight pressure control systems. The air vehicle shall have special sybsystems or characteristics as follows: ________________.

3.3 Reliability. The landing gear system reliability requirements shall be as follows: ______________.

3.4 Maintainability. The landing gear system maintainability requirements shall be as follows: ________________.

3.5 System safety. The landing gear system safety requirements shall be as follows: __________________.

3.6 Environmental conditions. The landing gear system equipment shall be capable of withstanding or operating under the following conditions:

Environment	Requirement
Temperature	
Humidity	
Fungus	
Vibration	
Dust	
Salt fog	
Explosion proof	
Acceleration	
Shock	
Electromagnetic	

3.7 Interface requirements

3.7.1 Related systems. The landing gear system shall interface with other air vehicle systems as follows: __________________.

3.7.2 Ground support equipment. The landing gear system shall interface with the following ground support equipment as follows: ______________.

3.7.3 International standardization. Where applicable, utilize standard parts from international standardization lists, including NATO and ISO documentation.

4.0 Quality assurance provisions

4.1 General. The following analyses, laboratory tests, demonstrations, taxi and flight tests, and service tests are to evaluate the ability of the landing gear system to support the air vehicle in the ground environment and to accomplish the required functions with specified capacity and durability. All evaluations are the responsibility of the contractor; the Government reserves the right to witness any verification.

4.2 Characteristics

4.2.1 Landing gear system

4.2.1.1 General. The landing gear component service life shall be evaluated by ______________. The ground flotation characteristics shall be evaluated by ____________________. Performance during and after operation on surfaces of specified roughness shall be evaluated by _________________.

4.2.1.2 Arrangement. Air vehicle stability during turns shall be evaluated by ground handling analysis substantiated by air vehicle taxi test as follows: ____________. Pitch stability shall be verified by _________ for the following conditions: _______________.

4.2.1.3 Clearances. Clearance between the landing gear and other air vehicle components shall be verified by _________________. Demonstration that the wheels do not rotate in the retracted position shall be shown by ____________. Ground clearance after tire failure and strut deflation shall be determined analytically.

4.2.1.4 Damping. Landing gear system damping shall be determined analytically and substantiated by ______________.

4.2.2 Structure

4.2.2.1 General. Review of the structural design criteria and component material and process selection shall be included in ____________________. Landing gear energy absorption performance with a deflated strut or flat tire shall be evaluated by: _________________________. Provisions for rework of joints and wear surfaces shall be evaluated by inspection of engineering drawings and analysis. Component performance during landing gear structural failure shall be evaluated analytically.

4.2.2.2 Shock absorption. Landing gear shock absorption performance shall be evaluated by: _______________. Other performance characteristics of the shock absorber, such as _________, shall be demonstrated. Ride quality performance shall be evaluated analytically and substantiated by flight test. Design features shall be evaluated by inspection.

4.2.2.3 Tail bumpers. Ground clearance and protection by tail bumper shall be evaluated by dynamic analysis of the air vehicle. The tail bumper operation and controls shall be evaluated by air vehicle test.

4.2.3 Brake system

4.2.3.1 General. Total air vehicle stopping performance and the ability to hold the air vehicle static during engine runup shall be evaluated by air vehicle tests as follows: ______________. The effect of component malfunctions shall be evaluated by ___________________.

4.2.3.2 Brake actuation system. Performance and suitability of the emergency braking system shall be evaluated by flight test. Brake actuation and parking brake performance shall be evaluated by _______________. The brake control force versus control travel relationship shall be measured on the air vehicle.

4.2.3.3 Anti-skid brake control. The operating characteristics of the anti-skid brake control system and design features of the system shall be evaluated by _______________. The system performance, including compatibility with interfacing subsystems, shall be evaluated by _____________. The effects of system malfunctions shall be evaluated by __________________.

4.2.4 Rolling components

4.2.4.1 Tires. Laboratory tests shall be conducted to evaluate the following requirements:

a. Takeoff, landing, and taxi performance

b. Retreading capability

c. Electrical conductivity

d. Overload capability

The service life shall be evaluated on the air vehicle during flight test. An analysis is required to show __________ growth potential in the selected tire sizes.

4.2.4.2 Wheels. Laboratory tests shall be conducted to evaluate the following requirements:

a. Takeoff, landing, and taxi performance

b. Service life

c. Wheel overheat capability

Design features shall be evaluated by inspection.

4.2.4.3 Brakes

Brake durability, operating characteristics and compatibility with interfacing subsystems such as _______ shall be evaluated by ________________. The 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.

4.2.5 Directional control system

4.2.5.1 General. Directional control performance requirements of the total system shall be evaluated on the air vehicle during flight test. Crosswind control limits shall be determined by analysis substantiated by flight test. Emergency directional control characteristics shall be evaluated as follows:

_________________.

4.2.5.2 Nose gear steering system. System performance and control characteristics shall be evaluated by an analysis and flight test. A formal demonstration of the steering system operation with the static air vehicle shall be accomplished to determine compliance with factors that can not be verified by flight test. Probability of system failure shall be assessed by a failure mode analysis and historical failure rate data. Critical failure modes shall be further evaluated by _________. Configuration design requirements including __________ shall be verified by inspection of engineering drawings and hardware.

4.2.6 Landing gear actuation

4.2.6.1 Retraction-extension system. Retraction-extension system operation and operating characteristics shall be demontrated by ____________. Limits of speed for retraction and extension shall be determined by analysis of flight test results. The effectiveness and limits of the emergency extension system shall be evaluated on the air vehicle during flight test.

4.2.6.2 Actuation system indication. The gear position indicator system and warning system shall be evaluated during flight test.

4.2.6.3 Retraction-extension time. Retraction and extension times shall be evaluated by a __________________________.

4.2.6.4 Position restraint. The adequacy of the landing gear position restraint shall be evaluated by ______________. Failure mode and effect will be determined analytically and further evaluated by ____________. The effectiveness and adequacy of the ground safety provisions shall be evaluated during flight tests.

4.2.7 Auxiliary deceleration devices

4.2.7.1 Arresting hook systems. 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 inspection. Service life of the hook shall be evaluated by laboratory tests for fatigue life and air vehicle tests for durability. The probability of successful engagement shall be determined by analysis of flight test results.

4.2.8 Ground handling

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

4.2.8.2 Towing. Performance of the towing system shall be demonstrated on the air vehicle during the flight test program.

4.2.6.3 Mooring. The air vehicle shall be moored to __________ during the flight test program. Design characteristics and component compatibility shall be evaluated.

4.2.9 Specialized subsystems

4.2.9.1 General. The __________ system shall be evaluated by __________.

4.3 Reliability. The reliability requirements of 3.3 are verified as follows: __________.

4.4 Maintainability. The maintainability requirements of 3.4 are verified as follows: __________.

4.5 System safety. The system safety requirements of 3.5 are verified as follows: __________.

4.6 Environmental conditions. Environmental testing shall be conducted to verify the requirements of 3.6 as follows: __________.

4.7 Interface requirements

4.7.1 Related systems. Characteristics of the landing gear system interface with other air vehicle systems shall be verified by __________.

4.7.2 Ground support equipment. The interface of the landing gear system with specified ground support equipment shall be evaluated by __________.

4.7.3 International standardization. Use of NATO or ISO standard parts shall be verified by __________.

5.0 Packaging

5.1 All deliverable items shall be prepared for shipment as directed by the procuring activity.

6.0 Notes

6.1 Responsible engineering office. The office responsible for development and technical maintenance of this document is ASD/ENFEM. Requests for additional information or assistance on this specification can be obtained from Mr. D.E. Williams, ASD/ENFEM, Wright-Patterson AFB, OH 45433; autovon 785-4156, commercial (513) 255-4156. Any information obtained relating to Government contracts must be obtained through contracting officers.

Custodians:
Air Force - 11

Preparing activity:
Air Force - 11

Project 1620-F106

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APPENDIX

LANDING GEAR SYSTEMS HANDBOOK

Rationale, Criteria Background, Lessons Learned,
Verification Requirements

10. SCOPE

10.1 Scope. This appendix contains the instructions that are necessary to tailor sections 3 and 4 of MIL-L-87139 for Landing Gear Systems for specific applications. The activity that has been designated the responsible engineering office for the specification is ASD/ENFEM, Wright-Patterson AFB, Ohio 45433. The individual who has been assigned the responsibility for this handbook is Mr. D.E. Williams, ASD/ENFEM, Wright-Patterson AFB, Ohio 45433, Commercial Telephone: (513) 255-4158, Autovon: 785-4158.

10.2 Purpose: This appendix provides information to assist the Government procurement activity in use of MIL-L-87139 and provides rationale, background for the criteria, lessons learned, and verification requirements to meet required performance and characteristics.

10.3 Use: This appendix is designed to assist the project engineer in tailoring MIL-L-87139. MIL-L-87139 contains blanks that must be filled in to meet operational needs of the equipment being developed. Sections 3 and 4 of this document parallel the MIL-L-87139 and indicate the type of data to be placed within the blanks.

10.4 Format: Section 3 provides the requirement as stated in MIL-L-87139, a Rationale which contains suggested wording or concepts for the blanks, and a discussion of the factors or parameters impacted or involved in the achievement of the stated requirement. Each item also contains a section on Lessons Learned, reflecting input from all available agencies. The Section 4 Verification, which applies directly to the Section 3 Characteristic or Requirement, is included in the discussion along with the Rationale, discussion on why this type of verification is best suited for the occasion. The appendix is prepared as a complete package for each Section 3 requirement. This permits addition or deletion of all the discussion of a single requirement as a package.

20. REFERENCE DOCUMENTS

The following documents are referenced in this appendix. Unless otherwise indicated, the reference is solely to provide supplemental technical data.

20.1 Government documents

Military

MIL-W-5013	Wheel and Brake Assemblies; Aircraft
MIL-T-5041	Tires, Pneumatic, Aircraft
MIL-T-6053	Tests, Impact, Shock Absorber, Aircraft

MIL-B-8075	Brake Control Systems, Antiskit, Aircraft Wheels, General Specification for
MIL-L-8552	Landing Gear, Aircraft Shock Absorbers (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, General Specification for
MIL-A-8862	Airplane Strength and Rigidity, Landplane Landing and Ground Handling Loads
MIL-A-8865	Airplane Strength Rigidity, Miscellaneous Loads
MIL-A-18717	Arresting Hook Installation
MIL-T-81259	Tie Down, Airframe Design, Requirements for
MIL-A-83136 (USAF)	Arresting Hook Installation
MIL-S-XXXXX	Structural Systems, Aircraft, General Specification for

STANDARDS

International

NAT-STD-3220	Location,Actvation, and Shape of Airframe
NAT-STANAG	Controls for Fixed Wing Aircraft

Military

MIL-STD-203	Aircrew station Controls and Displays for Fixed Wing Aircraft
MIL-STD-470	Maintainabillity Program Requirements (For Systems and equipments)
MIL-STD-471	Maintainabillity Demonstration
MIL-STD-621	Test Method for Pavement Subgrade, Subbase and Base Course Material.
MIL-STD-785	Reliability Program for Systems and Equipment Development and Production
MIL-STD-805	Towing, Fittings and Provisions for Fixed Wing Aircraft, Design Requirements for
MIL-STD-809	Adapter, Aircraft, Jacking Point, Design and Installation of
MIL-STD-810	Environmental Test Methods

MIL-STD-826	Electromagnetic Interference Test Requirements and Test Methods
MIL-STD-878	Method of Dimessioning and Determining Clearance for Aircraft Tires and Rims
MIL-STD-1566	Materials and Processes for Corrosion Prevention and Control in Aerospace Weapons Systems
MIL-STD-1587	Materials and Process Requirements for Air Force Systems

OTHER PUBLICATIONS

Manuals

Air Force

86-3	Planning and Design of Theater of Operations Air Base
86-8	Airfield and Airpace Criteria
88-6	Airfield Design

Handbooks

Air Force Systems Command

DH 2-1	Design Handbook 2-1, Airframe
80-1	Handbook of Instructions for Aircraft Design

Bulletin

ANC-2	Ground Loads

Reports

U.S. Air Force Aeronautical Systems Division

ASD-TR-68-4	Evaluation of Aircraft Landing Gear Ground Flotation Characteristics for Operation from Unsurfaced Civil Airfields
ASD-TR-70-43	Aircraft Grond Flotation Analysis Procedures - Paved Airfields
WADC TN55-1	Stability and the Elastic tire
WADC TR 56-197	Experimental Study of Moreland's Theory of Shimming

U.S. Navy, Naval Research Laboratory

Bulletin 39, Part 3 The Shock and Vibration Bulletin (January 1969)

20.2 Other documents

American Institute of Aeronautics and Astronautics

Volume 21, Number 12	Journal of the Aeronautical Sciences, December 1954

American National Standards Institute, Inc.

346.1	Surface Texture (Surface Roughness, Waviness and Lay)

(Application for copies should be addressed to American National Standards Institute, 1430 Broadway, New York, New York 10018.)

American Society of Civil Engineers

Vol 99, No. TE4	Transportation Engineering Journal of ASCE November 1973

(Application for copies should be addressed to American Society of Civil Engineers, 345 East 47th Street, New York, New York 10017)

Society of Automotive Engineers, Inc.

ARP 1107	Tail Bumpers for Piloted Aircraft

(Application for copies should be addressed to the society of Automative Engineerts, Inc., 400 Commonwealth Drive, Warrendale, PA 15096.)

30. REQUIREMENTS

The following sub paragraphs carry the same numerical identification as the paragraphs and sub paragraphs in the specification.

3.1 System Description. The Component Categories for the Landing Gear System are:

- Landing Gear System
- Landing Gear Structure
- Brake Control System
- Rolling Components
- Directional Control System
- Gear and Door Actuation System
- Auxiliary Deceleration Devices
- Ground Handling Functions
- Specialized Subsystems

3.2 Operating Requirements

3.2.1.1 Landing Gear System - General

3.2.1.1 - a "With the stated exceptions, the landing gear component service life shall be ________________."

Rationale and Guidance: Design life of the landing gear components is a significant driver of life cycle costs. This requirement is necessary to establish a minimum acceptable service life for design. This is to insure minimum cost but acceptable utility of the completed system.

The requirement should be stated in terms of the minimum acceptable number of landings or years of service. The anticipated utilization of the system must 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. This is logical for major structural components of the landing gear but not applicable to consumable components such as tires, brakes and fluid seals. Consumable components can be excepted from the requirement. Service life for consumable components can be defined in the section of this specification applicable to the components.

Performance Parameters:

Parameters which affect this performance requirement include operating environment, mission spectrum, scheduled maintainance overhaul skills, NDI methods, material selection, production processing, and protective finish systems. The life should be expressed in terms of fleet average life rather than the preformance of any single assembly.

Background and source of Criteria: This is a new requirement. An attempt is being made to quantify the most important characteristic of the landing gear system and its components, durability. In the final analysis, service life is the user's measure of success.

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

There are numerous examples of fatigue failures due to stress concentrations due to inadequate design. Emphasis must be placed on design details to avoid high K_T. Fatigue failures have occurred on virtually every landing gear in the inventory, including B52, B66, KC135, C130, C141, Century Series fighters, F4, F111, all trainers, and the A37. Careful attention must be paid to lug areas, holes, etc.

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 B52, KC135, C141, Century Series fighters, and F4. 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 which had high sustained stresses, such as outer cylinders which were pressurized. Stress corrosion failures with these alloys were not as prevalent when used as beam members in axial loading.

Many landing gear structural failures occur in overstressed parts. Examples of landing gears with overstress failures include virtually every air vehicle in the inventory. This appears to 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 must be reviewed for structural implications to avoid designed in deficiencies.

Numerous landing gear failures have been initiated by inadequate process and manufacturing control. Prime examples are the F111 pin failures stemming from damage due to grinding of the chrome plating.

Frequently, major components are lost from the inventory due to insufficient material to permit rework dictated by corrosion or wear. This consideration and allowance must 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.

Verification (Paragraph 4.2.1.1):

"The landing gear component service life shall be evaluated by ____________."

Verification Rationale: It is intended to verify this requirement in a manner consistent with the remainder of the structural verification program or by definition of a fleet service demonstration. If a structural demonstration is selected, a jig fatigue test will be conducted with suitable instrumentation to a negotiated test spectrum. A flight by flight spectrum is preferred over block spectrum. If a service demonstration is selected, the index site and method should by fully coordinated with AFLC.

Verification Lessons Learned:

3.2.1.1 Landing Gear System - General

3.2.1.1 - b "The landing gear shall have ground flotation capability to permit the air vehicle to ____________________."

Rationale and Guidance: The purpose of this requirement is to insure that the load that the air vehicle applied to the airfield is compatible with the bearing strength of the airfield surface. Details of the requirement are very dependent upon the air vehicle mission and basing concepts. The primary consideration for a large cargo air vehicle, for example, might be to insure ability to operate on existing commercial jet air vehicle airfields without causing an unacceptable rate of pavement deterioration. Tactical cargo and fighter air vehicle, on the other hand, may need to be designed to perform a specified mission on an unpaved airfield. 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 must be expanded to include the significant engineering parameters. The exact wording must be tailored for each system using the following parameters.

Performance Parameters.

Air vehicle Gross Weight Condition
Air vehicle Center of Gravity Position
Type of Airfield Surface (Paved or Unpaved)
Strength of Airfield Surface
Level of Operation (Frequency or Total Number)
Tire Operating Limits

Background and Source of Criteria: Flotation criteria was previously identified in AFSC DH 2-1.

Lessons Learned: Air Vehicle Conditions: In the case of paved airfields, it is usually best to specify the maximum gross weight that will be used for ground operation. Center of gravity position may not be too critical for paved airfields, however, specification as nominal or average or most critical makes the requirement more exact. The gross weight and center of gravity specified for unpaved airfield operation will usually be specified in terms of a specific mission condition. A specific weight (pounds, etc.) should no be specified.

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

Strength of Airfield Surface:

Paved Airfields - Possible approaches to this paramenter include the following:

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

b. Analyze the pavement evaluation reports of airfields to be used and develop a single chart to summarize most critical pavement characteristics. This has the same disadvantage as "a" but has an advantage in that it avoids the necessity for the Air Force to positively identify 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. Use ASD-TR-70-43 to develop the chart. This approach has been used successfully. Although less exact, it permits establishment of a requirement without knowledge or examination of the exact airfields to be used.

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

e. Specify the minimum Load Classification Number (LCN) of airfields to be used. The LCN method is an index approach used in many foreign countries to match air vehicle loading to airfield strength. Administrative limits prohibiting operation of air vehicle with LCN exceeding the airfield LCN are common. If the air vehicle is to be used extensively on airfields under foreign control, the LCN of the airfields to be used should be reviewed and an appropriate LCN specified. A detailed description of LCN can be found in ASCE Transportation Engineering Journal, November 1973, page 785. The U. S. Army Corps of Engineers does not recognize the LCN approach as a valid method of pavement strength rating. Caution is advised in use of only the LCN approach if the air vehicle is to be oprated in both foreign and U. S. military airfields.

Unpaved Airfields:

a. The strength of unpaved airfields is usually expressed in terms of California Bearing Ratio (CBR). CBR is defined and measured in accordance with MIL-STD-621. The U. S. Army Corps of Engineers recommends use of a CBR 4 for design because this is the minimum strength that is suitable for airfield construction. This concept assumes that an area will not be used for air vehicle operation unless it is suitable for operation of airfield construction equipment. Recently, joint Army/Air Force operational analysis has indicated that CBR 6 is a more practical limit to opration. A CBR 9 was used for C-5A 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 accurately predict landing mat performance to repeated landing.

b. An alternative to specification of CBR is to use a cone penetrometer reading known as Airfield Index (AI). CBR measurement is a tedious process not practical for extensive measurements during air vehicle test on unpaved surfaces. AI measurements can be made rapidly. Consequently, nearly all air vehicle test data is presented in terms of AI rather than CBR. AI and CBR correlation varies from soil to soil. This is because CBR is a measure of confined bearing strength of soil, whereas AI is a measure of bearing strength plus soil cohesion. Figure 3.2.1.1-b-1 is a generalized correlation curve of AI/CBR, but should be used cautiously in analysis of test data and establishment of requirements. 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.

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

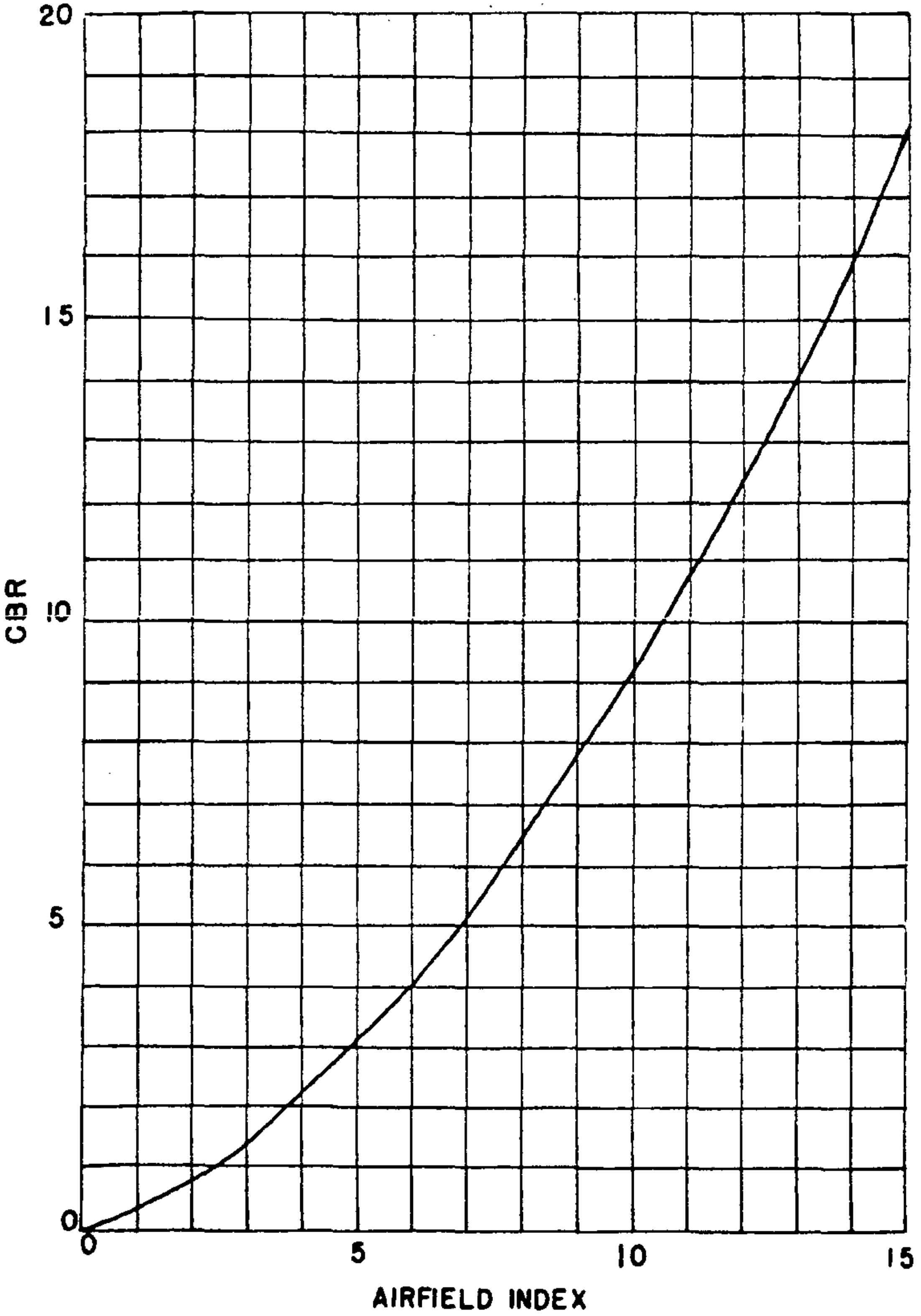


FIGURE 3.2.1.1.b-1. Airfield index.

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.

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 (underinflation). 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 forty per cent deflection. This must 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. Enroute deflation to permit use of low pressure at the destination was applied to the C-5A air vehicle. This approach is not recommended because it adds excessive complexity to landing gear and wheels.

Verification (Paragraph 4.2.1.1): "The flotation characteristics shall be evaluated by ______________."

Suggested wording: "Analysis using the procedures contained in ASD-TR-70-43 for paved airfields and ASD-TR-68-34 for unpaved airfields." or "Analysis in accordance with the LCN procedure of ASCE Transportation Engineering Journal, November 1973."

Verification Rationale:

The precedures contained in the referenced documents were developed over a period of several years and included coordination with airframe contractors. They represent standardized procedures rather than technically exact procedures. Basis for the procedures are results of US Army Corps of Engineers test of pavement and soil sections. All tests were accomplished at low speeds with ground carts. The failure criteria for paved airfields is surface cracking. The failure criteria for unpaved airfields is three inches of permanent rutting. All tests on unpaved surfaces were accomplished by straight rolling of an unbraked wheel.

The rigid pavement procedures of ASD-TR-70-43 evaluates 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% greater than the method used by ASD-TR-70-43. This increase is somewhat offset by assumption of level transfer to adjacent concreate 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.

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

Verification of flotation should be accomplished by submitted results of analysis with the original proposal. The complete analysis should be accomplished within 90 days of contract award and updated as necessary, as air vehicle design changes cause significant changes in flotation characteristics.

Verification Lessons Learned:

3.2.1.1 Landing Gear System - General

3.2.1.1 - c "The landing gear shall meet the requirements of this specification during and after operation of the air vehicle on surfaces with the following roughness characteristics: ____________________."

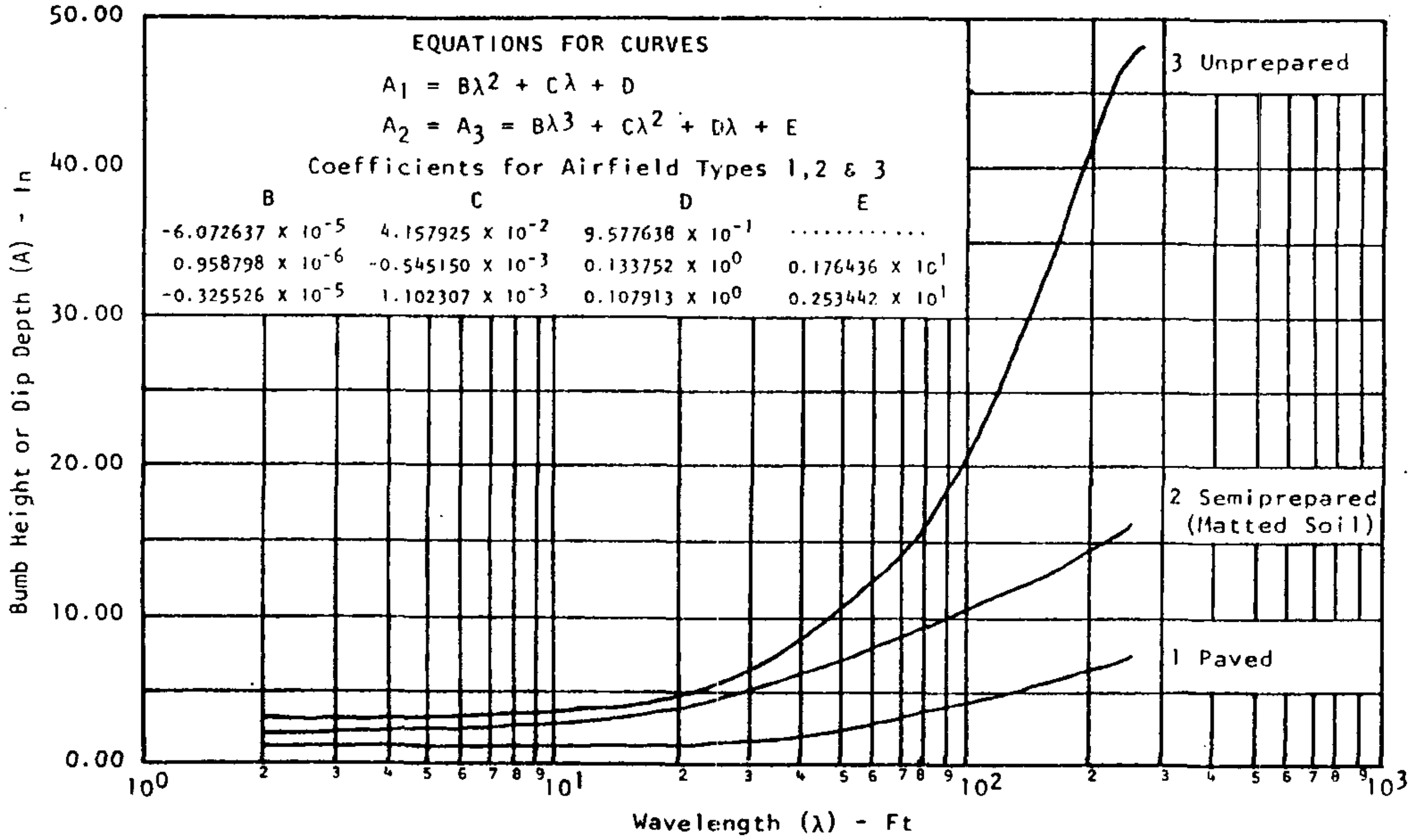
Rationale and Guidance: The roughness of the surfaces to be used by the air vehicle is a major consideration in design of the landing gear. In all cases it provides the input for design of landing gear response to control ground loads to a level to provide the required air vehicle life. In the case of operation on unpaved airfields, it may also establish limits on landing gear arrangement and tire size to ensure that the air vehicle is not immobilized by the specified roughness.

Two aspects of roughness need to be specified. The first is discrete bump or dip criteria that establishes the maximum roughness to be encountered. The second is the frequency of occurrences of the various levels of 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.

Figure 3.2.1.1.c-1 Provides criteria for discrete bumps and dips. 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.

Performance Parameters: Performance parameters include gross weight, ground speed, lift characteristics and frequency of operation on unpaved airfields.

Background and Source of Criteria: This requirement was previously stated in MIL-A-008862. The criteria is based on airfield roughness surveys conducted by the Air Force Flight Dynamics Laboratory in the early 1960's.



EQUATIONS FOR CURVES

$A_1 = B\lambda^2 + C\lambda + D$

$A_2 = A_3 = B\lambda^3 + C\lambda^2 + D\lambda + E$

Coefficients for Airfield Types 1,2 & 3

B	C	D	E
-6.072637×10^{-5}	4.157925×10^{-2}	9.577638×10^{-1}	....
0.958798×10^{-6}	-0.545150×10^{-3}	0.133752×10^{0}	0.176436×10^{1}
-0.325526×10^{-5}	1.102307×10^{-3}	0.107913×10^{0}	0.253442×10^{1}

Figure 3.2.1.1.c-1

Lessons Learned:

(Verification (Paragraph 4.2.1.17))

"Performance during and after operation on surfaces of specified roughness shall be evaluated by ________________."

Verification Rationale and Guidance: 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 Lessons Learned: 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/dip wavelength critical for one design will not be critical for another.

Several simulated rough surfaces have been constructed at Edwards 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 AFPR at the Lockheed-Georgia Company should be contacted concerning availability of these surfaces.

3.2.1.2 Landing Gear System - Arrangement

3.2.1.2 - a "The landing gear shall be arranged so that the airframe structure will not contact the ground during a ground turn producing ________________ lateral acceleration at the most critical operational c.g. configuration."

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

The requirement 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.

It may be necessary to expand this requirement to adequately define overturn stability for VTOL aircraft. Side load during landing of VTOL aircraft may exceed that normally encountered during ground turns. Ground runup of helicopters may also present an overturn stability problem. It is suggested that the following words be used: "The landing gear shall also be arranged to prevent overturn during ground run-up of engines and during landing under the following conditions _________." 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, c.g. location and strut-tire dynamic characteristics.

Background and Source of Criteria: The concept for this requirement comes from AFSC Design handbook DH2-1, and is described as turnover angle. Rather than identify a limit on turnover angle, the requirement is expressed in air vehicle performance. The 63° turnover angle limit in DH 2-1 was established to provide approximately a .5g side load turning capability. This requirement was originated in 1950 or earlier. It should be noted that meeting the 63° limit does not assure a .5g turn capability due to shock strut and tire deflection.

Lessons Learned: Generally, the criteria applied at .5 g side load is 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.

Figure 3.2.1.2.a-1 relates lateral acceleration to speed and radius of turn. Figure 3.2.1.2.a-2 provide the estimated capability of several current air vehicles.

Air vehicle turning capability may be degraded by increased gross weight. During design of new air vehicle, consideration should be given to growth potential.

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.

FIGURE 3.2.1.2.a-1. Air vehicle turning capability

Air Vehicle	Gross Weight	Center of Gravity	Acceleration to Overturn
A-7			
A-10			
A-37			
B-52			
C-5			
C-7			
C-123			
C-130			
C-135			
C-141			
F-4			
F-5			
F-15			
F-16			
F-100			
F-105			
F-106			
F-111			
T-37			
T-38			
T-39			

Figure 3.2.1.2.a-2

Verification (Paragraph 4.2.1.2):

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

Verification Rationale:

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 is 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 Lessons Learned:

3.2.1.2 Landing Gear System - Arrangement

3.2.1.2 - b "The landing gears shall be arranged to provide pitch stability such that safe air vehicle ground control is maintained and no part of the air vehicle, other than the landing gear, contacts the ground under the following conditions: ____________________."

Rationale and Guidance: The most aft center of gravity must 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. This requirement includes conditions during engine run-up and during cargo handling. In the event the air vehicle design permits c.g. excursions which preclude meeting this criteria, provisions must 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.

Performance Parameters: Air vehicle c.g. location, fore and aft pitch characteristics, aerodynamic tail power during takeoff rotation, strut-tire dynamic characteristics, and aft fuselage design.

Background and Source of Criteria: 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 c.g., main wheel contact, and the vertical must be at least as large as the maximum tail down landing contact angle, limited by fully extended wheel contact and the tail bumper or aft fuselage. The intent was to try to insure that the air vehicle would rotate to a three point attitude upon contact with the ground. It was arbitrary criteria satisfied by geometric analysis.

Lessons Learned: Since the F111 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 F111B, aboard ship.

A classic example of critical c.g. 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 c.g. and the center of main gear contact with a vertical line through this contact is 15° with a most aft c.g. configuration.

Verification Paragraph 4.2.1.2)

"Pitch stability shall be verified by ____________ for the following conditions: ________________."

Verification Rationale:

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 Lessons Learned:

3.2.1.3 Landing Gear System - Clearances

3.2.1.3 - a "Clearances shall be provided so that the landing gear in the position for landing, and during any phase of the air vehicle 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: ________________________."

Rationale and Guidance: Experience has shown that failure to provide adequate clearance between movable parts of the landing gear and fixed structure will result in operational problems. Design of the aircraft 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.

Performance Parameters: Requirement influenced and controlled by: tire growth characteristics, strut physical dimensions, tire production dimensional tolerances, and gear kinematics.

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

Lessons Learned: In past designs, it has been determined that is is good design practice to leave clearance between the wheel, brake, and tire assemblies and the support structure or fairings. It was found best to leave clearances particularly around the tire to accommodate growth, maximum production tolerances, and centrifugal forces for rotating tires. Special consideration must be given to installations utilizing a fork. Prime examples are the F-4 and F-105. Figure 3.2.1.3.a-1 shows a reasonable criteria for design. Many aircraft have little or minimum clearance for the landing gear. Prime examples are B58, F111, F15, EF111 and other high density aircraft.

Verification (Paragraph 4.2.1.3):

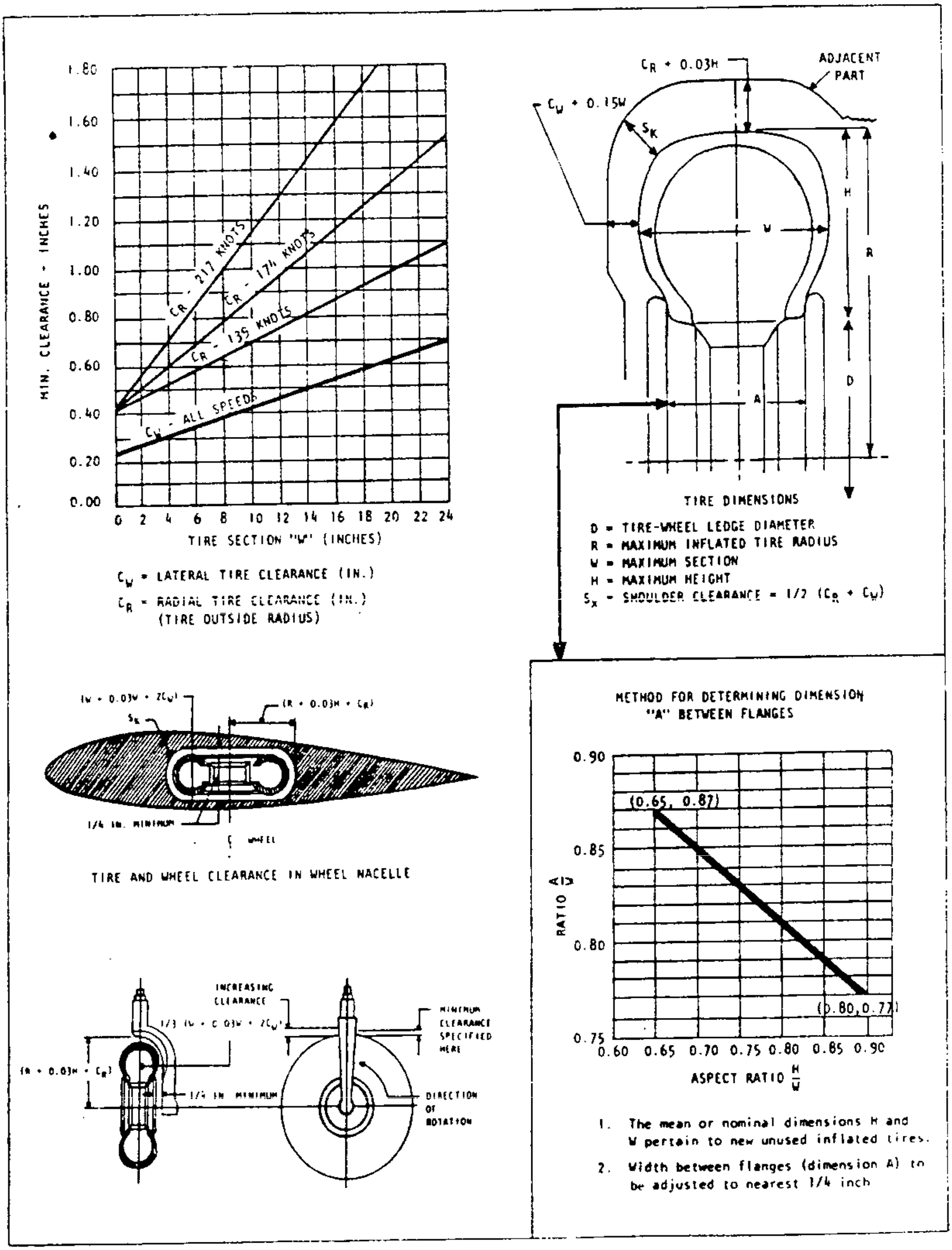
"Clearances between the landing gear and other air vehicle components shall be verified by ________________."

Verification Rationale: The method of verification will depend on the program. If a simulator is available, it may be suitable for verification of clearances. Measurement on the air vehicle will usually be required.

Verification Lessons Learned:

3.2.1.3 Landing Gear Systems - Clearances

3.2.1.3. - b "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



C_W = LATERAL TIRE CLEARANCE (IN.)

C_R = RADIAL TIRE CLEARANCE (IN.)
(TIRE OUTSIDE RADIUS)

D = TIRE-WHEEL LEDGE DIAMETER
R = MAXIMUM INFLATED TIRE RADIUS
W = MAXIMUM SECTION
H = MAXIMUM HEIGHT
S_x = SHOULDER CLEARANCE = 1/2 (C_R + C_W)

1. The mean or nominal dimensions H and W pertain to new unused inflated tires.
2. Width between flanges (dimension A) to be adjusted to nearest 1/4 inch

FIGURE 3.2.1.3.a-1

fairing doors, that results in degradation of life or performance of any air vehicle component. This requirement applies with the following conditions or restrictions: ______________________."

Rationale and Guidance: This is a further expansion of 3.2.1.3 -a to insure no interference between the landing gear components and the stationary structure or adjacent wheel well equipment. The blank should be filled out to reflect the speed, temperature, altitude, operating condition of tires (stationary or rotating, etc.), aircraft speed, operating mode of the aircraft (takeoff, touch and go), aircraft attitude, etc. It should consider malfunctions such as a flat strut, etc.

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

Background and Source of Criteria: This is a further expansion of the basic clearance requirements of 3.2.1.3-a. There are numerous conditions which potentially cause interference. It is a new requirement and is not generally found in previous documentation.

Lessons Learned: 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 F15 is a rcent example which required aircraft modification.

The C5A 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 assist in preventing these incidents from occurring.

Verification (Paragraph 4.2.1.3):

"Clearances between the landing gear and other air vehicle components shall be verified by ___________________."

Verification Rationale: If a simulator is provided it may be suitable for verification of clearances. Verification on the air vehicle will usually be required.

Verification Lessons Learned:

3.2.1.3 Landing Gear System - Clearances

3.2.1.3 - c "_____ wheels shall be stopped from rotating during retraction or prevented from rotating in the retracted position."

Rationale and Guidance: 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. Normally all wheels should be stopped. In some cases it may be cost effective to stop only the main wheels. Fill the blank with "All" or "main".

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

Background and Source of Criteria: This requirement reflects the statement made in AFSC DH 2-1. It was originally included in ARDCM 80-1 (HIAD) as a result of fleet retrofit of the C133 from trouble generated from free-rotating design.

Lessons Learned: In addition to the C133 mentioned above, several other air vehicle 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 has generally not been any 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.

Verification (Paragraph 4.2.1.3):

"Demonstration, that the wheels do not rotate in the retracted position shall be shown by _______________."

Verification Rationale: If snubbing of all or some of the wheels is required, this requirement must be completed to provide for verification. The method of verification must be specified. 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 Lessons Learned:

3.2.1.3 Landing Gear System - Clearances

3.2.1.3 - d "In the event of flat tire and flat strut, the lowest part of the landing gear, door fairing, or air vehicle components, including external stores shall not ________________."

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

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

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

Lessons Learned: With the extensive use of arresting systems within the Air Force, most runways are equipped with arrestment cables at the ends of runways. Some runways also have midpoint barrier installations. Therefore, it is very important to not have a rigid member of the air vehicle extending low enough to engage the barrier cable in the event of a flat tire and/or a flat strut. The YF16 was designed with a gear member extending low enough to engage the cable with a flat tire. This resulted in an incident causing significant damage. Six inch ground clearance under these circumstances should be a target for design.

Verification (Paragraph 4.2.1.3):

"Ground clearance after tire failure and strut deflation shall be determined analytically."

Verification Rationale:

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 Lessons Learned:

3.2.1.4 Landing Gear System - Damping

3.2.1.4 - a "All landing gears shall have natural or augmented damping so that the amplitude of any landing gear oscillations after ______ cycles is reduced to ________ or less of the original disturbance, with the following exceptions: ________________. The damping requirement applies to all initial displacements of the landing gear under the following conditions:____."

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

It is recommended that the statement be completed by requiring that the amplitude be reduced to 1/3 of the original amplitude within 3 cycles. This has been recognized as a standard by the airframe industry for damping of steered landing gear. Suitability for other oscillations has not been verified.

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

The fourth blank is 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, wear surfaces worn to the operational limit, etc.

Performance Parameters: Gear damping characteristics are controlled by tire dynamics characteristics, landing gear component stiffnesses and damping characteristics, individually and "as installed." If friction damping is utilized, wear of the friction surfaces must be assumed and accounted for in the design. Air vehicle ground speed range defines the range of concern.

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

Lessons Learned: Shimmy and various forms of gear vibration have historically been a serious landing gear problem. Nose gear shimmy has been a problem on the A37, T30, F-5, F104, F15, C141A, and numerous other air vehicle. Solution of the problems include change of tires, balancing tires, adding friction dampers, changing hydraulic dampers, improving maintenance and servicing procedures, changing materials, etc.

There is industry evidence that main gear shimmy is most likely on dual wheel installations. A couple of commercial air vehicle 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 phenomenon, but the damping criteria proposed may not necessarily apply. The source of the vibration is the brake assembly. Therefore, system response and compatibility is a function of design of that component. See "Aircraft Landing Gear Brake Squeal and Strut Chatter, Investigation" by F.A. Biehl, The Shock and Vibration Bulletin, January 1969 for an explanation of the phenonenon and a method of analysis.

Verification (Paragraph 4.2.1.4):

"Landing gear system damping shall be determined analytically and substantiated by __________.

Verification Rationale:

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 estimatd and the analysis must 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 Lesson Learned:

3.2.2 Structure

3.2.2.1 Structure - General

3.2.2.1 - a "Landing gear structure shall be designed in accordance with _____, except as modified by _______________.

Rationale and Guidance: Since the structural modes of failure for major landing gear components are the major modes of failure, the objective of the requirement is to identify the criteria for design. It is assumed that a structural criteria document will be generated for the intended system, tailored from MIL-S-XXXXX structural design general military specification in the same manner that the landing gear criteria is generated. The blank should reflect the selected criteria document for the system at issue.

Performance Parameters: Intended operating environment, intended usage and factors of safety are major concerns. Landing characteristics, taxi responses, ground handling characteristics are the areas of load generation. Stress analysis and structural tests are methods of technical assessment.

Background and Source of Criteria: Unless the Definition portion of this specification contains specific items applicable to the system involved, the definitions of weight, speed, and configurations of the System Structural Design criteria shall govern. These definitions came primarily from MIL-A-8860. The discrete loading conditions of MIL-A-008862 (USAF), MIL-A-8865 generally compromise the ground loads criteria. Some of these requirements date back to ANC-2 and their origin is not known. Some of the more recent requirements, such as dynamic loads in terms of discrete bumps or PSD criteria, are the result of the Air Force Flight Dynamics Laboratory research into the field.

Lessons Learned: Frequently, there are special missions for design of various systems. The landing gear handware is very sensitive to operational environments. For example, if bare soil operation is intended, the special configurations impact the design loads and other gear characteristics. Therefore, mission definitions and configurations become important considerations. They may require specific landing gear configuration design mission definitions.

Runway roughness has a significant impact on landing gear design. Every effort should be made to resolve this design criteria early in the system evolution. It can impact gear approach and location (articulated versus cantilever).

Verification (Paragraph 4.2.2.1):

"Review of the structural design criteria and component material and process selection shall be included in ______________."

Verification Rationale:

This review, as pertaining to landing gear design, is achieved early in the system development and is a continuous process throughout the program. This interface is probably as important as any in this system. The blank should reflect the system decisions for the total structure.

Verification Lessons Learned:

3.2.2.1 Structure - General

3.2.2.1 - b "Material selection shall be made in accordance with MIL-STD-1587 and corrosion control established in accordance with MIL-STD-1568, except as modified by ________________."

Rationale and Guidance: Frequently it will be necessary to tailor these standards for specific applications. The statement should be completed by reference to the document used to tailor the standards.

Performance Parameters: 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.

Background and Source of Criteria: The material selection methods and corrosion control plans idntified in MIL-STD-1587 and MIL-STD-1568 are a compilation of experience and lessons learned by the Air Force Materials Laboratory and the ASD/Industry counterparts. They were evolved as AFML 70-7, "Do's and Don'ts of Materials Application." This unofficial documentation has been directly inserted in several recent development programs System Specifications. It reflects much of the experience of the landing gear industry and lessons learned on landing gear service difficulties. Much of the criteria were contained in specification MIL-L-8552, Amendment 1. These reflect ASD/Ogden ALC Task Group lessons learned.

Lessons Learned: There have been many lessons learned in landing gear material and processes. Ogden ALC personnel have 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:

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

- 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.

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

-Many parts are received with forging laps, inclusions, etc, that were in the part at time of manufacture. These defects may not be detrimental to the service of the part; however, when the part is magnetic particle inspected at depot after service, inspectors cannot determine that these indications are forging laps and not fatigue cracks and, therefore, the part may be rejected.

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

- All joints should be bushed to facilitate depot rework.

- Considerable number 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 and/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.

- All surfaces, except holes under 3/4 inch in diameter, of structural forgings forged from stress-corrosion susceptible alloys which, after final machining, exhibit transverse grain exposed in the surface, shall be shot peened or placed in compression by other suitable means.

- 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 ASTM B 46.1, or should be shot peened, with a surface roughness prior to peening of not over 125 rhr. Unmachined aluminum die forgings should be approximately 250 rhr, except surfaces where flash has been removed.

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

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

Verification (Paragraph 4.2.2.1):

"Review of the structural design criteria and component material and process selection shall be included in ___________________."

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

Verification Lessons Learned:

3.2.2.1 Structure - General

3.2.2.1 - c "In the event of a flat tire or a depressurized shock absorber, the gear shall be capable of _________________ without structural damage to the gear or the air vehicle."

Rationale and Guidance: 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. The material inserted into the blank should describe an average landing condition. For example, a design landing could be a landplane landing gross weight air vehicle landing at 6 feet/second vertical contact velocity. It will also be necessary to identify ground handling limits which might be expected under these conditions, such as, maximum landing weight taxi for 20,000 feet at 30 mph and .2 g turns.

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

Background and Source of Criteria: 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-A008862 (USAF) for flat tire design load conditions. Dating back to ANC-2, there has been a requirement for design strength, but only an implied operational capability which has never been demonstrated.

Lessons Learned: 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.

Verification (Paragraph 4.2.2.1):

"Landing gear energy absorption performance with a deflated strut or flat tire shall be verified by ________________."

Verification Rationale: 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 analyis of the condition is the least that can be expected.

3.2.2.1 Structure - General

3.2.2.1 - d "Where joints and wear surfaces are required, they shall have material for rework by _______________."

Rationale and Guidance: 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 requiremnt results in high operating cost because expensive landing gear forgings must be replaced when contact surfaces are corroded or worn out of tolerance. Landing gear functional and structural requirements do not insure that parts can be refurbished. It is usually to the contractors advantage to provide little if any rework capability.

The requirement should usually 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.

This requirement is primarily intended to present scrapping of major landing gear forgings due to normal wear and corrosion. Small linkage parts that are more economical to replace than repair should be excluded from the requirement. A suggested statement is: "This requirement shall not apply to any component such as small linkage parts that are more economical to replace than repare.

Background and Source of Criteria: This requirement is intended to reflect to 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.

Lessons Learned: There are numerous air vehicle which have experienced wear in the joints. Examples would include KC135 bushed axle and beam, B-52 pistons, C141 axle bogie beam fretting, etc. Therefore to save the expense of repair and/or replacement, it is vital to allow enough material for rework.

Joint designs have proved to be extremely critical in maintaining hardware in the fleet. Lessons learned include use of positive lubrication for all joints, static and dynamic. All joints should be bushed. Avoid all pressed fit or matched fit joints. These features have contributed to great cost at the depot level during overhaul. They should be considered in the original design recognizing the service life commitment of paragraph 3.2.1.1 a.

Commercial airline usage has made extensive use of lubrication and replacable bushings to achieve extended us of major landing gear components. It is impossible to legislate against corrosion or wear; you can only design for minimized detrimental effects.

Extreme difficulty has been encountered in the use of keyways and threaded parts on the B52. These have been the source of stress concentration and has resulted in numerous field failures from fatigue cracking.

Verification (Paragraph 4.2.2.1):

"Provisions for rework at joints and wear surfaces shall be evaluated by inspection of engineering drawings and analysis."

Verification Rationale: Close engineering monitorship of design details during the development program is the only effective means of transfer of lessons learned. The source of these lessons learned come from Using Commands, Ogden ALC, and ASD engineering monitors.

Verification Lessons Learned:

3.2.2.1 Structure - General

3.2.2.1 - e "In the event of landing gear structural failure, no landing gear component shall ____________."

Rationale and Guidance: This requirement is to establish limits on structural failure modes to minimize secondary effects.

The requirement should be completed by a statement of applicable 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 shall be assumed that failure occurs during takeoff or landing and that landing gear loads are acting in the upward and aft directions."

Performance Parameters: Gear geometry is the most significant factor in this requirement.

Lessons Learned: 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 must 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 F89 and commercially on the 747. Subsequent redesigns have corrected these modes of failure.

There was an incident with the KC135 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 which struck the fuel tanks and caused fires. However, with proper precautions and cautions this problem has been minimized.

Verification (Paragraph 4.2.2.1):

"Component performance during landing gear structural failure shall be evaluated analytically."

Verification Rationale: By analysis, all conceivable modes of failure can be assessed. The cost and risk are too high to prmit evaluation by test or demonstration. Analysis permits a wide variety of options to be studied and evaluated.

Verification Lessons Learned:

3.2.2.2 Structure - Shock Absorbers

3.2.2.2 - a "The landing gear system shall absorb sufficient energy of landing such that ____________________ is not exceeded under the following conditions: ____________________."

Rationale and Guidance: This requirement is to establish shock absorber performance without any failure, to be identical to structural load criteria defined in the system structural criteria documents. Normally, these requirements are established as 10 feet/second sink speed at landplance landing weight and 6 feet/second at maximum landing weight. If special system design conditions exist, they should also be reflected in these performance requirements as an addition to this criteria. In the past, a reserve energy criteria of 12.5 feet/second sink speed at landplane landing weight was imposed, with minor failures permitted. This represents a 50% margin in energy capacity since the velocity function is squared in calculating the absorbed energy.

Performance Parameters: Metering Pin-orifice combination and gear mechanical design to prevent leakage are the most influential parameters. Aerodynamic characteristics controlling rate of sink and air vehicle flare characteristics control the probability of encountering these design conditions.

Background and Source of Criteria: The sink speed or vertical energy requirements for shock absorber and landing gear design are currently defined in MIL-A-008862 (USAF). 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.

Lessons Learned: Recent examples of special consideration of sink speed included C5A and AMST. The C5A 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.

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.

Verification (Paragraph 4.2.2.2):

"Landing gear shock absorption performance shall be evaluated by _______ ______."

Verification Rationale: Normally, this requirement is satisfied by demonstration during a jig drop test. The test not only assess the ability to absorb the vertical energy, they also serve the purpose of evaluation of rebound and other dynamic characteristics.

There are several air vehicles which 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 Lessons Learned:

3.2.2.2 Structure - Shock Absorption

3.2.2.2 - b "The landing gear system shall provide a ride such that the vertical accelerations at the pilot's station shall not exceed ________ on a ________ runway under the following conditions: ____________________."

Rationale and Guidance: Objective of the requirement is to establish quantitative ride quality requirements which can be verified. Runway roughness has long been recognized as impacting the peak design loads and the fatigue life of the basic airframe structure. Ride quality relates to pilot comfort and his ability to function in the cockpit dynamic environment induced by ground loads and aircraft response.

The blanks should be filled by insertion of the acceleration levels recommended by aeromedical personnel and the required runway surface. Runway surface roughness must be specified in detail. The third blank should be filled with air vehicle weight and speed conditions or ranges that must be considered. Detailed trade studies may be required to determine the most cost effective combination of requirements.

Performance Parameters:

Fuselage stiffness, strut air-oil characteristics, internal strut damping and fluid flow, landing gear arrangement, and runway roughness.

Background and Source of Criteria: This is a new requirement. 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 funtions. Air crew physical comfort must also be considered.

Lessons Learned: 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 F-111 uses dual pistons but has a single air chamber. It has been a relatively good performer in the field.

Verification (Paragraph 4.2.2.2):

"Ride quality performance shall be evaluated analytically and substantiated by flight test."

Verification Rationale: 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 Lessons Learned:

3.2.2.2 Structure - Shock Absorption

3.2.2.2 - c "The landing gear subsystem shall be designed for, and specify the use of charging agents which will not cause corrosion nor support combustion."

Rationale and Guidance: Rather than dictate a charging agent, this requirement is presented to reflect the desired performance and characteristics. The industry standard to meet this requirement is nitrogen and it will exclude the use of air.

Performance Parameter: Material selection, protective finishes and internal shock absorber design are the parameters which control or influence the ability to meet this requirement. The available type of servicing equipment will dictate whether the requirement can be met.

Background and Source of Criteria: There have been sufficient number of military and commercial shock absorber failures caused by internal corrosion and explosive failures, whether caused by design or maintenance practices to direct requirements which will reduce the probability of occurrence. This requirement does not reflect a current requirement in any Air Force documentation.

Lessons Learned: In the past, most shock absorbers have been the air-oil type with the cylinder being charged by high pressure bottled air. The difficulty which was encountered was the introduction of moisture and the resultant corrosion. There always was the threat of oxygen support for combustion, even though such incidents were extremely rare.

Recent maintenance and design practices have been to use dry nitrogen. The use of nitrogen retards corrosion and explosion tendencies. The airlines were leaders in the use of this charging agent.

Verification (Paragraph 4.2.2.2): "Design features shall be evaluated by inspection."

Verification Rationale: Review of design drawings and continual monitoring of the development are adequate to determine compliance with this requirement.

Verification Lessons Learned:

3.2.2.2 Structure - Shock Absorption

3.2.2.2 - d "The following types of shock absorber servicing shall be accomplished without removal of the shock absorber from the air vehicle or jacking of the complete air vehicle: ________________."

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

It is suggested that the following be required as a minimum: "gas charging, oil replacement and inspection for proper servicing."

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

Background and Source of Criteria: This requirement was previously contained 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.

Lessons Learned: 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 to insure that line maintenance personnel accomplish the required functions.

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

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

Verification (Paragraph 4.2.2.2): "Other performance characteristics of the shock absorber, such as ____________, shall also be demonstrated..... Design features shall be evaluated by inspection."

Verification Rationale: 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 Lessons Learned:

3.2.2.2 Structure - Shock Absorption

3.2.2.2 - e "The shock absorber shall be capable of performing its required function within ______________ after positioning for landing."

Rationale and Guidance: Unless care is exercised in design, the internal shock absorber chamber arrangement can impede fluid flow. Assemblies with this characteristic have difficulty in performing the basic energy absorption function upon extension if they have been stowed with the centerline above horizontal and the fluid is required to flow from chamber. The purpose of this requirement is to establish a time limit consistent with system needs for fluid flow between chambers to insure proper metering during energy absorption. The consequences of improper flow are foaming improper metering, cavitation, etc. 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 identifiable.

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

Lessons Learned: Fluid flow between chambers should be carefully considered in the internal strut design. The following air vehicles have struts stowed with the centerline above the horizontal:

Review of the design details for these applications should give insight to proper internal design.

Verification (Paragraph 4.2.2.2): "Other performance characteristics of the shock absorber, such as _______________, shall be demonstrated."

Verification Rationale: 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 Lessons Learned:

3.2.2.2 Structure - Shock Absorption

3.2.2.2 - f "The shock absorber shall not prevent accomplishment of successive ____________ landings with __________ between landings."

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

Performance Parameters: Strut foaming characteristics, fluid level, and drainage characteristics are parameters influencing this requirement.

Background and Source of Criteria: This performance characteristic was previously identified in MIL-T-6053. It represents a condition which 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 precess, 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.

Lessons Learned: There are various circumstances which affect the metering characteristics of a gas-oil shock absorber. Included among these are: The ability to recirculate the oil, rebound characteristics of the strut, and temperature. Recirculation and rebound are a function of Internal design and the temperature impacts the air curve from which the taxi loads are determined. Higher temperature will result in noticeable load increases. The source of temperature increase can be ambient and internal friction.

Verification (Paragraph 4.2.2.2): "Other performance characteristics of the shock absorber, such as ______________, shall be demonstrated."

Verification Rationale: The laboratory drop test is the best method of demonstrating this requirement because the exact conditions 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 Lessons Learned:

3.2.2.2 Structure - Shock Absorption

3.2.2.2 - g "Friction characteristics of the shock absorber shall not cause ____________________."

Rationale and Guidance: This requirement is intended to minimize operational problems due to high mechanical friction of the shock absorber. Mechanical friction is normally not too critical to meeting of design landing conditions or dynamic taxi response characteristics. It may however 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. As a minimum the requirement should say: "adverse effects in shock absorber servicing, air vehicle landing and taxi, and mission loading or unloading." 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.

Performance Parameters: Air Vehicle arrangement, landing gear arrangement, shock strut function, external stores requiremets.

Background and Source of Criteria: This is a new requirement. It was suggested as a result of operationsl problems on A-10 and F-15 aircraft.

Lessons Learned: Static strut function on the A-10 aircraft 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 assymmetric loading presented the other strut from stroking for several seconds. During this time the aircraft ground rollout was in a skewed attitude adversely affecting control.

Verification: (Paragraph 4.2.2.2)" Other performance characteristics of the shock absorber, such as ______________, shall be demonstrated."

Verification Rationale: This requirement is best met by careful analysis and design. except for some bearing 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. The blank should include "friction characteristics". In some cases specific tests such as weapons loading, fueling or servicing may be specified in detail to verify the function characteristics.

Verification Lessons Learned:

3.2.2.3 Structure - Tail Bumpers

3.2.2.3 - a "The tail bumper, if used, shall incorporate the following features: ____________________."

Rationale and Guidance: There are numberous design features that are optional on a tail bumper. Each affects the design cost. If the Using Command has a preference on these features, they should be expressed before a contracted development is finalized. Special control features include: Retraction, automatic extension based on throttle setting and gear position, emergency extension capability, position indication, etc.

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

Background and Source of Criteria: This is a new requirement, not previously documented in design requirements. Since these special features impact the cost, it is necessary to state the requirements in the original documentation. Much of the special features are Using Command preferences and they should be consulted extensively on these requirements. Since they are cost drivers, the user must be appraised and be willing to accept the impact on reliability and maintainability. Tail bumpers are frequently safety features that represent protection of more expensive and delicate airframe hardware which is jeopardized by extreme tail down landings, abrupt rotation on takeoff and ground maneuvering.

Lessons Learned: 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 overrotation on takeoff or high attitude landing, the device becomes in fact an energy absorber. If the strikes are frequent enough, a replaceable contact should be considered by the designer.

Another feature which is optional is the ability to position the bumper from the pilot's station. 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.

Society Automative Engineers ARP 1107, "Tail Bumpers for Piloted Aircraft" is a useful reference for recommended practice for design and installation of Tail bumpers.

Verification (Paragraph 4.2.2.3): "Ground clearances and protection by tail bumper will be evaluated by dynamic analysis of the air vehicle. The tail bumper operation and controls will be evaluated by air vehicle test."

Verification Rationale: The need for a bumper must 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 Lessons Learned:

3.2.3 Brake system

3.2.3.1 Brake System - General

3.2.3.1 - a "The air vehicle shall be capable of stopping under the following conditions: ______________________________."

Rationale and Guidance: This requirement is a primary performance characteristic of the air vehicle. It directly determines the runway length requirement of the air vehicle and can be a major design and cost driver. Although the primary impact is on the design of the landing gear brake systems, it also indirectly influences air vehicle aerodynamic characteristics. It will also be the basis for determining need for auxiliary deceleration devices such as spoilers and deceleration parachutes.

Considerable detail must be provided in definition of the performance required. The requirement will consist of several stopping conditions to be met. Each condition must contain essential parameters listed below. Failure to include these parameters will result in a requirement that cannot be enforced. The basic stopping performances which are identified should be related to the primary missions of the air vehicle. Each critical condition, such as, maximum design gross weight aborted takeoff, shall be included in this requirement. Definition of additional stopping performance for other purposes such as efficient training of aircrews may also be necessary, and should be included in the blank for this requirement.

Performance Parameters

Each stopping condition requirement must contain at least the following parameters:

(1) air vehicle gross weight condition

(2) speed condition at the start of the stop

(3) the type of runway surface upon which the stop must be accomplished

(4) environmental extremes that must be considered. This must include altitude of the runway and temperature extremes as a minimum

(5) maximum stopping distance permitted.

Optional parameters that may apply to some conditions include:

(1) definition of air vehicle system failure conditions

(2) maximum elapsed time between subsequent stops and air vehicle condition between stops

(3) number, order and frequency of stops.

Background and Source of Criteria: This requirement is unique to each air vehicle. The basis is usually contained in the General Operating Requirement (GOR) with additions and modifications as necessary to provide a complete engineering definition of the stopping performance.

Lessons Learned: Total system performance is a function of performance of many subsystems and components. The brake must be capable of producing adequate torque and have the heat sink capacity to absorb the energy.

The anti-skid system must function to control in an efficient manner to permit maximum utilization of all the available coefficient of friction. The tire must have sufficient footprint in contact with the ground to generate the stopping force required to meet this performance guarantee.

On past air vehicle, sufficient emphasis has been placed on meeting the dry runway stopping performance that it is possible that wet runway stopping may have been compromised. The anti-skid control adjustment or "tuning" required for optimized performance on wet versus dry runway surfaces can vary. Every effort should be made to clarify this item before the contract is finalized. A decision must be made whether the anti-skid control system is a safety device on wet runways or an automatic braking control system for dry runway performance.

Tire tread design and construction have been demonstrated to have an influence on wet runway stopping performance. Care must be taken to insure that traction is not compromised for life in selection of tire tread compounds.

Several recent aircraft with high power to weight ratios have required that significant braking be used during taxi to maintain a safe speed. This not only has a significant impact on brake wear but also can influence stopping performance during an aborted takeoff. If it is likely that the air vehicle will have high power to weight ratio, the stopping performance must include consideration of taxi operations before and after the normal stopping requirements.

<u>Verification</u> (Paragraph 4.2.3.1): "Total air vehicle stopping performance and the ability to hold the air vehicle static during engine runup shall be evaluated by air vehicle test as follows: ______________________________."

<u>Verification Rationale</u>: Since total system stopping performance is the result of the combined performance of the various systems and components, demonstration on the air vehicle is the only reasonable way to evaluate this requirement.

The requirement should normally define the stopping conditions to be demonstrated and the number of times each condition should be demonstrated. Several demonstrations should be included because uncontrollable variables such as pilot proficiency usually results in large data scatter. Demonstrations at the exact conditions specified may not be possible. In this case, verification is accomplished by analysis of the actual demonstration conditions.

This requirement is a significant air vehicle test program cost driver and is normally considered a hazardous test at least during the extreme test conditions.

<u>Verification Lessons Learned</u>:

3.2.3.1 Brake System - General

3.2.3.1 - b "The total system shall provide restraining force to hold the air vehicle static on a dry paved surface during application of ____________."

<u>Rationale and Guidance</u>: This establishes the need to hold the air vehicle static for functions such as engine run-up. If holding the wheels locked still does not hold the air vehicle static, further design refinement will be required to achieve this total system need. It may be determined that this

operational check will require wheel chocks to achieve this objective, then an operational assessment can be made on whether such support equipment will be available in the full operational spectrum of when this will be required. The blank should reflect the level of engine run-up during which it is required to remain static.

Performance Parameters: Brake torque characteristics, available tire to ground static coefficient of friction, tire contact area, and system hydraulic characteristics control the ability to meet this requirement.

Background and Source of Criteria: This requirement was not previously stated in any specification documentation. However, it has always been implied and understood as desired practice and generally demonstrated during the flight test program.

Lessons Learned: Depending on Using Command practices, this requirement may vary. Most jet air vehicle 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.

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

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

Verification (Paragraph 4.2.3.1): "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: ______________________."

Verification Rationale: 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 Lessons Learned:

3.2.3.1 Brake System - General

3.2.3.1 - c "______________ failure of the brake control system shall not result in a total loss of air vehicle braking capability."

Rationale and Guidance: Objective is to define whether single or dual failures will be permitted before loss of control. If the redundancy of dual failure concepts are significant cost drivers, the program management will have to determine what level of risk they are willing to take. The user must commit their feelings on this matter. The blank should indicate "single" or "dual."

Performance Parameters: brake system design and redundancy, reliability, etc. are key words in arriving at a decision for this requirement.

Background and Source of Criteria: 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.

Lessons Learned: The sources of failure which impact the ability of the system to maintain control are numerous. Failures may occur in the actuation system (hydraulic, pneumatic, or mechanical), the brake assembly, the pedal linkage, or the tire.

Figures 3.2.3.1 c-1, 3.2.3.1 c-2, and 3.2.3.1 c-3 show accident and incident statistics for various types of air vehicle for the hardware mentioned above:

Type Air vehicle	Number of Annual Accidents/Incidents
Fighter	
Cargo	
Bomber	
Trainer	
Misc	

Figure 3.2.3.1 c - 1. Actuation System

Type Air vehicle	Number of Annual Accidents/Incidents
Fighter	
Cargo	
Bomber	
Trainer	
Misc	

Figure 3.2.3.1 c - 2. Brake Assembly

Type Air vehicle	Number of Annual Accidents/Incidents
Fighter	
Cargo	
Bomber	
Trainer	
Misc	

Figure 3.2.3.1 c - 3. Tire

Verification (Paragraph 4.2.3.1): "The effect of component malfunctions shall be evaluated by _______________."

Verification Rationale: Options available for this verification include simulator demonstrations, flight test, or analysis. Depending on the complexity of the system, the availability of the simulator, and experience level of the proposed contractors, the blank should be completed. It is also a function of economics, since each approach has associated costs. Technically, the simulator in conjunction with an analysis is most desirable because the interfaces can be evaluated and the conditions can be controlled.

Verification Lessons Learned:

3.2.3.2 Brake System - Brake Actuation System

3.2.3.2 - a "A separate and independent emergency braking system shall be provided with the capability to _________ with _________ control."

Rationale and Guidance: This requirement is necessary to establish performance requirements for the emergency braking system. An emergency braking system is nearly always required by the using command. Experience indicates that a system is essential to provide adequate safety and reliability. Life cycle cost of the emergency system is strongly dependent upon required operating characteristics.

The statement provide for definition of both stopping performance and the level of control. 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. Antiskid control should be considered but may be optional.

Performance Parameters: Hydraulic system design, system capability, and failure modes are key words in evaluation of designs suitable to meet this requirement.

Background and Source of Criteria: This is a reflection of the criteria previously stated in specification MIL-B-8584, AFSC DH 2-1, and AFSC DH 1-6. It reflects the lessons learned from WWII air vehicle and has been standard criteria for over 20 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.

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

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 F111, B-1, and F16 utilize this approach.

Verification (Paragraph 4.2.3.2): "Performance and suitability of the emergency braking system shall be evaluated by flight test."

Verification Rationale: Since the requirement is for a level of performance, the only suitable demonstration is for the total system. It should be scheduled in a similar manner to the demonstration of the normal braking system.

Verification Lessons Learned:

3.2.3.2 Brake System - Brake Actuation System

3.2.3.2 - b "Brakes shall be applied by the following action: __________."

Rationale and Guidance: Rather than define the classical methold of applying brakes through the rudder pedals, this requirement is adjustable for the situation. If the Using Command or the state-of-the-art dictate a change in concept, the blank should reflect the desires. If no preference is stated, the classical statement of "foot pressure on the tip of the rudder pedal" should be inserted.

Performance Parameters: Cockpit design, rudder pedal design, feel spring characteristics, and pedal force versus pedal travel are important considerations in meeting this requirement.

Background and Source of Criteria: This requirement reflects the criteria previously contained in specification 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.

Lessons Learned: Some foreign air vehicle utilize a hand lever for brake application.

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

Verification (Paragraph 4.2.3.2): "Brake actuation and parking brake performance shall be evaluated by ______________."

Verification Rationale: Since brake actuation is not a measurable item, the evaluation is qualitative and subect to personal preferences. A mock-up or actual air vehicle must be used for preliminary evaluation. Final review is subject to program limitations.

Verification Lessons Learned:

3.2.3.2 Brake System - Brake Actuation System

3.2.3.2 - c "The brake control shall have the following force and travel characteristics: _________________."

Rationale and Guidance: This requirement is to establish force and travel limits, and response characteristics necessary to insure controllability, pilot comfort and minimum transition training. Content of this statement will depend upon the type of control used. The following should be considered:

Maximum breakout force:

Maximum force for full braking:

Maximum travel:

Travel for initial braking:

Deceleration rate/application force gradient (mean):

Deceleration rate/application rate tolerance:

Performance Parameters: Seat to pedal relationship, pilot size and qualitative measures such as "feel" are influential in meeting this requirement.

Background and Source of Criteria: This requirement has previously been defined in specification MIL-B-8584. Originally, the pedal travel versus pedal force relationship was developed by an aero-medical study conducted in the 1950 time period for manually operated systems. It has been maintained from that time period, and the power systems were a direct outgrowth of these requirements in an attempt to maintain similar pedal travel and "feel" from air vehicle to air vehicle.

Lessons Learned: There are numerous problems of interface and compatibility associated with the brake pedal installation and design. On mechanical systems which directly link the pedal to the brake metering valve, there are problems with break-out forces and system friction. This is particularly the case where linear motion linkage, such as that used on the F111, is used for this linkage. On any system, the level of break-out or force required for initial travel is important. If the break-out is high, the pilot may not be able to restrain additional force and will tend to overpressure the brakes on application. This can be a problem on landing.

If the break-out forces are too low, the pilot can easily apply brakes inadvertently during crosswind taxi or takeoff, along with his rudder control. This may be a much more prevalent problem than is currently realized by operators.

Most pedal travel versus pedal force relationships have a problem with hysteresis. The force versus travel will not be the same for return as it is for application. This can lead to pilot confusion and diminish the level of control. Frequently, this relationship can be a function of the individual installation as well as the general design of the system, and little or no control is provided in the general criteria, etc. Usually, each airframe manufacturers have their own internal controls, but they are not necessarily uniform.

Design of the seat and pedal arrangement to accommodate the various sizes and shapes of pilots is difficult. Much study has been done on comfort angles, but the criteria of acceptance is still qualitative. Pedal forces for holding brakes locked can be a problem, and is a function of the brake static properties. Therefore, pedal forces must be compatible with dynamic and static brake characteristics between a new and worn brake. This is particularly true with steel brakes.

The most recent trend in brake control is to use electrical controls. The range of the associated problems are yet to be bared. With the wide-spread use of power brakes over manual, and now the use of electrical controls, the pilots cannot tell when brakes are or are not applied. Therefore, most systems utilize a feel spring to provide some resistance to foot force. Position and design of this device has a significant impact on forces and hysteresis.

A pedal force limit of 300 pounds applied to the tip of the rudder pedals for brake application has been specified in the past. the forces required for brake disc movement and contact has previously been established at 15-20 pounds for manual systems and power systems. Many modern aircraft brake systems have limited maximum brake pedal force to 200 pounds to provide more comfortable operation.

Verification (Paragraph 4.2.3.2): "The brake control force versus control travel relationship shall be measured on the air vehicle."

Verification Rationale: Since there is interplay between so many components and flexibility in the mounting, the only logical place to evaluate this aspect of the design is on the air vehicle.

Verification Lessons Learned:

3.2.3.2 Brake System - Brake Actuation System

3.2.3.2 - d "A parking brake shall ________ to hold the air vehicle static under the following conditions: ________________."

Rationale and Guidance: Frequently, use of a parking brake is an optional design feature. Therefore, use of such an item is a Using Command option to be identified at the start of a program, since it must be included in the total system design. With statement of parking brake preference, there must be a statement of performance when a unit is desired. Some measurable performance, such as allowable pressure drop within a given time period and temperature drop, is recommended. The preferred method of application and release of the parking brake should also be specified.

Performance Parameter: Operational concept of the air vehicle, maintenance plans and user preference are controlling considerations under this requirement.

Background and Source of Criteria: The requirements for a parking brake and the required performance were previously defined in specification MIL-B-8584. Optional omission was extended to jet powered interceptors or fighters. One of the reasons for this stems from the inherent leakage associated with anti-skid plumbing and the infrequency of need for such a feature. The requirement was generally associated with light weight air vehicle equipped with manually controlled master cylinder systems.

Lessons Learned: Design reliability and internal leakage are the most frequent problems associated with parking brake designs. On the T-37, the installation was difficult to bleed, and with a small displacement manual system, erratic brake performance resulted from the trapped air.

Verification (Paragraph 4.2.3.2): "Brake actuation and parking brake performance shall be evaluated by __________."

Verification Rationale: The installation can be evaluated on the simulator or on the air vehicle. The decision on which installation to perform the evaluation should be based on economic considerations.

Verification Lessons Learned:

3.2.3.3 Brake System - Anti-Skid Brake Control

3.2.3.3 - a "The anti-skid brake control system shall be tuned for optimum performance on a ___________ surface, considering both braking and cornering forces throughout the control speed range."

Rationale and Guidance: There has been a tendency within the Industry to attempt to achieve a minimum stop distance on a dry runway, and then to assume a factor to be applied to predict wet stop distances (FAA). This is demonstrated most safely and under more controlled conditions. However, the real need of the system is to have the skid control system to be tuned on the surface where the greatest need exists. Therefore, every attempt should be made to tune the production adjustments of the anti-skid brake control system for a wet runway, where the performance is most critical. 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 control to assist steering are equally important to stopping performance. This must be considered equally in tuning system.

Performance Parameters: Brake actuation system response characteristics, anti-skid system response, brake torque characteristics, tire friction and dynamic characteristics, braking coefficient of friction, cornering power, and coefficient of friction, all have influences on whether the system provides "optimum" performance. "Optimum" is defined as the best compromise between braking and directional control.

Background and Source of Criteria: This criteria is generally stated in specification MIL-B-8075. Difficulty has been encountered on numerous systems where the anti-skid control system components are adjusted to provide minimum stop distance on a dry concrete surface. Then the wet runway performance is left to chance and is frequently less than optimum. The requirement for consideration of wet system adjustment was not introduced into specification language until 1971. Prior documentation reflected ancient state of the art design and evaluation.

Lessons Learned: In tuning an anti-skid system or adjusting the response rates, etc. 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 (slope, etc.), 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, etc., more use has been made of paired wheel control. This decision is made primarily for dynamic stability and ground control reasons. If release and reapplication of brakes on one side of the air vehicle at a time can induce control problems, paired wheel control should be considered. However, individual wheel control is more efficient from a stopping efficiency point of view, because each braked wheel is producing all the torque that is possible. With paired wheel control designs, caution must be used in valve selection to insure retention of differential braking capability in crosswind situations. Some systems reduce both wheels to a common threshhold pressure and offset the differential pressures that the pilot thinks that he is applying. Other paired wheel control valves operate like individual wheel control systems.

Verification (Paragraph 4.2.3.3): "The system performance, including compatibility with interfacing subsystems, will be evaluated by ________."

Verification Rationale: Ultimately, the final production tuning must 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 Lessons Learned:

3.2.3.3 Brake System - Anti-Skid Brake Control

3.2.3.3 - b "During air vehicle system power interruption or system malfunction, the system shall ________."

Rationale and Guidance: It is the intention of this requirement to state how the user wants the system to respond to circumstances of power interruption or system malfunction. It indicates the reaction which is most acceptable to the Using Command for system design. It is not intended to tell the designer how to achieve the stated response. Usually, the blank will be filled by stating, "return to pressure as metered, with adequate pilot notification."

Performance Parameters: This requirement is a function of system circuit design with the methods of system failure as the variables in the design.

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

Lessons Learned: On fighter air vehicle or relatively simple multi-tired gear designs, most systems revert to manual upon system failure with suitable notification to the pilot. On complex systems, such as the C5A, the effected wheel/brake assembly is isolated and the remainder of the system continues to function with anti-skid control.

Verification (Paragraph 4.2.3.3): "Effects of system malfunctions shall be evaluated by: ____________________."

Verification Rationale: There are numerous means of evaluation of anti-skid system malfunction. These include failure mode analysis under the Reliability Program, Simulator studies on the full scale landing gear mock-up, and flight test evaluation. The flight test portion is normally on a routine monitorship basis.

Verification Lessons Learned: Often test sets will not detect all types 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.

3.2.3.3 Brake System - Anti-Skid Brake Control

3.2.3.3 - c "The pilot shall be able to engage or disengage the anti-skid system by the following action: ______________."

Rationale and Guidance: This requirement is to provide a method for the pilot to override anti-skid system operation. Although this is a controversial feature, experience has indicated that it is usually desirable. In the event of faulty normal braking, it permits the pilot to select normal braking without antiskid as an alternative to emergency braking. This is desirable if the emergency system has limited capacity or is difficult to control. In the past it has frequently been desirable to shut off antiskid during taxi to prevent unexpected brake release. The argument against the control is that it leads to inadvertent operation without antiskid. Also if the pilot is given several alternatives, he may try all of them and overrun the runway. (i.e. direct selection of an emergency system may provide a shorter total stop distance).

The antiskid override is usually accomplished by removing power from the antiskid control box. The control for this can vary from a circuit breaker to a switch (stick or panel mounted) to a complex control and warning system (semi-automatic shut down). The control should be as simple as possible but must accommodate using command requirements. If the using command does not indicate a preference, complete the statement with the following: "Activation of a switch shall disable antiskid control of the normal brake system. Braking force shall be that commanded by the pilot. The pilot shall be provided with a warning that the antiskid has been disabled."

Performance Parameters: System response, available coefficient, tire hydroplaning characteristics, crosswind velocity and switch design, and position are influential parameters.

Background and Source of Criteria: The criteria for pilot control is a restatement of requirements previously stated in specification MIL-B-8075 and AFSC DH 1-6. It generally was the expressed desire of the Using Command to retain such a feature.

Lessons Learned: Most air vehicle utilize an on-off switch for the anti-skid control system.

Verification (Paragraph 4.2.3.3): "The operating characteristics of the anti-skid system and design features of the system shall be evaluated by ____."

Verification Rationale:

Verification Lessons Learned:

3.2.4 Rolling Components

3.2.4.1 Rolling Components - Tires

3.2.4.1 a "The tires shall be capable of performing on the air vehicle for the following: ________________."

Rationale and Guidance: 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 A/C 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 must also be considered, such as aborted takeoffs and maximum landings. If aerodynamic heating exceeds 160°F during flight, this must be considered.

Performance Parameters:

a. Tire Sizing Parameters

1. Air vehicle Configuration - This will tend to dictate the gear geometry and possibly the decision for a small number of large diameter tires or a large number of small diameter tires.

2. Flotation - This requirement will tend to dictate tire pressure, gear configuration and may drive the design of the air vehicle fuselage. If flotation does drive the design, tire service life problems will be nil.

3. Tire Load - This requirement will be dependent on 1 and 2 above.

4. Growth Allowances - This requirement will tend to dictate tire size if not established by flotation.

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 shall 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 shall be -65°F (-54°C).

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.

Background and Source of Criteria: This requirement reflects the concept generated in specification MIL-T-5041, AFSC DH 2-1, and AFSC DH 1-6. This is an Industry accepted practice for military and commercial tire development.

Lessons Learned: 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 tend 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 A/C, such as fighter or interceptor types.

The use of air to inflate main wheel tires, where thermal fuse plugs are used, is not recommended. Release of the fuse plug will result in discharge of the air on to the hot brake increasing the probability of fire. Nitrogen is used to inflate most commercial and some military aircraft tires.

Figures 3.2.4.1.a - 1 through 3.2.4.1.a - 13 provides design characteristics for tires used on current military aircraft. Selection of one of these designs for use on new air vehicle design may reduce logistics cost.

Size, Construction, and Performance of Type III (Low Pressure) Tires

Wheel Type 1/	Size	Ply Rating (PR)	Static Load Rating (Max) 2/	Inflation Pressure (Max) 3/	Bead Width (Max)	Weight of Tire (Max)	Moment of Static Unbalance (Max)	Mold Skid Depth for R or N Tread Pat. (Min)	Total Tread Thickness for P Tread Pat. (Min) 4/	USAF Drawing or MS No.
			Lb	PSI	In.	Lb	In.-Oz	In.	In.	
T-TT	5.00-4	6	1,200	55	.70	6.5	14	.09		
M-TT	5.00-5	4	800	31	.70	5.0	14	.11	---	53D917
M-TT	5.00-5	6	1,260	49	.70	5.0	14	.11	---	
M-TT	5.00-5	10	2,150	88	.90	7.5	14	.16	---	
T-TT	5.50-4	8	1,225	50	.875	9.0	5	NA	---	62C31331
M-TT	6.00-6	6	1,750	42	.75	8.5	8	.18	---	
M-TL	6.00-6	8	2,350	55	.90	10.5	8	.18	---	
M-TL	6.50-8	6	2,300	51	.85	11.5	16	.20	---	
M-TT	6.50-8	6	2,300	51	.75	11.5	16	.20	---	53D916
M-TT	6.50-8	8	3,150	75	.95	12.0	16	.20	---	
M-TL	6.50-8	8	3,150	75	.95	12.0	16	.20	---	
M-TT	6.50-10	6	2,770	62	.75	12.0	16	.20	---	
M-TL	6.50-10	6	2,770	62	.85	12.5	16	.20	---	
M-TL	6.50-10	10	4,750	100	.95	17.5	16	.20	---	
M-TT	7.00-6	6	1,900	38	.75	10.0	16	.19	---	
M-TL	7.00-8	16	6,650	125	1.30	24.0	16	.15	---	67J1951
M-TT	7.50-10	6	3,000	46	.80	16.0	16	.21	---	
N-TT	7.50-10	12	1,800	80	1.50	31.0	16	.90	Channel TR	
M-TT	7.50-14	8	5,700	87	1.00	30.0	16	.37	---	
M-TT	8.00-4	4	900	18	.65	8.7	16	.06	.12	
M-TT	8.00-6	8	2,800	54	.64	10.5	16	.17	---	
M-TT	8.50-10	6	3,250	41	.90	20.0	16	.33	---	
M-TL	8.50-10	6	3,250	41	.90	20.0	16	.33	---	
M-TT	8.50-10	8	4,400	55	1.05	22.0	16	.12	---	
M-TT	8.50-10	10	5,500	70	1.20	21.0	16	.12	---	54C763
M-TL	8.50-10	10	5,500	70	1.35	24.0	16	.12	---	54C763

See footnotes at end of table.

FIGURE 3.2.4.1.a - 1

Size, Construction, and Performance of Type III (Low Pressure) Tires

Wheel Type 1/	Size	Ply Rating (PR)	Static Load Rating (Max) 2/	Inflation Pressure (Max) 3/	Bead Width (Max)	Weight of Tire (Max)	Moment of Static Unbalance (Max)	Mold Skid Depth for R or N Tread Pat. (Min)	Total Tread Thickness for P Tread Pat. (Min) 4/	USAF Drawing or MS No.
			Lb	PSI	In.	Lb	In.-Oz	In.	In.	
M-TL	8.50-10	12	8,000	100	1.50	29.5	16	.33	---	
M-TT	8.50-10	12	8,000	100	1.50	29.0	16	.33	---	
T-TT	9.00-6	10	4,500	58	1.00	24.0	16	.28	---	
M-TT	9.50-16	10	9,250	90	1.40	55.0	20	.41	---	
T-TT	10.00-7	12	7,100	80	1.65	34.0	18	.35	---	
M-TT	29x11.00-10	8	5,000	45	1.25	28.0	20	.15	---	MS90444
M-TT	29x11.00-10	10	7,070	60	1.40	34.0	20	.35	---	MS90444
M/B-TT	11.00-12	6	6,900	55/66	1.00	38.0	24	.23	---	
M-TT	11.00-12	8	6,300	45	1.20	45.0	24	.30	---	
M-TL	11.00-12	8	6,300	45	1.35	46.0	24	.30	---	
M-TL	12.50-16	12	12,800	75	1.90	86.0	34	.45	---	64F1880
M-TT	15.00-16	10	12,200	53	1.65	90.0	44	.33	---	64D30454
M-TT	15.50-20	14	20,500	90	2.38	132.0	52	.46	---	
M-TT	15.50-20	20	29,900	135	2.60	170.0	52	.46	---	
M-TT	17.00-16	12	16,000	60	1.90	126.0	52	.48	---	
M-TT	17.00-20	16	25,500	95	2.50	173.0	80	.51	---	
M-TT	17.00-20	22	34,500	130	2.70	190.0	80	.51	---	
M-TT	19.00-23	16	29,000	85	2.75	210.0	80	.47	---	
M-TT-TL	20.00-20	22	38,500	95	3.375	232.0	90	.40	---	64D30452
M-TT-TL	20.00-20	26	46,500	125	3.50	270.0	90	.40	---	65D1542
M-TT	25.00-28	30	55,000	85	3.75	530.0	400	.55	--	45M58

1/ M - main wheel; T - tailwheel; TT - tube-type tire; TL - tubeless tire.

2/ For nosewheel application, multiply the static load rating of main wheel tires by 1.45 to obtain the maximum allowable load during braking.

3/ Vertical deflection under the static loads and inflation pressures specified for beaching wheel tires shall be 40 +1, -4 percent.

4/ Total minimum tread thickness for nonskid and ribbed tires includes mold skid depth plus underskid thickness.

FIGURE 3.2.4.1.a - 1 (Cont'd)

Dimensions of Type III (Low Pressure) Tires

Wheel Type 1/	Size	A Inflated Outside Diameter (Inches)		B Inflated Section Width (Inches)		C Inflated Shoulder Diameter (Inches) (Max)	D Inflated Shoulder Width (Inches) (Max)
		(Min)	(Max)	(Min)	(Max)		
T	5.00-4	12.99	13.47	5.26	5.54	13.47	4.27
M	5.00-5	13.65	14.20	4.65	4.95	12.55	4.20
H	5.00-5	13.65	14.55	4.65	5.15	12.85	4.35
M	6.00-6	16.80	17.50	5.90	6.30	15.45	5.35
H	6.00-6	16.80	17.95	6.18	6.55	15.85	5.55
M	6.50-8	19.15	19.85	6.55	6.95	17.70	5.90
M	6.50-10	21.35	22.10	6.25	6.65	19.90	5.65
H	6.50-10	21.35	22.60	6.25	6.90	20.50	5.90
M	7.00-6	18.00	18.75	5.90	7.00	16.45	5.95
H	7.00-6	18.00	19.25	6.60	7.30	16.85	6.20
M	7.50-10	23.30	24.15	7.20	7.65	21.60	6.50
H	7.50-10	23.30	24.70	7.20	7.95	22.05	6.75
M	7.50-14	27.00	27.75	7.20	7.65	25.30	6.50
M	8.00-4	17.15	18.00	7.80	8.30	15.50	7.05
M	8.50-10	24.70	25.65	8.20	8.70	22.80	7.40
H	8.50-10	25.30	26.30	8.20	9.05	23.25	7.70
T	9.00-6	21.40	22.40	8.70	9.25	19.45	7.85
M	9.50-16	32.50	33.35	9.10	9.70	30.25	8.25
T	10.00-7	24.30	25.45	9.65	10.25	22.15	8.70
M	29x11.00-10	28.10	29.00	10.40	11.00	25.60	9.35
M	11.00-12	31.00	32.20	10.50	11.20	28.55	9.50
H	11.00-12	31.00	33.00	10.50	11.65	29.25	9.90
M	12.50-16	37.50	38.45	12.00	12.75	34.40	10.85
M	15.00-16	41.40	42.40	14.40	15.30	37.65	13.00
M	15.50-20	44.30	45.25	15.05	16.00	40.70	13.60
M	17.00-16	43.70	45.05	16.35	17.40	39.80	14.80
M	17.00-20	47.70	48.75	16.40	17.25	43.60	14.65
M	19.00-23	53.15	55.10	18.25	19.38	49.30	16.50
M	20.00-20	54.30	56.00	19.20	20.10	49.50	17.10
M	25.00-28	69.30	71.15	24.70	25.70	63.40	21.85

1/ T - Tailwheel; M - Main wheel; H - Helicopter.

FIGURE 3.2.4.1.a - 2

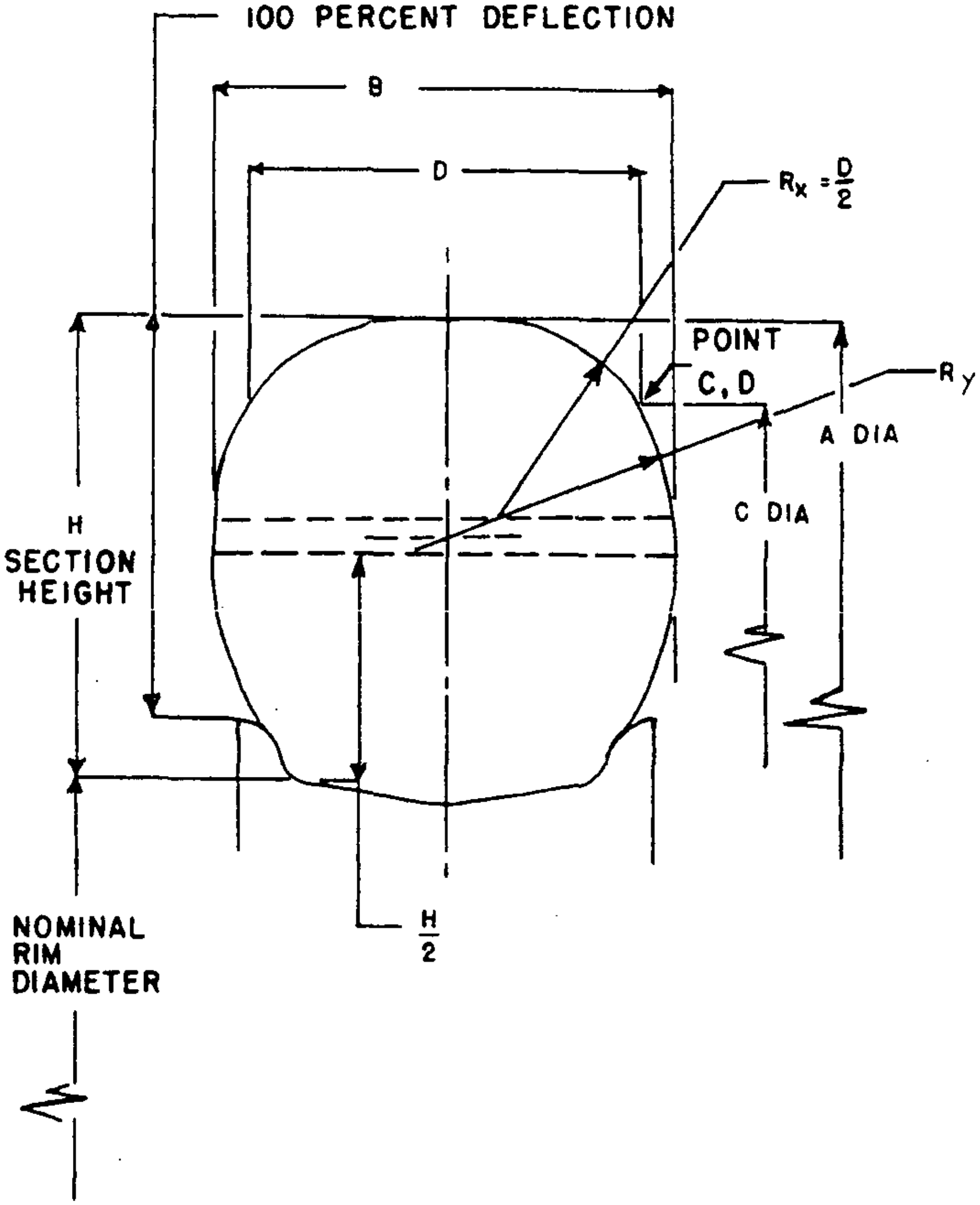


FIGURE 3.2.4.1.a - 3

Rim Dimensions for Type III (Low Pressure) Tires

Wheel Type 1/	Size	Standard No.
M & H	5.00-5	AND10578
M & H	6.00-6	AND10562
M	6.50-8	
M & H	6.50-10	AND10562
M	7.00-8	
M & H	7.50-10	AND10562
M	7.50-14	
M	8.00-4	AND10562
M & H	8.50-10	AND10562
T	9.00-6	AND10567
M	9.50-16	
T, N & B	10.00-7	AND10571
M & H	11.00-12	AND10562
M	12.50-16	
M	15.00-16	
M & B	15.50-20	AND10566
M	17.00-16	AND10563
M & B	17.00-20	AND10566
M	19.00-23	AND10562
M	20.00-20	
M	25.00-28	AND10583

1/ M - main wheel; H - helicopter wheel; T - tailwheel; N - nosewheel; B - beaching wheel.

FIGURE 3.2.4.1.a - 4

Size, Construction, and Performance of Type VII (Extra High Pressure) Tires 1/

Wheel Type 2/	Size	Ply Rating (PR)	Static Load Rating (Max) 3/	Inflation Pressure (Rated)	Bead Width (Max)	Weight of Tire (Max)	Moment of Static Unbalance	Mold Skid Depth (Min)	Drawing or MS No.	Speed Rating (Knots)
			Lb	PSI	In.	Lb	In.-Oz	In.		
T-TT	10.5x4	8	1,200	85	.75	4.7	5	0.07	---	---
T-TT	12.5x4.5	14	3,000	165	1.25	8.0	10	.25	65D30091	139
M-TT	16x4.4	6	1,700	85	0.70	9.5	9	.20	57D793	139
M-TL	16x4.4	8	2,300	120	1.125	8.0	9	.20	59C520	139
M-TL	18x4.4	6	2,100	100	1.00	11.0	5	.17	56D1172	174
M-TT	18x4.4	12	4,350	225	1.15	13.5	5	.17	58D514	217
M-TL	18x5.5	8	3,050	105	1.25	12.5	10	.17	MS26535	139
M-TL	18x5.5	12	5,050	170	1.40	17.5	10	.17	MS26535	139
M-TL	18x5.5	14	6,200	215	1.50	18.5	5	.17	66D1895	239
M-TL	18x5.5	14	6,200	215	1.50	21.5	5	.17	MS26535	139
M-TT	20x4.4	10	4,250	190	1.15	13.5	11	.26	MS26538	139
M-TL	20x4.4	10	4,250	190	1.30	15.6	11	.26	MS26538	139
M-TL	20x4.4	12	5,150	225	1.30	15.0	11	.26	56D1171	174
M-TL	20x5.5	12	6,150	180	1.38	20.0	12	.18	MS26540	140
N-TL	21x7.25-10	20	12,000	320	2.10	30.0	16	.22	67J2186	196
M-TL	22x5.5	8	4,350	135	1.25	16.0	13	.19	MS26539	139
M-TT	22x5.5	12	7,100	235	1.30	20.0	13	.19	MS26539	139
M-TL	22x5.5	12	7,100	235	1.45	22.5	13	.19	MS26539	139
M-TL	22x6.6-10	16	9,150	190	2.00	23.0	15	.22	EC76301A328A651	195
M-TL	22x6.6-10	20	12,000	270	2.00	29.0	15	.22	AS1DCVBG005	190
M-TT	24x5.5	12	7,500	230	1.30	23.0	8	.20	48F84	174
M-TT	24x5.5	12	8,070	250	1.25	22.5	8	.20	MS26526	139
M-TL	24x5.5	12	8,070	250	1.35	25.0	8	.20	MS26526	139
M-TT	24x5.5	14	9,700	300	1.375	25.0	8	.20	MS26526	139
M-TL	24x5.5	14	9,700	300	1.50	27.5	15	.20	MS26526	139
M-TL	24x5.5	16	11,500	355	1.40	27.0	15	.20	MS18060	174

See footnotes at end of table.

FIGURE 3.2.4.1.a - 5

Size, Construction, and Performance of Type VII (Extra High Pressure) Tires

Wheel Type 2/	Size	Ply Rating (PR)	Static Load Rating (Max) 3/	Inflation Pressure (Rated)	Bead Width (Max)	Weight of Tire (Max)	Moment of Static Unbalance	Mold Skid Depth (Min)	Drawing or MS No.	Speed Rating (Knots)
			Lb	PSI	In.	Lb	In.-Oz	In.		
M-TT	24x7.7	10	5,100	85	1.25	22.5	17	.30	---	139
M-TT	24x7.7	10	5,100	85	1.25	25.0	17	.30	MS26558	140
M-TL	24x7.7	14	8,200	135	1.50	30.0	17	.12	58D510	217
M-TT	25x6.0	16	12,000	330	1.65	32.0	15	.21	MS26543	139
M-TL	25x5.75	18	13,000	300	2.00	38.0	17	.21	59D502	239
M-TL	26x6.6	12	8,000	180	1.60	31.6	17	.30	MS26564	174
M-TT	26x6.6	14	10,000	225	1.60	32.0	17	.30	53C11	174
M-TL	26x6.6	14	10,000	225	1.625	36.5	17	.30	60C4280	174
M-TL	26x6.6	14	10,000	225	1.75	36.5	17	.30	MS26533	139
M-TL	26x6.6	16	12,000	270	1.85	38.0	17	.30	MS26533	174
M-TL	28x7.7	14	11,000	195	1.75	40.0	17	.30	MS17838	174
M-TL	28x9.0	22	16,650	235	2.25	50.0	20	.25	MS90443	174
M-TT	29x7.7	16	13,800	220	1.75	46.0	20	.31	51F601	174
M-TT	30x6.6	14	12,950	320	1.60	46.0	20	.30	63D31622	174
M-TT	30x7.7	18	16,500	270	2.00	51.0	20	.23	MS26536	139
M-TL	30x7.7	18	16,500	270	2.15	53.5	20	.23	MS26536	139
M-TL	30x7.7	22	21,300	360	2.25	---	20	.23	MS26536	139
M-TL	30x8.8	22	21,000	295	2.40	75.0	20	.28	60D90767	217
M-TT	32x8.8	12	11,000	135	1.75	44.1	20	.24	---	139
M-TT	32x8.8	16	15,100	200	1.90	50.0	20	.40	---	139
M-TT	32x8.8	18	15,800	200	2.00	60.0	20	.24	MS26537	139
M-TL	32x8.8	18	15,800	200	2.15	65.1	20	.24	MS26537	139
M-TT	32x8.8	22	22,000	290	2.50	73.0	20	.28	58D512	217
M-TL	32x8.8	24	23,300	355	2.75	80.0	20	.24	63D31707	239
M-TT	34x9.9	14	14,000	150	1.75	60.0	25	.31	---	139
M-TL	34x9.9	14	14,000	150	1.90	66.0	25	.31	---	139

See footnotes at end of table.

FIGURE 3.2.4.1.a - 5 (Cont'd)

Size, Construction, and Performance of Type VII (Extra High Pressure) Tires

Wheel Type 2/	Size	Ply Rating (PR)	Static Load Rating (Max) 3/	Inflation Pressure (Rated)	Bead Width (Max)	Weight of Tire (Max)	Moment of Static Unbalance	Mold Skid Depth (Min)	Drawing or MS No.	Speed Rating (Knots)
			Lb	PSI	In.	Lb	In.-Oz	In.	MCAIR	
M-TL	34x9.75-18	22	23,400	260	2.55	68.5	20	.26	EC76301A328A657	174
M-TL	36 x 11	22	23,300	200	2.70	88.0	16	.28	61D4306	174
M-TL	36 x 11	24	26,000	235	2.90	92.0	30	.26	61D3065	217
M-TL	36 x 11	28	31,500	290	2.80	99.0	30	.28	MS90346	174
M-TL	37x11.5-16	28	31,200	245	3.15	95.0	30	.30	MS14152	190
M-TL	38 x 11	14	15,400	130	2.20	90.0	18	.25	61D3069	195
M-TL	39 x 13	16	17,200	115	2.30	97.0	10	.30	63D3009	195
M-TT	40 x 12	14	14,500	95	2.38	95.0	40	.37	---	---
M-TL	40 x 14	26	30,500	175	3.10	133.0	35	.30	MS26563	174
M-TT	44 x 13	26	35,000	210	3.00	155.0	50	.31	---	---
M-TL	44 x 13	26	35,000	210	3.15	165.0	50	.31	64D30453	174
M-TL	44 x 13	26	35,000	200	3.15	155.0	50	.26	MS26557	174
M-TL	44 x 16	28	38,400	185	3.25	167.0	50	.38	61F4307	174
M-TL	46 x 16	28	41,800	210	3.10	186.0	52	.33	63D3008	195
M-TL	47x18-18	30	43,700	175	3.50	170.0	50	.30	69E177	195
M-TL	47x18-18	36	54,000	215	3.90	205.0	50	.30	65J1971	217
M-TL	49 x 17	26	39,600	170	3.05	215.0	50	.40	60D2561	195
M-TL	56 x 16	24	45,000	178	3.88	275.0	75	.35	68D29340	174
M-TL	56 x 16	32	60,000	250	3.95	319.0	90	.35	57D908	217
M-TL	56 x 16	38	76,000	315	4.50	355.0	90	.35	60D510	217

1/ Main wheel tires shall conform to the contour outlined on figure 4.
2/ T - tailwheel; M - main wheel; TT - tube type; TL - tubeless type.
3/ For nosewheel application, multiply the static load rating of main wheel tires by 1.5 to obtain the dynamic (braking) load rating for normal landing aircraft gross weight.

FIGURE 3.2.4.1.a - 5 (Cont'd)

Dimensions of Type VII (Extra High Pressure) Tires

Wheel Type 1/	Size	A Inflated Outside Diameter (Inches)		B Inflated Section Width (Inches)		C Inflated Shoulder Diameter (Inches)		D Inflated Shoulder Width (Inches)	
		(Min)	(Max)	(Min)	(Max)	(Min)	(Max)	(Min)	(Max)
T	10.5x4	10.15	10.60	3.30	3.55	10.10	10.50	3.85	4.10
T	12.5x4.5	12.10	12.85	4.45	4.85	11.90	12.40	3.95	4.20
M	16x4.4	15.50	16.00	4.15	4.45	--	14.55	--	3.90
M	18x4.4	17.40	17.90	4.15	4.45	--	16.50	--	3.79
M	18x5.5	17.30	17.90	5.35	5.70	--	16.20	--	5.00
M	20x4.4	19.50	20.00	4.15	4.45	--	19.45	--	3.95
M	20x5.5	19.55	20.15	5.35	5.70	--	19.30	--	4.75
M	22x5.5	21.55	22.15	5.35	5.70	--	21.30	--	4.95
M	24x5.5	23.55	24.15	5.35	5.70	--	23.30	--	4.95
M	24x7.7	23.00	23.75	7.20	7.65	--	21.28	--	6.75
M	25x6.0	24.35	25.00	5.80	6.15	--	23.70	--	5.00
M	25x6.75	24.80	25.50	6.45	6.85	--	23.44	--	6.03
M	26x6.6	25.05	25.75	6.25	6.65	--	23.55	--	5.85
M	28x7.7	26.60	27.40	7.40	7.85	--	24.90	--	6.95
M	28x9.0-12	26.80	27.60	8.35	8.85	--	24.80	--	7.80
M	29x7.7	27.60	28.40	7.40	7.85	--	25.90	--	6.95
M	30x6.6	29.40	30.12	5.95	6.50	--	28.20	--	5.50
M	30x7.7	28.60	29.40	7.40	7.85	--	26.90	--	6.95
M	30x8.0-16	29.40	29.80	7.76	7.96	--	26.90	--	6.95
M	30x8.8	29.50	30.40	8.35	8.90	--	27.40	--	7.90
M	32x8.8	30.05	31.00	8.35	8.90	--	28.05	--	7.90
M	34x9.75-18	33.70	34.50	9.15	9.75	--	31.55	--	8.60
M	34x9.9	32.45	33.40	9.55	10.20	--	30.10	--	8.80
M	36x11	34.00	35.10	10.80	11.50	--	31.65	--	10.10
M	37x11.5-16	36.10	37.00	10.90	11.50	--	33.20	--	10.10
M	38x11	36.00	37.10	10.80	11.50	--	33.65	--	10.10

See footnotes at end of table

FIGURE 3.2.4.1.a - 6

Dimensions of Type VII (Extra High Pressure) Tires

Wheel Type 1/	Size	A Inflated Outside Diameter (Inches)		B Inflated Section Width (Inches)		C Inflated Shoulder Diameter (Inches)		D Inflated Shoulder Width (Inches)	
		(Min)	(Max)	(Min)	(Max)	(Min)	(Max)	(Min)	(Max)
M	39x13	37.30	38.25	12.25	13.00	--	34.25	--	11.45
M	40x12	38.55	39.70	11.70	12.35	--	35.50	--	10.90
M	40x14	38.85	39.80	13.25	14.00	--	35.10	--	12.00
M	44x13	42.30	43.55	12.80	13.50	--	39.45	--	11.80
M	44x16	42.30	43.25	15.05	16.00	--	38.20	--	13.70
M	46x16	44.30	45.25	15.05	16.00	--	40.70	--	14.10
M	47x18-18	46.00	46.90	17.75	17.90	--	41.60	--	15.75
M	49x17	47.70	48.75	16.40	17.25	--	43.00	--	14.50
M	56x16	54.95	56.40	15.40	16.20	--	51.40	--	14.30
M	56x16	54.80	55.90	15.50	16.20	--	50.85	--	14.26

1/ T - Tailwheel; M - main wheel.

FIGURE 3.2.4.1.a - 6 (Cont'd)

Rim Dimensions for Type VII (Extra High Pressure) Tires

Wheel Type	Size	Standard No.
Main wheel	16 x 4.4	
	18 x 4.4	
	18 x 5.5	MS24370
	20 x 4.4	AND10581
	22 x 5.5	MS24370
	24 x 5.5	MS24370
	24 x 7.7	AND10576
	24 x 7.7 (14 PR)	
	25 x 6.0	
	26 x 6.6	AND10573
	29 x 7.7	
	30 x 7.7	AND10573
	30 x 8.8	MS24369
	30 x 8.8	AND10573
	32 x 6.6	
	32 x 8.8 (22 PR)	
	34 x 9.9	AND10573
	36 x 11	AND10573
	36 x 11 (20 PR)	
	38 x 11	
	39 x 13	
	40 x 12	AND10573
	44 x 13	AND10573
	46 x 9	
	46 x 16	
	49 x 17	MS24368
	56 x 16	MS24368
Tailwheel	10-1/2 x 4	
	12-1/2 x 4-1/2	

FIGURE 3.2.4.1.a - 7

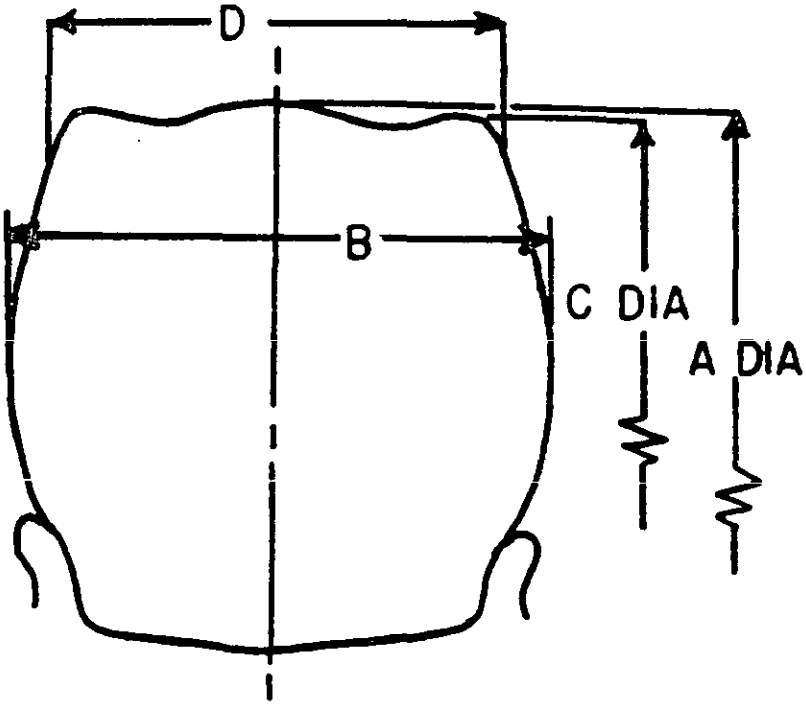


FIGURE 3.2.4.1.a - 8

Size, Construction, and Performance of Type VIII
Extra High Pressure Low Profile Tires 1/

Wheel Type	Size	Ply Rating (PR)	Static Load Rating (Max) 2/	Inflation Pressure (Max)	Bead Width (Max)	Weight of Tire (Max)	Moment of Unbalance (Max)	Mold Skid Depth (Min) 3/	Drawing No.	Speed Rating (Knots)
			Lb	PSI	In.	Lb	In.-Oz	In.		
TL	18x6.5-8	12	5,000	150	1.50	12.0	6	.20	63J4242	217
M-TL	22x7.7-12	16	10,500	280	1.94	27.0	14	.17	61D3037	239
M-TL	22x8.5-11	16	10,000	210	1.875	27.0	14	.20	63J4241	217
M-TL	24x8.0-13	18	12,500	285	2.05	29.0	13	.21	73453	217
M-TL	26x8.0-14	16	12,700	235	2.10	44.0	14	.20	61D3001	239
M-TL	28x9.0-14	22	18,100	280	2.25	61.0	15	.30	74201	186
M-TL	30x11.5-14.5	24	25,000	243	2.75	75.0	19	.26	62J4031	210
M-TL	31x11.50-16	22	23,300	275	2.65	80.0	19	.25	57F794	239

1/ Main wheel tires shall conform to the contour outlined on figure 6.

2/ For nosewheel applications, multiply static load rating of main wheel tires by 1.4 to obtain the dynamic (braking) load rating.

3/ Skid depth shall be measured at the approximate centerline of the tread.

FIGURE 3.2.4.1.a - 9

Dimensions of Type VIII
(Extra High Pressure Low Profile) Tires (See Figure 4)

Wheel Type	Size	A Inflated Outside Diameter		B Inflated Section Width		C Inflated Shoulder Diameter	D Inflated Shoulder Width
		(Min)	(Max)	(Min)	(Max)		
		In.	In.	In.	In.	In.	In.
	18x6.5-8	17.45	18.00	6.2	6.5	15.95	5.70
	22x7.7-12	21.75	22.35	7.25	7.7	20.25	6.80
	22x8.5-11	21.40	22.00	8.1	8.5	19.65	7.50
	24x8.00-13	21.50	22.00	7.55	8.00	22.00	7.05
	26x8.0-14	25.30	26.00	7.50	8.00	23.85	6.00
	28x9.0-14	27.30	27.85	8.60	9.00	25.25	8.00
	30x11.5-14.5 1/	--	31.00	--	11.85	27.54	10.40
	31x11.50-16	30.20	31.00	10.80	11.50	28.30	10.10

1/ Max thrown and grown dimensions.

FIGURE 3.2.4.1.a - 10

Rim Dimensions for Extra High
Pressure Tires, Type VIII

Size	Drawing No.
18 x 6.5-8	63J4242
22 x 7.7-12	61D3037
22 x 8.5-11	63J4241
24 x 8.0-13	73453
26 x 8.0-14	61D3001
28 x 9.0-14	74201
30 x 11.5-14.50	62J4031
31 x 11.50-16	57F794

FIGURE 3.2.4.1.a - 11

Bead Seating Pressures

Normal Rated Inflation Pressure	Minimum Bead Seat Pressure (PSI)	Maximum Bead Seat Pressure (PSI)
40 or less	25	40
40 to 100	25	1/
Over 100	50	1/

1/ In no case shall the maximum bead seat pressure exceed either the rated tire inflation pressure or 200 psi, whichever is the lesser.

FIGURE 3.2.4.1.a - 12

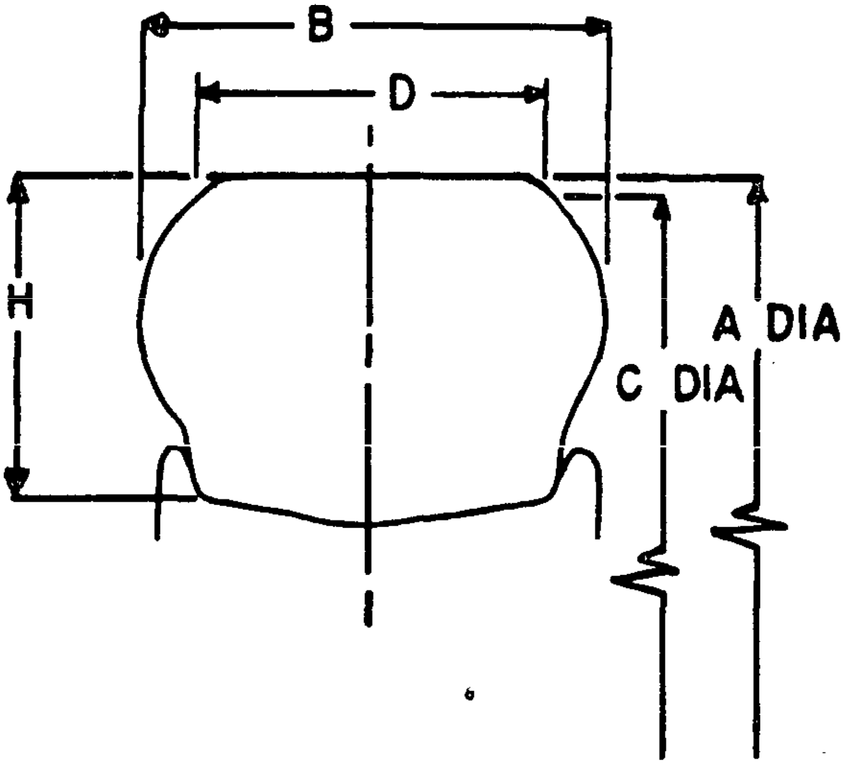


FIGURE 3.2.4.1.a - 13

It is sometimes desirable to mold a ridge in the tire sidewall to deflect water spray or other debris thrown up the 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 aircraft nose landing gears. Chine tires must be tailored for each application. Flight testing is necessary to confirm suitability of design.

Verification (Paragraph 4.2.4.1): "Laboratory tests shall be conducted to evaluate the following requirements:

a. Takeoff, landing, and taxi performance"

Verification Rationale: The use of a laboratory dynamometer to evaluate the tire performance characteristics permits evaluation to the limits of the tire capability with risk. The design conditions are carefully controlled and are repeatable. The Industry has always utilized this method of evaluation prior to installation on an air vehicle to determine performance limits and to establish Safety of Flight. It is significantly more economic than any other verification method. The tire will also be observed and evaluated during the routine flight test program.

Verification Lessons Learned:

3.2.4.1 Rolling components - Tires

3.2.4.1 - b "Tires shall have a service life, due to tread wear only, of not less than __________ landings. This shall apply during operation of the air vehicle as follows: ____________________.

Rationale and Guidance: 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. The blank should be filled with a reference to Figure 3.2.4.1 b-1, showing the number of A/C cycles required for a given tire diameter and speed rating range. The second blank should describe the operation during which the life requirement is to be applied.

Performance Parameters: The performance parameters controlling service life are:

1. Tire diameter   Establishes thickness

2. Velocity rating   of tread

3. Tire pressure due to load - Stress in tread rubber

4. Installation

Background and Source of Criteria: The source of this criteria is specification MIL-T-5041 and is supplemented by the AFSC-Ogden ALC LCC program. A similar arrangement is a worthy candidate for future programs.

	Main Tire Size	Average Tire Life	Nose Tire Size	Average Tire Life
A-7	28 X 9.00 - 14	66	22 X 5.5	N/A (Not Available)
A-10	36 X 11	N/A	24 X 7.7	N/A
B-52	56 X 16	202	Tip 32 X 8.8	N/A
C-5	49 X 17	310	49 X 17	317
C-7	11.00 - 12	N/A	7.50 - 10	N/A
C-123	17.00 - 20	N/A	33	N/A
C-130	20.00 -20	685	12.50 - 16	596
KC-135	49 X 17	440	38 X 11	230
C-141	44 X 16	401	36 X 11	348
F4	30.5 X 11.5 - 14.5	53	18 X 5.5	41
F5A	22 X 8.5 - 11	61	18 X 6.5 - 8	N/A
F15	25.5 X 9.75 - 18	N/A	22 X 6.6 - 10	N/A
F16	25.5 X 8.0 - 14	N/A	18 X 5.5	N/A
F100	30 X 8.8	29	18 X 4.4	74
F105	36 X 11	68	24 X 7.7	36
F111	47 X 18 - 18	155	21 X 7.25 - 10	N/A
T-37	20 X 4.4	N/A	16 X 4.4	N/A
T-38	20 X 4.4	93	18 X 4.4	N/A
T-39	26 X 6.6	83	18 X 4.4	N/A

FIGURE 3.2.4.1 b-1

Lessons Learned: Figure 3.2.4.1 b-1 shows the fleet average tire life for various air vehicle. The data represents Index Test results from Ogden ALC. Tire life is frequently affected by the air vehicle installation. If there is excessive camber or yaw abnormal tread wear can be generated. Early F-15 aircraft are an example of this problem. Obviously, the tire design cannot be held accountable for this performance

Verification (Paragraph 4.2.4.1): "Service life shall be evaluated on the air vehicle during flight test."

Verification Rationale: The primary factor in tire service life is tread wear. Laboratory testing does not evaluate this aspect of tire performance. Therefore, the flight test program is the first opportunity to evaluate this aspect of the design. The service life evaluation will be continued into Using Command evaluation at Squadron level. AFLC will further extend this aspect with its wear index tests of the Life Cycle Cost Program.

Verification Lessons Learned:

3.2.4.1 Rolling components - Tires

3.2.4.1 - c "The tire carcass shall be capable of ____________ retreads without degradation of tire structure performance."

Rationale and Guidance: 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. The blank should be filled with a number for repeated retreads that would be compatible with the tire performance and life. If the tire life is relatively long on a large diameter slow speed tire, the aging life of the carcass may limit it to one retread. If the tire is medium in diameter, 34-40 inches and rated in the 225 mph range, it could be retreaded four or five times. A high speed fighter tire of 28-34 inch diameter could also be retreaded five times, providing the carcass could not be subjected to high working stress due to inflation pressure of 250 psi or greater. In this case, only one retread may be cost effective.

Performance Parameters: Performance parametes controlling retreadability include:

1. Tire velocity rating

2. Tire pressure rating

3. Tire construction (special requirements)

   a. Environmental heating

   b. Excessive deflection

c. Exotic designs

d. Age limitations

e. Balancing

Background and Source of Criteria: This is a new requirement not currently defined in any general military specification. It reflects the current state of the art and has been used on all recent systems in the interest of Life Cycle Cost.

Lessons Learned: 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 tests on the dynamometer, stripping the tread and retreading between cycles, and a good inspection of a used carcass prior to retreading.

Verification (Paragraph 4.2.4.1): "Laboratory tests shall be conducted to evaluate the following requirements:

b. Retreading capability"

Verification Rationale: The retread capability of the carcass, can be verified by requiring the tire to complete all the dynamic tests of 4.2.4.1 a, then buff the tread and repeat the cycle without the heat soak cycles unless the soak is above 300°F for one hour.

Verification Lessons Learned:

3.2.4.1 Rolling Components - Tires

3.2.4.1 - d "The electrical conductivity characteristics of tires shall be such that the tire will not store a static charge which will be detrimental to any other air vehicle system or harmful to personnel."

Rationale and Guidance: The objective is to provide a tire material that does not accumulate or store a static charge which could be detrimental to air vehicle component operation or harmful to personnel.

Performance Parameters: Performance parameters controlling are:

1. Tire construction

2. Tire materials

Background and Source of Criteria: This criteria was previously stated in specification MIL-T-5041. It was based on an industry recommended laboratory analysis and was in force for approximately 20 years. The basic criteria was presented by the Tire and Rim Association.

Lessons Learned: Static charges of electricity have been blamed for numerous problems on A/C, and in some instances, were blamed on the tires. This situation caused an investigation of the materials for conductivity in the completed tire. Limits were established based on tire industry evaluation of the problem.

Verification (Paragraph 4.2.4.1): "Laboratory tests shall be conducted to evaluate the following requirements:

c. Electrical conductivity"

Verification Rationale: Verification of tire conductivity is a specimen test which has been standardized by the Tire and Rim Association.

Verification Lessons Learned:

3.2.4.1 Rolling Components - Tire

3.2.4.1 - e "In selecting tire sizes, make an allowance for ___________ growth in air vehicle maximum design weight within the same size tire."

Rationale and Guidance: The objective is to provide a tire with growth potential within the original clearance envelope. Historically, even in the 1970 years, air vehicle continue to grow in gross weight, which would overload original tire capabilities. Whereas, by adding plies, the tire can easily be changed to carry the extra load within the same envelope. The blank should be filled with 25% based on past experience.

Performance Parameters: Performance parameters controlling growth are:

1. Burst pressure

2. Bulk modulous

3. Taxi distances/velocity/temperature

Background and Source of Criteria: This requirement was contained in AFSC DH 1-6 and AFSC DH 2-1. This requirement was originally generated in the mid 1950's based on lessons learned with air vehicle growth. Since change in tire size impacts stowage area and airframe sizing, it is considered to be an important concern.

Lessons Learned: Most air vehicle developed in the last 25 years have grown in gross weight from 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 A/C developed in the late 60's and early 70's.

Verification (Paragraph 4.2.4.1): "An analysis is required to show ________ growth potential in the selected tire sizes."

Verification Rationale: The requirement for tire growth can be verified by analysis of actual plies to ply rating, to maximum number of plies and maximum ply rating allowed.

Verification Lessons Learned:

3.2.4.1 Rolling Components - Tires

3.2.4.1 - f "For multiple tire gear designs, capacity shall be provided to accommodate ____________ tire failure (s) without additional tire failure, when operating at all gross weights under the following conditions: ________."

Rationale and Guidance: The objective is to provide tires with the dynamic load carrying capability to withstand an overload for a short period of time and not cause a catastrophic failure. Should a tire fail during taxi at maximum gross weight, the other tire(s) on that strut should have the capability to support the additional dynamic load while taxiing back to an apron or repair area. On takeoff, the remaining tire(s) should have the capability to support the dynamic load for either aborting or completion of takeoff, followed by a landing at landplane landing gross weight. The first blank should be filled with a statement such as; "one" or "fifty percent of assembly". The second blank should describe the minimum operation with the failed tire(s).

Performance Parameters: Performance parameters controlling include:

1. Load rating
2. Ply rating
3. Air vehicle gross weight
4. Center of gravity locations
5. Tire construction
6. Operating spectrum

Background and Source of Criteria: Criteria for overload capability factors in tire capacity were previously documented in AFSC DH 2-1. The requirement, as expressed, is a new requirement defining the conditions of overload from which the remaining tires are expected to continue to operate. This will allow the airframe manufacturer to properly develop and demonstrated this overload capability.

Lessons Learned: 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% to 150% of the static load rating. The dynamic loads usually are not verified by test.

Development of a tire to withstand a sustained overload, such as excess load due to a mating flat tire, requires a tire test program simulating this condition. For example, if a tire is required to operate safely after a mating tire has failed, at least investigate the following:

a. Failure of a tire during taxi out for takeoff will result in an overload on the mating tire(s). The mating tire should have capability to endure the excess load for taxiing back to a repair area.

b. Tire failure during takeoff run. The mating tire should have the capability to endure the excess load for an aborted stop.

Verification (Paragraph 4.2.4.1):

"Laboratory tests shall be conducted to evaluate the following requirements:

d. Overload capability"

Verification Rationale: Laboratory dynamometer tests provide the opportunity to conduct a controlled test to the required limits without risk to air vehicle or personnel. It is the most economic approach from a cost and schedule viewpoint.

Verification Lessons Learned:

3.2.4.2 Rolling Components - Wheels

3.2.4.2 - a "The wheel assemblies shall be capable of performing on the air vehicle for the following: ________________."

Rationale and Guidance: The purpose of this requirement is to identify the operating conditions which will establish the design envelope for the main, nose, and auxiliary wheel equipment. The conditions must 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. The environment developed by the wheel-brake-tire combination must be accounted for in the design conditions of the wheels. If high brake temperatures are typically encountered with main wheels, the design spectrum must include this condition. Eccentric loads induced by installation on the air vehicle or operational usage must be suitably reflected in the requirements. These will not be known until the design of the installation is complete, but provisions for such eventualities must be included in the basic requirements. Examples might be: high frequency pivot, cambered roll, yawed roll, etc.

Performance Parameters: 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.

Background and Source of Criteria: This requirement summarizes the various load discussions previously stated in specification MIL-W-5013, AFSC DH 1-6, and AFSC DH 2-1. This is the very backbone of the wheel design requirements. It establisheds the static strength and fatigue requirements for the wheel assemblies.

Lessons Learned: 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 C141A main wheel. It was designed and tested to maximum load MIL specification criteria with an arbitrary cambered roll fatigue requirement. On the airplane, with ± 80° steering available to the pilot, the landing gear was experiencing numerous full pivots during routine taxi usage. The result was over 75 wheel flange failures in service. The wheel was redesigned to accommodate this specific condition of pivot turn. Since the revised wheel has been put into service (approximately 1970), there have been no further wheel flange failures.

Use of arbitrary criteria does not always drive the designs to structural inadequacy. A recent example has been the use of .5 g turn for yawed roll criteria in design. This particular condition has produced numerous laboratory failures (F5, F15, B-1, etc.) which drove redesign of the wheel hub area. There has never been evidence of field difficulties in this area with the wheels involved. It is suspected that the criteria is quite conservative and is resulting in heavy hub wheels. Research is planned by Flight Dynamics Laboratory to measure stress in various wheels for straight yawed roll versus turn techniques on a dynamometer flywheel to try to resolve this issue.

Another aspect which is some concern is the aspect of corrosion effects in the field as compared with development testing. Corrosion has a significant impact on inventory life, but current criteria does not account for this phenomenon. Recent painting technique improvements will potentially diminish this disparity.

Verification (Paragraph 4.2.4.2):

"Laboratory tests shall be conducted to evaluate the following requirements:

a. *Takeoff, landing, and taxi performance*"

Verification Rationale: 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 Lessons Learned:

3.2.4.2 Rolling Components - Wheels

3.2.4.2 - b "The wheel service life shall be ______________."

Rationale and Guidance: From a logistic consideration, an arbitrary average service life must be established for wheels, consistent with operational needs. In the past, an arbitrary laboratory life of 1500 miles at rated load was selected for design and the service life which achieved was accepted. However, our needs are actually service life, so average field service life should be specified. The number selected is a function of the type of air vehicle on which it will be installed and the overall logistic plan. Some air vehicle place premium on light weight and the wheel criteria should knowingly reflect this priority. Weight and life are directly related. 10,000 service miles for cargo air vehicle is consistent with airline criteria. 2000 service miles for high performance air vehicle wheels seems to reflect the primary concept of design.

Performance Parameters: Maintenance procedures, air vehicle usage, wheel material; and operating technique are major factors in achieving service life.

Background and Source of Criteria: Wheel fatigue life requirements were contained in specification 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 anomalities. This has resulted in improved service performance. In most cases where frequent service failures occur, the cause can be traced to service induced conditions which were not accounted for in the development criteria and evaluation. Therefore, duplication of operating environment in development evaluation is a paramount consideration.

Lessons Learned: Actual wheel service life is difficult to determine. Ogden ALC is attempting to initiate a system to track wheel forgings by serial number. Commercial wheels are traced and tracked. Each major forging is warranteed for a given life.

Maintenance has a major role in extending or shortening wheel service life. Bearing and axle nut installation, handling during tire changes, and tire-wheel inflation technique and diligence contribute to wheel life.

Being able to predict a realistic usage spectrum and qualifying to this criteria represents a major factor in achieving long service life.

Wheel flanges are the most frequent source of service failure. Extra attention should be placed on this portion of the design.

Verification (Paragraph 4.2.4.2):

"Laboratory tests shall be conducted to evaluate the following requirements:

b. Service life"

Verification Rationale: 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 Lessons Learned:

3.2.4.2 Rolling Components - Wheels

3.2.4.2 - c "Protection shall be provided to the wheel from brake heat to prevent ______________________________ after exposure to ______________ energy."

Rationale and Guidance: The purpose of this requirement is to establish performance requirements for heat dissipation. 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, wheel fuse plugs, etc. The blank should normally reflect the emergency energy level associated with maximum landing weight landing, which is the highest energy from which you could expect a serviceable assembly.

Performance Parameters: Peak brake heat sink temperature, thermal conductivity properties of material, effectiveness of heat shields, and fuse plug eutectics are parameters affecting this requirement.

Background and Source of Criteria: Performance requirements similar to this statement on heat dissipation are contained in specification MIL-W-5013, AFSC DH 1-6, and AFSC DH 2-1. Direct requirements for fuse plugs are contained in specification 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.

Lessons Learned: 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 must be taken with the threads.

The fuse plugs should be located directly within the heat path from the brake to insure an environment similar to that being seen at the tire' bead seat. Since this is the area which suffers degradation due to heat, the fuse plug must accurately reflect the environment.

Heat shields can cause structural damage to the wheel forging upon installation by inflicting a scratch. Care must be taken to insure relatively simple installation. Heat shield retention has been a difficult problem to solve on many wheel designs.

Verification (Paragraph 4.2.4.2):

"Laboratory tests shall be conducted to evaluate the following requirements:

c. Wheel overheat capability"

Verification Rationale: 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 Lessons Learned:

3.2.4.3 Rolling Components - Brakes

3.2.4.3 - a "Brake assemblies used to provide any portion of the air vehicle stopping performance specified in 3.2.3.1 - a shall have the following characteristics: ___________________."

Rationale and Guidance: 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.

The requirement will usually be complex in that several aspects of "success" need to be considered. Brake performance criteria may be different for the different stopping conditions specified in 3.2.3.1. Requirements to be considered should be selected from the following performance parameters and modified as necessary to clearly indicate the applicable stopping performance.

The following success criteria should be considered in completion of this requirement.

1. There shall 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.
2. The required stopping performance shall be provided at any time during the specified operational life of the brake.
3. After initial installation, it shall not be necessary to perform manual adjustment of the brake to permit the stopping performance to be met.
4. Brakes shall not squeal, chatter or cause any vibration during the stop that results in malfunction or reduces the life of any air vehicle component.
5. Brakes shall not cause heating of any air vehicle component that causes component malfunction prior to attainment of required life.
6. Brakes shall release upon release of the normal brake control during and after the stop.
7. No damage to the air vehicle, including rolling components, except wear of brake friction surfaces and ground contracting elements shall result from stopping with the following exceptions: _______________.
8. Prevention of structural overload due to braking shall not be dependent upon pilot proficiency.
9. Overheating of brake assemblies due to malfunction or abuse shall be indicated by _________________.

<u>Performance Parameters</u>:

<u>Background and Source of Criteria</u>: Most of the suggested brake criteria were previously stated or implied in specification MIL-W-5013.

<u>Lessons Learned</u>: Figure 3.2.4.3 a-1 presents a summary of Air Force brake structural failures between 1970 and 1976. A very large percentage of these failures were brake disc failures. Most generally, these failures are not necessarily design failures, but are induced by improper production processing. Another potential cause of brake disc failure is excessive heat input. If a brake is abused by dragging or some other operational input, 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. Examples of frequencies and spring rates are presented in Figure 3.2.4.3 a-2.

Brake Structural Failures

Aircraft	Number of Structural Failures
B-52	7
B-57	4
C-5	2
C-7	1
C-47	1
C-123	3
C-130	5
KC-135	7
C-141	1
F-4	12
F-5	1
F-15	1
F-100	1
F-102	1
F-105	5
F-106	1
F-111	2
T-33	1
T-37	2
T-38	2
T-39	5
H-3	1

Figure 3.2.4.3 a-1

Aircraft	Type of Gear	Fore & Aft Natural Frequency (cps)	Torsional Spring Rate (in-lb/RAD)	Fore & Aft Spring Rate (lb/in)
A-7D	Single			
A-10	Single			
B-52	Twin	9-11	5.9×10^6	15,000
B-57	Single	11.7	-----	9,350
C-130	Tandem Single	10.0	----	14,000
KC-135	Twin Tandem	10.0	51.3×10^6	40,000
C-141	Twin Tandem	24.0		
F-4	Single			
F-5	Single			
F-15	Single			
F-16	Single			
F-100	Single	11.1	3.45×10^6	10,300
F-101	Single	10.3	1.0×10^6	5,240
F-102	Single	27.5		19,430
F-105	Single	6.35	1.99×10^6	5,500
F-106	Single	25.3		13,970
F-111	Single			
A/T-37	Single			
T-38	Single	14.0	0.56×10^6	2,120

Figure 3.2.4.3 a-2

Brake squeal is the induced vibration of the stationary parts of the brake assembly and its mounting. It generally has a natural frequency of several hundred cps as compared to chatter frequency of 6-25 cps.

Brake chatter has been so severe that gear walk was induced on the F101 and F105 aircraft. There are numerous design changes within the brake which 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, F100 and F101 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 aircraft.

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 which 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. Figure 3.2.4.3 a-3 shows a typical distribution of peak torque.

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 motor section and contribute to seal deterioration and ultimately to leaks. It can produce excessive disk warpage. It can produce damage to the tire bead through the wheel assembly. Ventilation and elimination of conductive and convective heat is a major concern for assembly design. The problem of distribution is significantly increased with introduction of carbon brake discs. They may be lighter, but they do operate at a significantly higher temperature. Beryllium brake discs operate at significantly lower temperatures than steel or carbon brakes.

Overheating of brake assemblies may be encountered in operational use due to malfunction or abuse. A combination of low energy stops or a dragging brake may result in gradual temperature buildup that will negate normal safety devices or cause fires. Consideration should be given to detection of this condition and design to minimize damage caused by inadvertent overheating of the brake assembly. Several methods of temperature detection have been conceived and tried without overwhelming success. We have tried "TEMP-STICKS," which are heat sensitive devices which melt at a prescribed value. Maintenance personnel place these units in direct contact with the hot brake to try to ascertain current temperatures. They read fairly reliably, but it is dangerous to place personnel in such close proximity to an overheated brake.

Brake temperature sensors and indicators have been used on some aircraft. 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 aircraft is

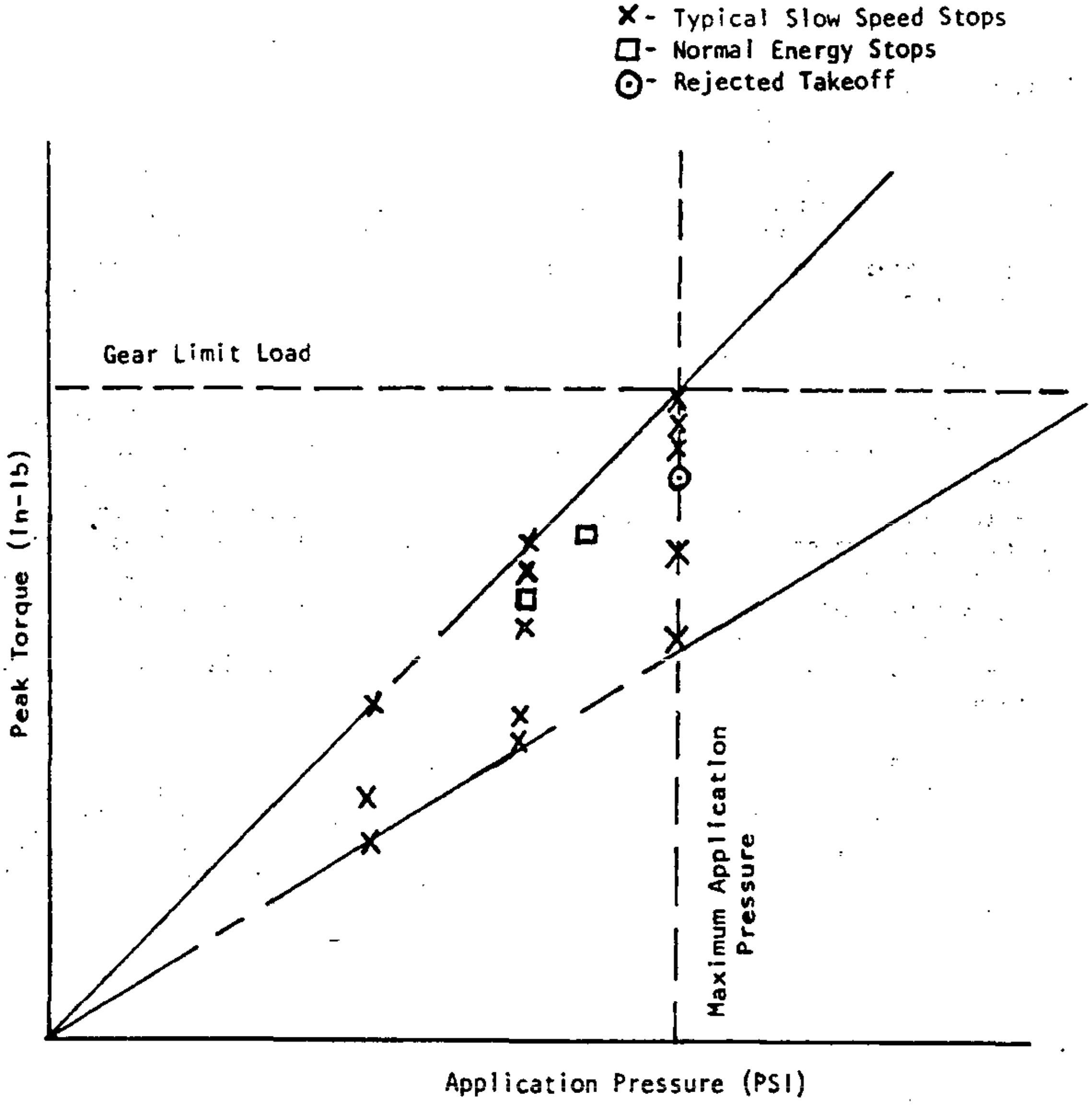


FIGURE 3.2.4.3.a-3

limited to the B-1 and C-9A. A system was installed on C-133 aircraft but removed in operational use due to maintainability problem. Brake temperature monitoring system have been developed and used in several commercial aircraft.

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 pressures 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 field 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 inadvertantly transmitted through wheel deflections. The torsional loads must be properly directed to avoid localized structural failure. Axial deflections of the heat sink must 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 antiskid 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 aircraft use automatic brake adjusters.

Figure 3.2.4.3 a-4 is a tabular summary of the types of adjusters used on some current aircraft. It is also noted whether the aircraft utilizes anti-skid brake control. The significance of the information is that only the C-141 has manual adjustment and employs anti-skid control.

Summary of Brake Adjustment and Anti-Skid Control

Air vehicle	Type of Adjuster	Technology of Anti-Skid Installed
A-7	Automatic	Intermediate
A-10	Automatic	New
B-52	Automatic	Old
B-57	Automatic	None
C-5	Automatic	New
C-7	Automatic	None
C-130	Automatic	Intermediate
C-135	None	Intermediate
C-141	Manual	Old
F-4	Automatic	New
F-5	Automatic	None
F-15	Automatic	New
F-16	Automatic	Intermediate
F-100		Old
F-102		None
F-105		Old
F-106		None
F-111	Automatic	Intermediate
A/T-37	Manual	None
T-38	Manual	None
T-39	Automatic	Intermediate

FIGURE 3.2.4.3 a-4

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 a refused take off stop with greater than maximum landing energy. Replacement of other landing gear components after any refused take-off 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 system. If maximum torque is limited, refused take-off stopping performance is degraded.

Verification: (Paragraph 4.2.4.3): "Brake durability, operating characteristics and compatibility with interfacing subsystem such as ________ shall be evaluated by ______________."

Verification Rationale and Guidance: Brake evaluation will normally consist of laboratory and flight testing. In so far as possible, verification should be by air vehicle stopping tests. Performance is likely to be highly dependent upon characteristics of the air vehicle and environment that are difficult to simulate simultaneously in the laboratory. Some extreme conditions such as maximum and minimum temperature can be duplicated only in the laboratory. Some extreme operating conditions may also be too hazardous for air vehicle test. The requirement should clearly indicate characteristics to be evaluated by air vehicle test because this can be significant cost and schedule driver.

Verification Lessons Learned: Brake failure modes experienced in the laboratory may have little correlation with failure modes on the air vehicle because of poor simulation of air vehicle operation. Modification of the brake to eliminate laboratory failure modes may induce additional failure modes on the air vehicle. An example is that large drive key clearances may result in severe battering damage to brake disc keyways. Reduction of the clearance to eliminate the problem can lead to severe dragging brake problems on the air vehicle. This is primarily due to the fact that the actual loading cycle on the aircraft is quite different than the accelerated life test usually used in the laboratory. Verification requirements must be structured to insure that performance on the air vehicle is the final success criterion. Laboratory test failures should not be ignored, however, laboratory successes are of no value to the operational Air Force.

3.2.4.3 Rolling Components - brakes

3.2.4.3 - b "Brake assembly heat sink members shall be capable of producing __________ operational landings and the brake structural members shall be capable of producing _________ operational landings without failure or wear beyond limits. The spectrum of operational landings is defined as _________."

Rationale and Guidance: Brake heat sink components are the consumable portions of the brake assembly. Rate of replacement directly impacts the logistic cost and support of the equipment. There are numerous design techniques and materials available which meet the design conditions but vary the average service life. Therefore, the objective of this requirement is to express the logistic needs of the system in a manner which will influence the design and material selected to produce the desired life. Some of the techniques available to extend life have adverse effects on other characteristics such as dynamic stability, peak torques, added weight, and temperature transmittal. So, establishing unrealistic life requirements may induce severe performance penalities. Caution must be exercised in this regard. It is recommended that minimum values such as "500" landings be established for minimum requirements.

Usually it is desirable to establish different requirements for the brake heat sink and the brake structural members (torque tube, actuation system, mounting hardware, etc...). In the past the structural components have been very expensive compared to the heat sink. This may not be true for more recent designs that use carbon composite or beryllium brake discs. In the case of steel disc brakes it was customary to require the brake structural members to have a life four times greater than that of the heat sink. Often this requires some refurbishment to attain. Brake structural member life may be somewhat less than overall air vehicle service life because the brake operates in a very severe environment.

Refurbishment of steel brake discs was normally not required. Refurbishment of carbon composite or berylliam discs should be carefully considered as a means to reduce operating cost.

Performance Parameters:

Heat sink mass, lining or rubbing surface power loadings, peak temperatures, operating techniques and engine idle speed have significant impact on the average operating life of the brake heat sink members. Material selection, stress levels, bolting techniques, housing and back plate stiffness and housing-torque tube design are parameters limiting brake structural life.

Lessons Learned: Figure 3.2.4.3 b-1 presents the average heat sink life of several current Air Force aircraft, and the type of brake lining/rotor combination in use on the design. This provides a basis for estimation of heat sink life for new design.

Figure 3.2.4.3 b-2 presents a summary of AFLC data on air vehicle and brake structural failures, including bolts, in the 1970-1976 time period.

Verification (Paragraph 4.2.4.3):

"Brake durability, operating characteristics and compatibility with interfacing subsystems, such as __________ shall be evaluated by ______________________."

Verification Rationale:

Utilization of laboratory, flight tests and squadron service tests covers the total usage spectrum. All facets contribute to the knowledge of performance for determining the life of brake equipment. Each contract should define limits, where they are known.

Verification Lessons Learned: Laboratory and flight test may predict brake life much higher or lower than that experienced in operational use. The primary variable is the test mission spectrum compared to the operational mission spectrum.

Air vehicle	Average Number of Landings	Type of Lining/Core
A-7		Sintered Metallic/Steel
A-10		Sintered Metallic/Steel
B-52		Ceramic-Metal/Steel
B-57		
C-5		Sintered Metallic/beryllium
C-7		
C-130		Sintered Metallic/Steel
C-135		Ceramic-Metal/Steel
C-141		Sintered Metallic/Steel
F-4		Sintered Metallic/Steel
F-5		Sintered Metallic/Steel
F-15		Carbon/Carbon
F-16		Carbon/Carbon
F-100		Sintered Metallic/Steel
F-102		Ceramic-Metal/Steel
F-105		Sintered Metallic/Steel
F-106		Ceramic-Metal/Steel
F-111		Sintered Metallic/Steel
A/T-37		Sintered Metallic/Steel
T-38		Sintered Metallic/Steel
T-39		Sintered Metallic/Steel

Figure 3.2.4.3 b-1. Average Number of Landings/Heat Sink

3.2.4.3 Rolling Components - Brakes

3.2.4.3 - c "Means shall be provided to determine current status of brake wear without disassembly or the use of special tools."

Rationale and Guidance: This is an expression of an operational need to be able to determine status of brake wear during a pre-flight inspection or after any given flight. Rather than dictate wear pins for measurement, the designer is free to develop any means which will provide this inspection capability, consistent with his overall maintainability plan.

Performance Parameters: 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.

Background and Source of Criteria: This item was previously expressed in specification MIL-W-5013, calling specifically for "brake lining wear indicators." This requirement has been established for over 10 years and stems from operational lessons learned, and generally expresses the desires of most Using Commands.

Lessons Learned: 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 which 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.

Verification (Paragraph 4.2.4.3):

"Brake durability, operating characteristics and compatibility with interfacing subsystems, such as ____________________ shall be evaluated by ________________."

Verification Rationale and Guidance: Brake evaluation will normally consist of laboratory and flight testing. In so far as possible, verification should be by air vehicle stopping tests. Performance is likely to be highly dependent upon characteristics of the air vehicle and environment that are difficult to simulate simultaneously in the laboratory. Some extreme conditions such as maximum and minimum temperature can be duplicated only in the laboratory. Some extreme operating conditions may also be too hazardous for air vehicle test. The requirement should clearly indicate characteristics to be evaluated by air vehicle test because this can be a significant cost and schedule driver.

Verification Lessons Learned: Brake failure modes experienced in the laboratory may have little correlation with failure modes on the air vehicle because of poor simulation of air vehicle operation. Modification of the brake to eliminate laboratory failure modes may induce additional failure modes on the air vehicle. An example is that large drive key clearances may result in severe battering damage to brake disc keyways. Reduction of the clearance to eliminate the problem can lead to severe dragging brake problems on the air vehicle. This is primarily due to the fact that the actual loading cycle on the aircraft is quite different than the accelerated life test usually used in the laboratory. Verification requirements must be structured to insure that performance on th 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.

3.2.4.3 Rolling Components - Brakes

3.2.4.3 - d "Structural failure of the brake heat sink shall not result in ________."

Rationale and Guidance: The intention of the requirement is to define the unacceptable modes of failure for the brake assembly. If the design can tolerate minor discrepancies, strict adherence to no crack philosophy may be an unnecessary cost driver. It is our intention to define unacceptable results. The blank should reflect unacceptable consequences of heat sink failure, such as locking, piston over-extension, pieces of disc inducing a locked wheel or structural failure of the wheel, etc.

Performance Parameters: Maximum surface and heat sink temperature, heat sink materials, lug loadings, peak torques, and running clearances provide technical influence in meeting this requirement.

Background and Source of Criteria: Specification MIL-W-5013 contains a very superficial discussion of brake disc failure in Section 4, which is inadequate to evaluate performance in the field. Therefore, this requirement is basically a new requirement to reflect all the lessons learned in maintenance and safety.

Lessons Learned: Brake disintegration can be the cause of serious accidents and potential fires. Figure 3.2.4.3a-1 summarizes the Air Force experience of failures of this nature for the period 1970 - 1976.

A design approach which has been used successfully to prevent fires as a result of brake disc failure is to use actuation piston stops. The stops prevent the pistons from being pushed from the housing and subsequent flooding of the brake with hydraulic fluid from the open ports.

Carbon disk brakes are more susceptible to disk disintegration than steel discs due to the lack of strength when loaded axially. Extra precaution should be taken with this type of design to insure piston retention and fire prevention. Carbon brake discs generally are operated at higher temperatures than its steel brake counterparts.

Verification (Paragraph 4.2.4.3):

"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: 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 Lessons Learned:

3.2.5 Directional Control Systems

3.2.5.1 Directional Control System - General

3.2.5.1 - a "Directional control of the air vehicle for operation on the ground shall be provided as follows: ____________."

Rationale and Guidance: This is a statement of the total system ground directional control requirements. It establishes overall constraints from which the contractor allocates specific performance to the landing gear steering, braking, propulsion and flight control systems. Two major requirements to be defined are: the expected performance during takeoff and landing, and ground maneuvering of the air vehicle for other reasons. Both must be defined because the allocation to the landing gear steering stystem will be different for each case. The requirement to meet both is usually a steering system design driver.

Performance Parameters:

Air vehicle Geometry
Landing Gear Geometry
Width of Runways and Taxiways
Type of Airfield Surface
Parking Area Restrictions
Cargo Handling (Loading Dock Compatibility)
Takeoff and Landing Speeds
Thrust Reversal

Background and Source of Criteria: This is a new requirement, which was not previously identified in any criteria document. 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. This type of performance has frequently been confused for purely steering system capability.

Lessons Learned:

(1) 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. Figure 3.2.5.1 a - 1 is a summary of this characteristic for some current air vehicle.

(2) 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.

(3) Excessive reliance should not be placed on use of differential braking for ground maneuvering. Minimum radius turns using this approach are difficult to accomplish with precision. Also, this condition frequently result 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.

(4) If it is expected that the air vehicle will have a reverse thrust capability, it may be disirable 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.

(5) Air vehicle ground directional control is usually severly 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.

(6) Airfield geometry for standard construction is controlled by the following manuals. These may be useful in establishment of requirements:

(a) AFM 86-3 Planning and Design of Theater of Operations Air Base

(b) AFM 86-8 Airfield and Airspace Criteria

Air vehicle Type	Pavement Width for 180 Turn *
A-7	
A-10	
B-52	
B-57	
C-5	
C-7	
C-123	
C-130	
C-135	
C-141	
F-4	
F-5	
F-15	
F-16	
F-100	
F-105	
F-106	
F-111	
T-37	
T-38	
T-39	

Figure 3.2.5.1 a-I

*Source: Air vehicle Flight Handbooks

Verification (Paragraph 4.2.5.1):

"Directional control performance requirements of the total system shall be evaluated on the air vehicle during the flight test."

Verification Rationale: 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 Lessons Learned:

3.2.5.1 Directional Control System - General

3.2.5.1 - b "Ground directional control characteristics shall permit the pilot to precisely control the air vehicle under the following crosswind conditions: _______________."

Rationale and Guidance: Crosswind limitations on precise directional control can severely limit operational utility of the air vehicle. The air vehicle characteristics depend upon performance of propulsion flight control and braking system characteristics, as well as the steering system. The crosswind limit, however, can significantly influence the steering system design both directly and indirectly. An example of indirect influence is that it may dictate main landing gear tread and landing gear wheel base. Two flight regimes should be considered. The first is the takeoff and landing case wherein the aerodynamic characteristics are predominant. The second is the ground maneuvering limit where the landing gear geometry and steering system performance become predominant.

Performance Parameters:

Aerodynamic Performance

Airfield Geometry

Airfield Surface Type

Airfield Surface Strength

Landing Gear Geometry

Background and Source of Criteria: This is a new requirement. It states the performance which has been implied or left to chance in various systems documents.

Lessons Learned:

(1) Operational crosswind limits for several existing air vehicle are shown in Figure 3.2.5.1 b - 1. Information was derived from air vehicle flight handbooks.

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

(3) 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.

(4) 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.

(5) 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. Requirements for crosswind positioning should be developed for section 3.2.9.

Air Vehicle Crosswind Operating Limits

Air vehicle	Maximum Crosswind Component (Knots)		
Type	Takeoff	Landing	Taxi
A-7			
A-10			
B-52			
B-57			
C-5			
C-7			
C-123			
C-130			
C-135			
C-141			
F-4			
F-5			
F-15		30	
F-16			
F-100			
F-105	30 to 40 *	40	
F-111			
T-37			
T-38			
T-39			

* Depends upon Gross Weight and Takeoff Speed

Figure 3.2.5.1 b - 1

Verification (Paragraph 4.2.5.1):

"Crosswind control limits will be determined by analysis, substantiated by flight test."

Verification Rationale: Due to the complex interaction of flight control, propulsion and landing gear systems, verification of the crossweind control limits must be accomplished by flight test. Prior to availability of flight test hardware, crosswind characteristics of the proposed design should be evaluated by analysis. This is normally accomplished as a part of the overall analysis of air vehicle stability and control characteristics.

Verification Lessons Learned:

3.2.5.1 Directional Control System - General

3.2.5.1 - c "Emergency directional control shall be provided with the following characteristics: ______________________."

Rationale and Guidance:

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

"The emergency directional control system shall permit the air vehicle to complete the ________________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."

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

"The emergency directional control system shall 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."

Performance Parameters: The following parameters should be considered:

Air Vehicle Weight
Air Vehicle Speed
Type of runway surface (Hard/Soft)
Control Precision

Verification (Paragraph 4.2.5.1)

"Emergency directional control characteristics shall be evaluated as follows: ________________________."

Verification Rationale and Guidance:

Emergency directional control should be evaluated by air vehicle test. Performance is the result of the complex interaction of the air vehicle and its environment that cannot be accurately simulated or analyzed. Since some emergency directional control tests could be hazardous, the evaluation should consist of a series of tests designed to gradually approach the specified condition.

Verification Lessons Learned:

3.2.5.2 Directional Control System - Nose Gear Steering System

3.2.5.2 - a "The steering system used to provide any portion of the directional control shall have the following characteristics: ________________."

Rationale and Guidance: 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 of the system such as method of control and type of indication. It may also be necessary to establish maximum control forces and response characteristics. This is required to standardize controls and insure that aircrew procedure is similar to previous air vehicles to minimize aircrew transition training. In the case of a large complex air vehicle, this requirement should establish self-test or built in test requirements.

Performance Parameters:

Takeoff and Landing Speed

Operating Environment

Landing Gear Arrangement

Airfield Surface Type and Strength

Steering Control Force

Steering Rate

Ability to Track a Straight Line

Steering Deadband

Method of Control (Rudder Pedals or Wheel)

Indicators (Strut Marking, Warning Lights)

Self-Test Provisions

Shimmy Damping

Background and Source of Criteria: 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 Design handbook 2-1. System rate and response characteristics have not been quantitatively stated in the past, but rather have been controlled by test pilot concensus. In the future, it may be desirable to establish quantified requirements to permit more orderly development of the system. The type of control (rudder pedal or wheel) has been dictated in the past by MIL-STD-203. Steering indication systems and built-in test have been given little consideration in the past.

Lessons Learned:

(1) Past aircraft have generally been designed to the following criteria:

"The steering system shall be designed with sufficient output torque to permit turning the steered wheels through the full range without the aid of motion of the aircraft or engine thrust or auxiliary power. The steering capability shall be available throughout the design temperature range of the aircraft, and with the most critical combination of weight and center of gravity at engine idle thrust and a design coefficient of friction of 0.80 at the tire ground interface. The tires shall 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."

Testing has indicated that the actual maxium tire to ground friction coefficient may be less than 0.8. Aircraft that have little or no capability to turn the nose gear with the aircraft static have generally been unacceptable and required redesign to increase steering torque.

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

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

(4) Deflection of cables, pulleys, pulley mounts, and pulley mount back up structure is a frequent cause of poor response in systems with mechanical control.

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

(6) Some aircraft 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 aircraft it may be desirable to indicate that landing gear are not centered. Indicators on the landing gear showing steering angle are useful for rigging of the steering system.

Verification: (Paragraph 4.2.5.2):

"System performance and control characteristics shall be evaluated by an analysis and flight test. A formal demonstration of the steering system operation with the static aircraft shall be accomplished to determine compliance with factors that can not be verified by flight test. Configuration design requirements, including ______________, shall be verified by inspection of engineering drawings and hardware."

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

Verification Lessons Learned:

3.2.5.2 Directional Control System - Nose Gear Steering System

3.2.5.2 - b "The probability of occurrence of a single failure that results in total loss of steering shall not exceed _____ per mission."

Rationale and Guidance: This requirement is to establish a limit on critical failure frequency (loss of steering) of the steering system. This in turn is expected to influence the contractor in selection of the type of steering system to be used and the degree of redundancy to be provided. It should be tailored to recognize the importance of steering to the particular air vehicle.

Performance Parameters:

Maneuverability of the Air vehicle without Steering

Operating Environment

Performance of Similar Air vehicle

Background and Source of Criteria: This item reflects criteria previously identified in specification MIL-S-8812. Requirements on failure mode and effect were introduced into this document in 1975 and they represent input from Industry. It is more specific than previous criteria in that it establishes a numerical value to be achieved. Previous requirements were qualitative.

Lessons Learned:

(1) Figure 3.2.5.2 b - 1 is a list of demonstrated failure rates for several air vehicle. These data were obtained from accident/incident reports. It is suspected that actual failure rates are much higher, because not all failures result in accidents/incidents. The failure rate for the F-4 air vehicle is considered accurate for a limited operating period. The rate is considered unacceptable for this air vehicle.

(2) Some air vehicle incorporate dual sources of steering power. This should be considered for air vehicle that must have operable steering to maintain control for takeoff and landing. It may also be desirable for air vehicle that can not 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.

Air vehicle Steering System Failure Rates

Loss of Steering

Air vehicle Period Type	Failure Rate Failures per Flying Hour	Observation Flying hours
A-7		
A-10		
B-52		
B-57		
C-5		
C-7		
C-123		
C-130		
C-135		
C-141		
F-4		
F-5		
F-15		
F-16		
F-100		
F-105		
F-111		
T-37		
T-38		
T-39		

Figure 3.2.5.2 b - 1

Verification (Paragraph 4.2.5.2):

"Probability of system failure shall be assessed by a failure mode analysis and historical failure rate data. Critical failure modes shall be further evaluated by ____________."

Verification Rationale: 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 Lessons Learned:

3.2.5.2 Directional Control System - Nose Gear Steering System

3.2.5.2 - c "The probability of occurrence of a single failure that results in "hardover' steering response shall not exceed _____ per mission."

Rationale and Guidance: This requirement is to establish a limit on critical failure frequency (steering hardover) of the steering system. This is usually a more dangerous failure mode than loss of steering and generally easier to prevent. It should, therefore, be established in addition to the failure rate established by 3.2.5.2 b. This should influence the contractor in selection of a basic design and provision of an adequate level of fail-safe features.

Performance Parameters:

Air vehicle Controllabiity with a Steering Hardover

Operating Environment

Performance of Similar Air vehicle

Lessons Learned:

(1) Figure 3.2.5.2 c-1 is a list of steering "hardover" failure rates experienced on some current air vehicle. These data were derived from air vehicle accident/incident records. Failure rates are considered acceptable with the exception of that shown for F-4 air vehicle.

(2) The acceptable failure rates generally result from structural failure of mechanical components only. Hardover failures due to malfunction of hydraulic and electrical components must be fully eliminated. This requires careful design practice to insure fail-safe design.

(3) Accident reports generally indicate that hardover steering failures are much less serious on large air vehicle as compared to small air vehicle. Apparently the large mass reduces response time and permits the pilot to regain control by other means.

Air vehicle Steering System Failure Rates

Hardover Steering

Air vehicle Period Type	Failure Rate Failures per Flying Hour	Observation Flying Hours
A-7		
A-10		
B-52		
B-57		
C-5		
C-7		
C-123		
C-130		
C-135		
C-141		
F-4		
F-5		
F-15		
F-16		
F-100		
F-105		
F-111		
T-37		
T-38		
T-39		

Figure 3.2.5.2 c - 1

Verification (Paragraph 4.2.5.2):

"Probability of system failure shall be assessed by a failure mode analysis and historical failure rate data. Critical failure modes shall be further evaluated by __________."

Verification Rationale: Acceptable failure rates are so low that verification by flight test is not practical. A failure mode analysis combined with failure rate data for similar components usually will provide adequate verification of the requirement. In some cases, it may be necessary to induce simulated failures in a laboratory simulator or on the air vehicle to verify failure modes and effects. This is recommended in the case of unique or complex designs. Component testing may also be required to develop suitable failure rate data for new design components.

Verification Lessons Learned:

3.2.5.2 Directional Control System - Nose Gear Steering System

3.2.5.2 - d "In the event of failure of the primary steering system, emergency steering shall be provided with the following characteristics: ____________."

Rationale and Guidance: If a nose gear steering system is required to provide normal directional control, consideration must be given to directional control in the event of failure of the system. This requirement is to define unique requirements, Possible characteristics include: pilot or automatic selection of an alternate power system, indication of primary failure, type and amount of steering to be accomplished, emergency steering shall not degrade normal or emergency brake system performance.

Performance Parameters: Gear locations, tire sizing, rudder control, and hydraulic system design influence the need for emergency steering capability.

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

Lessons Learned:

(1) Emergency systems that operate by providing a second source of hydraulic pressure must 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.

(2) 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 othr 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.

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

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

Verification (Paragraph 4.2.5.2):

"System performance and control characteristics shall be evaluated by an analysis and a flight test."

Verification Rationale: 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 Lessons Learned:

3.2.6 Landing Gear Actuation

3.2.6.1 Landing Gear Actuation - Retraction-Extension System

3.2.6.1 - a "The landing gear retraction and extension shall be actuated by crew members by ____________."

Rationale and Guidance: The intent of this requirement is to identify the technique required for landing gear actuation. Normally the gear actuation is accomplished by actuation of a standard gear handle, located in a prescribed position on the instrument panel (STANAG 3220). However, an option is needed to accommodate other than the standard installation without requiring a specification deviation. The need for standardization is to reduce aircrew training required for transition from one air vehicle to another. The blank should reflect the desired arrangement. The using command should have a positive input into this requirement. Another option would be to not specify the controls or include this requirement.

Performance Parameters: Gear handle design and placement, cockpit arrangement and standard operating procedures control this requirement.

Background and Source of Criteria: This requirement was previously stated in specification MIL-STD-203 and AFSC Design Handbook 2-2 in a form that could not be tailored. Previous requirements include International standardization agreement (STANAG 3220, Location, Actuation, and Shape of Airframe Controls for Fixed Wing Air vehicle).

Lessons Learned: The following criteria has been used in the past for location and actuation of the landing gear control:

"Install the landing-gear control lever so that it is forward of the power controls when they are in the full-open position (STANAG 3220, Location, Actuation, and Shape of Airframe Controls for Fixed Wing Air vehicle). Ensure that the landing-gear control is UP for wheels up, and DOWN for wheels down, and that it is so marked. In single- or tandem-pilot air vehicle, install the landing-gear control lever on the left side of the pilot's cockpit. In side-by-side air vehicle, install the landing-gear control lever where it is conveniently accessible to both the pilot and copilot (STANAG 3220, Location, Actuation, and Shape of Airframe Controls for Fixed Wing Air vehicle). In the case of exceptionally wide cockpits (where compromise of accessibility by both the pilots is required) locate the control lever so as to favor operation by the copilot."

Some air vehicle have a three position landing gear control that requires the pilot to use two movements during the landing gear retraction. The first applies pressure to the retraction system. The second depressurizes the system after the landing gear is retracted. A two position control with automatic removal of pressure is considered desirable because it reduces pilot workload.

The method of actuation should be given careful consideration. Usually, the control handle actuates several electrical switches or is mechanically connected to the selector valve. Both approaches have been used successfully. Equipment should be designed with minimum dependence on proper rigging. Figure 3.2.6.1 a-1 is a list of the types of control systems used on various air vehicle.

A solenoid operated mechanical lock is used on most air vehicle to prevent inadvertent selection of landing gear retraction while the air vehicle is on the ground. The lock is unlocked by an electrical signal from landing gear mounted switches that detect that the air vehicle is in flight. Usually, an override switch is provided to enable the pilot to retract the landing gear while on the ground, or in the event of failure of the lock to unlock. An alternate approach is to interrupt the retraction command electrical circuit directly. This approach has been successfully used on a recent air vehicle (F-15).

Verification (Paragraph 4.2.6.1):

"Retraction-extension system operation and operating characteristics shall be demonstrated by ______________."

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

Verification Lessons Learned:

Retraction/Extension Controls

Air vehicle Type	Type of Control	Failure Rate
A-7	Mechanical	
A-10		
B-52		
B-57	Electrical	
B-66	Electrical	
C-5		
C-7		
C-123	Electrical	
C-130		
C-135	Mechanical	
C-141	Electrical-Multivalve	
F-4	Electrical	
F-5	Electrical	
F-15	Electrical-Multivalve	
F-16	Electrical	
F-100	Electrical	
F-105	Mechanical	
F-106	Electrical	
F-111	Electrical	
T-37	Mechanical	
T-38	Electrical	
T-39	Electrical	

Figure 3.2.6.1 a-1

3.2.6.1 Landing Gear Actuation - Retraction-Extension System

3.2.6.1 - b "If used, fairing door actuation and locking shall be ________."

Rationale and Guidance: 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.

Performance Parameters: Door sequencing, normal operating positions, power sources sequence control, switch designs and functions, emergency controls, and maintenance procedures all impact the meeting of this requirement.

Background and Source of Criteria: This item was previously contained in AFSC DH 2-1 and AFSC DH 1-6. The requirement dates back to ARDCM 80-1 or HIAD in the 1955 time period.

Lessons Learned:

1. 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.

2. Current air vehicle use one or more of the three basic types of sequencing: mechanical, hydraulic, or electrical. Mechanical consists of use of links, bellcranks, torque tubes, etc. 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. Figure 3.2.6.1 b-1 is a listing of the types of sequencing used on various current air vehicle.

3. F-5, F15, and T-38 type air vehicle 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.

4. 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 must be developed that adequately simulate the in-flight operation. If this is not possible with the proposed design, the design must be changed to provide a practical operational air vehicle.

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

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

<u>Verification</u> (Paragraph 4.2.6.1):

"Retraction-extension system operation and operating characteristics shall be demonstrated by ____________."

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

<u>Verification Lessons Learned</u>:

Landing Gear Actuation System
Landing Gear/Fairing Door Sequence Method

Air vehicle Type Gear	Nose Landing Gear	Main Landing
A-7	Mechanical	Mechanical
A-10		
B-52		
B-57	Hydromechanical	Hydromechanical
B-66	Hydromechanical	Hydromechanical
C-5	Electrical	Electrical
C-7		
C-123		
C-130		
C-135		
C-141		
F-4	Hydromechanical	Hydromechanical
F-5	Electrical	Electrical
F-15	Electrical	Electrical
F-16		
F-100	Electrical	Electrical
F-105	Hydromechanical	Hydromechanical
F-106	Electrical	Electrical
F-111	Mechanical	Hydromechanical
T-37	Mechanical	Electrical
T-38	Electrical	Electrical
T-39	Mechanical	Electrical

Figure 3.2.6.1.b-1

3.2.6.1 Landing Gear Actuation - Retraction-Extension System

3.2.6.1 - c "The probability of occurrence of a single failure that results in failure of any landing gear assembly to extend and lock in the position for landing shall not exceed _______ per mission."

Rationale and Guidance: This requirement is needed to establish an acceptable level of failure rate for the extension system. It indirectly establishes component reliability and system redundancy requirements. Experience has indicated that it is impractical to eliminate all critical single failures. This requires full system redundancy that not only increase cost but also results in complex systems that are difficult to maintain. This requirement recognizes this fact, and should reduce the possibility of development delays and cost that result from trying to design a "perfect" system.

Perforamnce Parameters. System redundancy, power sources, lock designs, actuator reliability, and linkage stress levels all have an influence on meeting this requirement.

Background and Source of Criteria: This is essentially a new requirement in that a quantitative statement of performance has not been used in the past. The past approach was to specify a general level of redundancy and to prohibit or require certain design features. Requirements were contained in AFSC Design Handbook 2-1.

Lessons Learned:

1. Figure 3.2.6.1.c-1 is a list of landing gear extension failure rates experienced on several current air vehicle. These should be used as a basis for establishment of rates for new air vehicle.

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

Verification (Paragraph 4.2.6.1):

"Retraction-extension system operation and operating characteristics shall be demonstrated by _____________."

Verification Rationale: 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 Lessons Learned:

Landing Gear Extension Failure Rates

Air vehicle Type	Failures Per Flying Hour	Failures Per Landing	Observation Period	
			Hours	Landings
A-7				
A-10				
B-52				
B-57				
B-66				
C-5				
C-7				
C-123				
C-130	$.8 \times 10^{-6}$	1.0×10^{-6}	6.1×10^{6}	4.9×10^{6}
C-135				
C-141	$.8 \times 10^{-6}$	1.7×10^{-6}	4.9×10^{6}	2.3×10^{6}
F-4				
F-5				
F-15				
F-16				
F-100				
F-105				
F-106				
F-111				
T-37				
T-38				
T-39				

Figure 3.2.6.1.c-1

3.2.6.1 Landing Gear Actuation - Retraction-Extension System

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

Rationale and Guidance: This requirement is to insure 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.

Performance Parameters: Hydraulic or electrical system design, gear sequencing and methods of control are significant parameters.

Background and Source of Criteria: This requirement is from the AFSC Design Handbook 2-1. It is believed that all current operational air vehicle comply.

Lessons Learned: It may not be possible to meet this requirement with a system using mechanically actuated hydraulic valves to sequence landing gear and 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 is any critical time periods that a control reversal will create a problem. Consideration of dynamic loads and time delay functions of the system may be required for an accurate analysis.

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

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

Verification (Paragraph 4.2.6.1):

"Retraction-extension system operation and operating characteristics shall be demonstrated by ______________."

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

Verification of the control reversal characteristics should be accomplished on a landing gear simulator and 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:

3.2.6.1 Landing Gear Actuation - Retraction-Extension System

3.2.6.1 - e "Retractable landing gear shall retract into an aerodymanically faired enclosure and the fairing doors if used, shall close and lock without damage at all airspeeds from __________ to _________ for flight at _____."

Rationale and Guidance: 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 of 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 must be defined. This should include temperature (usually 59°F), altitude (usually sea level), air vehicle attitude (side slip, yaw, pitch, roll) and possibly configuration.

Performance Parameters: Minimum flying speed, landing gear extended and extension limit speeds, takeoff performance, air vehicle maximum and minimum weights, landing gear complexity and operating time are factors that influence the design need.

Background and Source of Criteria:

1. Landing gear retraction limit airspeed for several current air vehicle are shown in Figure 3.2.6.1.e-1.

2. Aerodynamic loads on the landing gear and doors are frequently difficult to predict. Errors to 100% have been experienced. This may result in severe restriction 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.

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

Verification Lessons Learned:

Verification (Paragraph 4.2.6.1):

"Limits of speed for retraction and extension shall be determined by analysis of flight test results."

Verification Rationale: 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 Lessons Learned:

Landing Gear Actuation Systems

Airspeed Limits

Air vehicle Type	Airspeed Limits Gear Down	Retract	Extend	Emergency Extend
A-7	244 knots	220 knots	220 knots	180 knots
A-10	200	200	200	200
B-52	305	220	305	305
B-57	200	200	200	200
B-66	250	250	250	250
F-4	250	250	250	250
F-5A/B	240	240	240	240
F-5E	260	260	260	260
F-15	300	300	300	250
F-16	300	300	300	300
F-100	230	230	230	230
F-105	275	240	275	275
F-106	280	280	280	250
F-111	295	295	295	295
T-37	150	150	150	150
T-38	240	240	240	240
T-39	180	180	180	180

Figure 3.2.6.1.e-1

3.2.6.1 Landing Gear Actuation - Retraction-Extension System

3.2.6.1 - f "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 ________ to ________ for flight at ___________."

Rationale and Guidance: 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. Rationale for statement completion include:

The minimum air speed 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."

Background and Source of Criteria: 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.

The maximum airspeed for landing gear extension should be the minimum acceptable to perform the required mission.

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

Performance Parameters: Maximum and minimum landing weights, gear placard speeds, actuator power, and strength, and fairing door designs are limiting factors for this requirement.

Lessons Learned:

1. Figure 3.2.6.1.e-1 is a list of extension limit speeds used on various current air vehicle. These values are pilot handbook recommendations and may not represent original design requirements.

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

3. 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.

4. 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.

Verification (Paragraph 4.2.6.1):

"Limits of speed for retraction and extension shall be determined by analysis of flight test results."

Verification Rationale: 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 Lessons Learned:

3.2.6.1 Landing Gear Actuation - Retraction - Extension System

3.2.6.1 - g "Loss of any landing gear fairing door used shall not result in ___________."

Rationale and Guidance: This requirement is to insure that the design approach minimizes the effect of loss of a fairing door. Usually the statement should be completed by the phase: "loss of the actuation power system." 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.

Performance Parameters: - Retraction - extension system power designs, line routing, door designs, lock positions, and position indication systems have significant influence on meeting this requirement.

Background and Source of Criteria: This is a new requirement which reflects lessons learned in the area of safety.

Lessons Learned:

1. Routing of hydraulic lines and electrical wires on fairing doors can cause severe problem with landing gear operation if the doors are lost in flight. Usually the landing gear remains operable after door loss if drive power to the actuator and control logic is maintained. Problems were experienced during flight test of C-5A air vehicle, because both electrical and hydraulic lines are mounted on the landing gear doors.

2. 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 inflight dimensions cannot be duplicated on the ground. Problems with door mounted mechanisms were encountered on the B-57 air vehicle.

3. 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.

Verification (Paragraph 4.2.6.1): Retraction - extension system operation and operating characteristics shall be demonstrated by ___________.

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

Verification Lessons Learned:

3.2.6.1 Landing Gear Actuation - Retraction - Extension System

3.2.6.1 - h "A separate emergency extension system shall be provided with the capability to ___________."

Rationale and Guidance: The intent of this requirement is to indicate that an emergency extension system is required and to define characteristics of the system. Usually it will be desirable to provide an expanded statement of characteristics such as: "shall be independent of the normal system except for components stressed by ground loads. "It shall extend the loading gear in not more than _________ seconds at all airspeeds from ________ to ______."

Performance Parameters: System and linkage design details, lock designs, method of emergency extension, redundancy of system with power sources influence this requirement.

Background and Source of Criteria: 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.

Lessons Learned:

1. Figure 3.2.6.1.e-1 is a list of limit speeds for emergency extension of landing gear on several current air vehicle. 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 extention gear limit speed was exceeded. At the time, the C-5A emergency extension limit speed was significantly lower than the present limit.

2. Figure 3.2.6.1.h-1 is a tabulation of the type of emergency extension system used on current air vehicle. 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

Air vehicle Type	Emergency Extension Main	Emergency Extension Nose
A-7	Hydraulic Accumulator	Hydraulic Accumulator
A-10	Mechanical	
B-52		
B-57		
B-66	Alternate Hydraulic	Alternate Hydraulic
C-5	Hydraulic Accumulator/ electric	Hydraulic Accumulator/ electric
C-7		
C-123		
C-130		
C-135		
C-141		
F-4	Pneumatic	Pneumatic
F-5	Mechanical	Mechanical
F-15	Hydraulic Accumulator	Hydraulic Accumulator
F-16	Pneumatic/Free Fall	Pneumatic
F-100	Mechanical	Hydraulic Accumulator
F-105	Hydraulic Accumulator/ Free Fall	Hydraulic Accumulator
F-106	Pneumatic	Pneumatic
F-111	Pneumatic	Pneumatic
T-37	Pneumatic	Pneumatic
T-38	Mechanical	Mechanical
T-39	Mechanical	Mechanical

Figure 3.2.6.1.h-1

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.

3. Manual uplock release - free fall systems. A major problem with these systems is degradation of performance due to inadequate lubrication and corrosion. It should be possible to functionally test such systems on the ground. As in the case of normal system operation, excessive reliance should not be placed on assisting airloads. Actuation forces should be carefully considered to be sure 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.

Verification (Paragraph 4.2.6.1)

"Effectiveness and limits of the emergency extension system shall be evaluated on the air vehicle during flight test."

Verification Rationale: Verification of emergency extension system characterisitcs must be accomplished during flight because air loads and the interface with other air vehicle systems cannot be accurately simulated.

Verification Lessons Learned:

The flight test used to verify performance of the emergency extension system must 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 must be accurately simulated

3.2.6.2 Landing Gear Actuation - Actuation System Indication

3.2.6.2 a "An indicator shall be provided to show ____________."

Rationale and Guidance: This requirement is to define characteristics of the system to be provided to indicate to the aircrew the position and status of the landing gear. This is required on air vehicle with retractable landing gear to enable the pilot to know that the landing gear is in the position required for the intended operation Also the system may warn the pilot of unsafe conditions and permit him to select the proper corrective action.

Performance Parameters: Landing gear complexity, aircrew size and mission requirements are primary considerations in establishment of this requirement.

Background and Source of Criteria: This requirement was formerly contained in AFSC Design Handbook 1-6 MIL-STD-203 also contained a requirement that the indicator(s) be located on the instrument panel or adjacent to the landing gear control lever visible to the pilot(s) in his (their) normal position(s). The general requirement for an indicator has existed in some form for at least 25 years.

Lessons Learned:

1. Normally an indicator should be provided for each separate landing gear assembly. The pilot usually needs to know which landing gear is not in the position selected to properly plan the corrective action.

2. Landing gear indicators are usually lights or electromechanical devices. Usually a green light is used for each landing gear to indicate that it is down and locked. Red lights are sometimes used to indicate that landing gear or doors are not up and locked. In some cases, no indicator is provided for up and locked, however, and unsafe uplock condition is indicated by the warning system (red light in gear handle plus an aural warning). Electromechanical indicators have been used in many air vehicle. These usually show green wheels for gear down, a barber pole design for in-transit and "up" for landing gear up and locked.

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

4. Indicator lights and panel lighting must be designed with replaceable bulbs. A sealed lighting system used on the C-5A air vehicle proved troublesome. Bulb replacement required removal of the entire landing gear control. Replacement of the landing gear control required a complete functional check of the landing gear retraction system. The functional check required that the air vehicle be jacked. What seemed like a good idea at component level had a major impact on system maintenance manhours.

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

6. Landing gear control circuits and the indicator circuits should be separate insofar as possible. This minimizes the possibility that a single switch failure will not only prevent landing gear operation but also falsely indicate the malfunction. Separation of the circuits also usually permits proper indication of landing gear position after emergency extension. Frequently, it is necessary to deactivate normal system control circuits to insure proper operation of the emergency system. Use of common components would result in simultaneous deactivation of the indication systems.

7. Indicator operation after a single failure of the normal 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 was given with the landing gear 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.

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

9. The original nose landing gear position indicator used on C-141A aircraft 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 aircraft accident. The deficiency was eliminated by installation of a switch to detect that the landing gear is extended.

Verification (Paragraph 4.2.6.2): "The gear position indicator system and warning system shall be evaluated during the flight test.

Verification Rationale: 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 fo 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 Lessons Learned:

3.2.6.2 Landing Gear Actuation - Actuation System Indication

3.2.6.2 - b "A warning system shall be provided to ___________."

Rationale and Guidance: This requirement is to define characteristics of the system required to warn the pilot of unsafe landing gear conditions. Normally it covers two conditions. The first is to warn the pilot that the landing gear is not in the position he has selected. The second is that the air vehicle is in a configuration or flight condition required for landing approach but the landing gear is not extended. The warning system is intended to improve safety by reducing the possibility of landing with the landing gear retracted. It also reduces the possibility that the pilot will exceed the landing gear limit speed during landing gear retraction.

Performance Parameters: Gear position monitoring system & design, throttle interconnect, warning system design and controls all impact the effective meeting of this operational need.

Background and Source of Criteria: This requirement was formerly stated in AFSC Design Handbook 2-2. The requirement specifies that a wheel shaped control knob with an internal red warning light and a Type MA-1 audio warning signal (complying with MIL-S-9320) shall be used. Most current air vehicle comply with this approach since the requirement has existed for at least 20 years.

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

"Provide a Type MA-1 audio warning signal (complying with MIL-S-9320) that automatically actuates when the following conditions exist simultaneously:

a. The air vehicle is below a preset altitude.

b. The IAS of the air vehicle is less than a preset value.

c. In turbine engine air vehicle, the throttle is less than a predetermined power setting. In reciprocating engine air vehicle, the throttle is less than normal cruise position.

d. The landing gear is not down and locked.

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.

Verification (Paragraph 4.2.6.2): "The gear position indicator system and warning system shall be evaluated during the flight test.

Verification Rationale: Suitability of operation of the warning system can be determined only by flight test of the air vehicle. Normally no special test is required. The warning system is evaluated as a part of general flight test evaluation of the air vehicle.

Verification Lessons Learned:

3.2.6.2. Landing Gear Actuation - Actuation System Indication

3.2.6.2 - c "An override shall be provided for aural warning system."

Rationale and Guidance: Frequently, an audible warning is provided to the pilot for gear positioning. This has been known to interfere with radio communication with the ground. Therefore, most using commands desire the ability to override the warning for better pilot control.

Performance Parameters: Warning system design, radio system, and pilot responsiveness impact this requirement.

Background and Source of Criteria: This requirement was formerly stated in AFSC Design Handbook 2-2. Most current air vehicle comply with the requirement.

Lessons Learned:

1. The recommended position for the aural warning signal silencing switch is adjacent to the landing-gear actuating lever.

2. The aural warning override switch should include a reset system. Gear up landings have occurred because the warning was silenced during landing approach practice only to be forgotten during the final landing. The warning should sound each time the unsafe condition occurs.

3. Override and reset logic sometimes becomes a complex problem for cargo air vehicle. Frequently the air drop conditions are similar to landing approach conditions. A landing closely following an airdrop operation may result in failure of the warning to sound during the landing approach.

Verification (Paragraph 4.2.6.2): "The gear position indicator system and warning system shall be evaluated during the flight test.

Verification Rationale: Suitability of the design approach can be determined only as a part of overall air vehicle evaluation. Evaluation should be accomplished as part of the normal flight test program. Specific demonstrations may be required to verify satisfactory operation of the override reset function.

Verification Lessons Learned:

3.2.6.3 Landing Gear Actuation - Retraction - Extension time

3.2.6.3 - a "The time from selection of landing gear retraction or extension until all landing gear are retracted and locked and all fairing doors where used, are closed and locked or gear is extended and locked shall be compatible with air vehicle performance."

Rationale and Guidance: This requirement is necessary to prevent compromise of the air vehicle performance by a slow operating landing gear. Several air vehicle in the past have been restricted during take off and climb because the air vehicle acceleration rate would result in landing gear limit speeds being exceeded before the landing gear is fully retracted. The restriction is very undesirable not only because of the reduced performance, but also due to the safety hazard created by the increase in pilot workload and the possibility of landing gear damage. The requirement also covers the possibility that the time of landing gear operation may be critical for the landing approach phase.

Performance Parameters: Temperature engine thrust, gear placard speeds, required maneuvers, air vehicle acceleration rates from various maneuvers, retraction - extension sequence, power source and limits, and lock designs are infuential in meeting this requirement.

Background Source of Criteria: This requirement is a new approach compared to former statements of landing gear operating time requirements. Formerly AFSC Design Handbook 2-1 established maximum time limits dependent upon the type of actuation system (manual or powered) and system operating temperature (twice normal time permitted for low temperature). It also required that the landing-gear be fully retracted prior to reaching 75% of the limit airspeed when a maximum acceleration take-off was performed. DH 2-1 requirements originated from ARDC Manual 80-1 (HIAD). HIAD requirements were generated in the early 1950 time period and generally were the result of lessons learned.

This requirement is more general and is intended to permit the air vehicle designer to trade landing gear limit speed for operating time.

Lessons Learned:

1. Figure 3.2.6.3.a-1 is a listing of design operating times for several current air vehicle. These times are considered compatible with the performance and original design mission requirements of these air vehicle.

2. Using commands may want to specify some maximum operating times based on mission requirements or experience with current air vehicle. Such requests should be fully analyzed to insure that the design constraint is necessary. Absolute maximum limits can be accommodated by addition of the statement to this paragraph.

3. Low temperature frequently severely degrades operating time due to increased viscosity of hydraulic fluid and lubricants. Rotary drive systems seem more susceptable 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.

4. 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.

5. Very short operating time usually result 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.

Verification (Paragraph 4.2.6.3): Retraction and extension times shall be evaluated by ______________________________."

Verification Rationale: The general suitability of the operating times can be determined only by flight test because the time is a result of the air vehicle flight configuaration, airspeed, performance and specific mission requirements. Suitability of the times for operation at abnormal conditions, such as a cold soak, may be easier to accomplish on a laboratory simulator. If the operating time is very dependent upon airloads, it will be necessary to simulate airloads in the laboratory. Accurate simulation of airloads and airload distribution is generally difficult.

Verification Lessons Learned:

LANDING GEAR ACTUATION SYSTEMS
OPERATING TIMES

Air vehicle Type	Retract	Extend	Emergency Extend
A-7	- sec	- sec	sec
A-10	6 - 9	6 - 9	
B-52	8 - 10	10 - 12	
B-52	-	-	-
B-66	10	8	
C-5	20	20	180
C-7	-	-	-
C-123	9	6	
C-130	19	19	
C-135	10	10	
C-141	-	-	
F-4			
F-5	6	6	
F-15			
F-16			
F-100	6 - 8	6 - 8	
F-105	4 - 8	5 - 9	
F-111	18	26	
T-37	10	8	
T-38	6	6	
T-39	-	-	

Figure 3.2.6.3.a-1

3.2.6.3 Landing Gear Actuation-Retraction-Extension Time

3.2.6.3 - b "The time from selection of landing gear extension by the emergency actuation system until all landing gears are extended and locked and all necessary fairing doors are in position required for landing shall _____________."

Rationale and Guidance: Emergency extension system operating time is more arbitrary than normal operating time. It is not as closely related to air vehicle performance but rather is driven by the need to minimize aircrew workload and attention requird for this phase of emergency landing. Some form of an absolute limit should be established based on operational experience because this design characteristic is very difficult and expensive to change once the design has been frozen. This requirement may be made somewhat flexible by completing the blank with a phrase such as "not exceed twice the normal extension time."

Performance Parameters: Emergency power versus normal power, control system designs, gear placard speeds or limitations, and temperature impact meeting this need.

Background and Source of Criteria: These requirements were previousy described in AFSC DH 2-1 and originally were presented in ARDCM 80-1 (HIAD).

Lessons Learned:

1. Figure 3.2.6.3.a-1 is a tabulation of emergency extension system operating times for several current air vehicle. These times are considered acceptable for the original design mission of the air vehicle.

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

3. 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.

4. 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.

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

Verification (Paragraph 4.2.6.3): "Retraction and extension times shall be evaluated by ____________________________."

Verification Rationale: Emergency extension operating time is normally a factor of the air loads. It usually will be necessary to determine suitability by flight test. In the event that emergency extension time is very close to normal operating time or is not influenced by air loads it may be acceptable to perform the test with the air vehicle on jacks. An alternative is to use a laboratory simulation. This may be the best approach for investigation of performance under adverse conditions such as low temperature.

Verification Lessons Learned:

3.2.6.4 Landing Gear Actuation - Position Restraint

3.2.6.4 - a "A means shall be provided to maintain each landing gear in the selected position."

Rationale and Guidance: The objective of the requirement is to establish performance for gear positioning. Generally, "locks" are the solution to the positioning problem.

Performance Parameters: Details of the lock design, system dynamics, impact on the latch, actuation and controls, lock positioning, gear kinematics system redundancy, gear and lock flexibility and deflections have individual influences on this operational need.

Background and Source of Criteria: The requirement for automatic operating positive mechanical locks was formerly stated by AFSC Design Handbooks 1-6 and 2-1. These requirements were based on ARDCM 80-1 (HIAD) that were generated primarily on lessons learned.

Lessons Learned:

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

2. Landing gear and door locks should be designed for proper rigging while on the ground. Some designs have been used in the past that require compensation for the fact that alignment of parts of the lock are dependent upon the amount of airload applied. These designs require considerable flight test effort to develop suitable rigging procedure. Frequently, the problem is not recognized and severe flight test delays result. In most cases, the problem can be avoided by mounting major lock components on fixed structure and providing guides to direct moving parts to the proper position.

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

4. Landing gear downlocks should be designed so that they are not stressed by ground loads. Downlocks subjected to ground loads are exposed to a severe fatigue stress environment that may be highly dependent upon lock rigging. Durability testing on a single landing gear may not accurately reflect operational design life. If the design dictates that the downlock must carry ground loads, it is recommended that the lock be non-adjustable.

5. hydraulic pressure variations due to surges or themal 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.

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

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

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

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

10. Uplocks should be designed so that flight inertia loads of the landing gear do not load the actuation mechanism.

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

Slight (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 uses air pressure in conjunction with strut extension for proper inflation of the shock struts. The strut extension is measured in one-eight inch increments and the air pressure is held to plus or minus twenty-five 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 pounds increments which makes accurate air servicing very difficult and almost impossible to meet the plus or minus 25 pound requirement.

Verification (Paragraph 4.2.6.4): "The adequacy of the landing gear restraint provisions shall be evaluated by ________. Failure mode and effect will be determined analytically and further evaluated by __________."

Verification Rationale: Suitability of the lock system should be evaluated by flight test. Evaluation of preformance 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 Lessons Learned:

3.2.6.4 Landing Gear Actuation - Position Restraint

3.2.6.4 - b "Where doors are used in conjunction with landing gear, the method used to restrain the landing gear in the selected position shall have the following characteristics: ___________________."

Rationale and Guidance: Experience has indicated that it is undesirable to retain the landing gear in the uplocked position by linkage to the doors or doorlocks. Loss of doors in flight is not unusual and not too hazardous. If linked to the landing gear, however, inadvertent extension of the landing gear will result and a major accident may occur. The following is suggested: "Gapping or loss of a landing gear door due to structural overload shall not result in extension of the landing gear."

Performance Parameters: Gear detail design, lock detail design, controls, power sources and sequences impact meeting this operational need.

Background and Source of Criteria: This is a reflection of AFSC DH 2-1 and 1-6 criteria previously contained in those documents and are based on lessons learned.

Lessons Learned:

1. This requirement should not prohibit use of systems that depend on the landing gear uplocks to keep doors closed. These systems have been used on fighter air vehicle, F-4 for example, with considerable success. An inherent disadvantage of this approach is that door linkage must be rigged to provide proper preload of the door. The preload must be enough to prevent door gapping 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.

2. 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. This can be avoided only by electrical or hydraulic interlocks. 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.

Verification (Paragraph 4.2.6.4): "The adequacy of the landing gear restraint provisions shall be evaluated by _________. Failure modes and effect will be determined analytically and further evaluated by __________."

Verification Rationale: Characteristics of the landing gear uplocking and the door locking can be determined by inspection of the hardware and engineering drawings.

Verification Lessons Learned:

3.2.6.4 Landing Gear Actuation - Position Restraint

3.2.6.4 - c "Ground safety provisions shall be provided to prevent retraction under of the following conditions: ______________. Provide indicators to alert ground crews to assure removal of safety devices prior to flight."

Rationale and Guidance: There have been numerous incidents of inadvertent or uncoodinated gear retractions during landing gear maintenance which have resulted in personnel injury. Therefore, operational needs exist to provide a design which precludes this characteristic. Inadvertant gear handle actuation, transient hydraulic or electrical signals, EMI, physical impact of gear linkages, flight maneuvers or other shall be included in the blank.

Performance Parameters: Lock and gear detail design maintenance procedures, and lock accessibility are important considerations in meeting this need.

Background and Source of Criteria: Previously, ground lock requirements were contained in AFSC DH 201 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.

Lessons Learned:

1. 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.

2. Landing gear locks used on cargo air vehicle should be designed so that they may be installed by the aircrew with the air vehicle in flight. This provides added assurance that landing gear are downlocked after emergency extension.

3. 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.

4. Permanently attach a red warning streamer to the safety lock or pin as an indication that it is in place. If required, provide a small flexible cable

(approximately one-sixteenth inch diameter) as an extension between the safety lock or streamer to insure a minimum visible streamer protrusion of 24 inches from the air vehicle.

5. 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.

Verification (Paragraph 4.2.6.4): "The effectiveness and adequacy of the ground safety locks shall be evaluated during flight test."

Verification Rationale: 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 Lessons Learned:

3.2.6.4 Landing Gear Actuation - Position Restraint

3.2.6.4 - d "The air vehicle, actuation system, or ground safety provision shall not be damaged in the event that ________________."

Rationale and Guidance: Normally this requirement should be completed with the phrase; "retraction is selected with the safety lock installed." This requirement is needed not only to verify that the lock will perform the required function, but also that the system will not be damaged if the ground locks are inadvertly left installed for flight. Experience indicates that the ground locks sometimes are forgotten. This error should not cause major system problems.

Performance Parameters: Lock designs, hydraulic system pressure and characteristics, maintenance procedures and functions all impact meeting this requirement.

Background and Source of Criteria: This reflects a requirement previously presented in AFSC DH 2-1.

Lessons Learned:

Verification (Paragraph 4.2.6.4) "... The effectiveness and adequacy of the safety locks shall be evaluated during flight test."

Verification Rationale: Compliance with this requirement should be determined by a demonstration with the air vehicle on jacks. The actuation mechanism and the ground locks should be carefully inspected for damage after the demonstration.

Verification Lessons Learned:

3.2.7 Auxiliary Deceleration Devices

3.2.7.1 Auxiliary Deceleration Devices - Arresting Hook Systems

3.2.7.1 - a "The arresting hook system shall be capable of decelerating ________ air vehicle to a stop by engaging __________ arrestment system at ________."

Rationale and Guidance: This is a performance statement for the emergency arresting hook system. The maximum weight or configuration of the air vehicle to be arrested should be defined. The intended arresting system belongs in the second blank. If this value is not known, use the BAK-13, which produces the highest hook load. The speed of engagement is inserted in the last blank and defines 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 shall be used.

Performance Parameters: Barrier system design and limits, hook compatibility, air vehicle configuration and engaging speeds control this requirement.

Background and Source of Criteria: This requirement was previously implied by Figure 1 of specification MIL-A-83136 (USAF). The verification aspects are defined in AFSC DH 2-1. The original emergency tail hooks were retrofitted on USAF air vehicle in the 1958-1959 time period, and modified criteria from the Navy specification MIL-A-18717, was used to establish criteria. Through the efforts and cooperation of Industry, specification 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.

Lessons Learned: The spring type hook shanks have exhibited numerous problems both during testing and operation in the field. If a spring type 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.

Figure 3.2.7.1 a-1 is a summary of the air vehicle which utilize arresting hooks and the type employed:

Air vehicle	Type of Arresting Hook
F-100	Cantilever Spring
F-101	Cantilever Spring
F-102	Full Shank
F-104	Cantilever Spring
F-105	Cantilever Spring
F-106	Full Shank
F-111	Full Shank
A-7D	Operational-Full Shank
F-4	Operational-Full Shank
F-15	Tubular Shank
F-16	Tubular Shank
F-5	Tubular Shank

Figure 3.2.7.1 a-1

Verification (Paragraph 4.2.7.1): "Performance limits for arresting hook systems shall be evaluated by air vehicle test with the specified arrestment system."

Verification Rationale: 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 demensional and dynamic response as a system.

Verification Lessons Learned:

3.2.7.1 Auxiliary Deceleration Devices - Arresting Hook Systems

3.2.7.1 - b "Arresting hook system and attachment shall withstand loads of __________ fly-in engagement."

Rationale and Guidance: 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.

Performance Parameters: Barrier system energy capacity, hook design loads, hook point design, air vehicle configuaration, and weight all impact and control meeting this operational need.

Background and Source of Criteria: This is a new requirement. The loads should be the same as taxi engagement for the same gross weight-velocity engagement. Specification MIL-A-83136 previously excluded fly-in engagements, but this requirement establishes performance for such a maneuver, since the user needs this option in case of emergency.

Lessons Learned: The fly-in engagement loads are significantly higher than those encountered when taxiing into the barrier. Therefore, the weight of air vehicle which can be recovered within the design load envelope is reduced. The impact dynamic loads are high, as well as the loads due to higher energy transmission. It would be anticipated that local damage to the underside of the air vehicle could be expected due to fly-in engagement.

Verification (Paragraph 4.2.7.1): "Performance limits for emergency arresting hook systems shall be evaluated by air vehicle flight test with the specified arrestment system."

Verification Rationale: Since the performance is basically a function of interface and compatibility with the arrestment system, the most logical demonstration is on the air vehicle with the intended barrier system. The dynamic effects play a major part in the ability to arrest the intended air vehicle.

Verification Lessons Learned:

3.2.7.1 Auxiliary Deceleration Devices - Arresting Hook Systems

3.2.7.1 - c "The probability of successful engagement of the arresting system shall be not less than ____________ for all air vehicle landing attitudes."

Rationale and Guidance: This requirement is to establish an acceptable level of reliability of the arresting hook system. It is primarily intended to insure consideration of proper positioning of the hook and prevention of hook bounce. The blank 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.

Performance Parameters: Runway roughness, damping characteristics, discrete bump characteristics, and hold-down force are parameters influencing the ability to meet this requirement.

Background and Source of Criteria: Design criteria were previously furnished in specification MIL-A-83136 and AFSC DH 2-1.

Lessons Learned:

1. Figure 3.2.7.1 c-1 provides rates of successful engagement with some current arresting hook systems. It can be used as a guide to establish a performance requirement.

Air vehicle	Attempted Arrestments	Arrestment Failures	Successful Arrestment Rate
F-100			
F-101			
F-102			
F-104			
F-105			
F-106			
F-111			
A-7D			
F-4			
F-5			
F-15			
F-16			

Figure 3.2.7.1 c-1. Successful Engagement Rates

2. 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 shall not exceed 2 1/4 inches before arrestment. This has been found to be one way to improve the probability of success and should be strongly considered by the designer. Hook bounce is limited by using a damper.

Damping is usually provided by a hydraulic or mechanical damping device. Figure 3.2.7.1 c-2 summarizes the type of damper provided on the various emergency arresting hook systems currently in our inventory.

Aircraft	Type of Damper
F-100	None
F-101	None
F-102	hydraulic
F-104	None
F-105	hydraulic
F-106	None
F-111	Hydraulic
A-7D	Hydraulic
F-4	Hydraulic
F-15	Hydraulic
F-16	Spring
F-5	Hydraulic

Figure 3.2.7.1 c-2. Available Damping Methods

Verification (Paragraph 4.2.7.1): "The probability successful engagement shall be determined by anlysis of flight test results."

Verification Rationale: The requirement must 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 must be considered. If the design or procedures that caused the arrestment failure are not corrected, probability of recurrence of the condition must be considered in the analysis.

Verification Lessons Learned:

3.2.7.1 Auxiliary Deceleration Devices - Arresting Hook Systems

3.2.7.1 - d "Hook installation shall have lateral freedom for ___________."

Rationale and Guidance: Frequently, air vehicle will contact the ground off-center on the runway and in a drift landing attitude, which would make engagement other than straight into the center of the cable span. Therefore, limits on off-center and alignment engagement should be established for operational requirements. In the past, 20% off-center and 20° misalignment have been selected for design purposes.

Performance Parameters: Lateral hook loads, centering forces, barrier characteristics, crosswind, direction and velocity, are characteristics impacted by this requirement.

Background and Source of Criteria: This requirement was previously stated in specification MIL-A-83136. A portion was in the Performance Section and a portion was previously in the Verification or Quality Assurance Section. It is expected that this requirement originally stemmed from the Navy requirement as expressed in MIL-A-18717.

Lessons Learned: 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 F111 and F5, it was found to be best to maintain control with the use of rudder rather than steering. Rollback after completion of the runout is also a problem. If the brakes are applied too abruptly, air vehicle with aft c.g. situations will sit back on the tail and suffer structural damage. Each air vehicle must develop the proper technique for the design for steering and handling of rollback. Another problem with rollback is catching the hook point on runway irregularities. This can accentuate the tendency to tip back.

A method should be provided to keep the shank on the aircraft centerline prior to engagement but permit movement after engagement.

Verification (Paragraph 4.2.7.1): "Performance limits for emergency arresting hook systems shall be evaluated by air vehicle flight test with the specified arrestment systems. The dynamic and design characteristics will be evaluated by inspection."

Verification Rationale: Compatibility with the arrestment system is best demonstrated by the air vehicle with the intended system. Dynamic response of the system can be predicted to a limited degree, but the final proof is an actual demonstration.

Verification Lessons Learned:

3.2.7.1 Auxiliary Deceleration Devices - Arresting Hook Systems

3.2.7.1 - e "Service life of the arresting hook shall be ______________ without replacement of components except: _________________."

Rationale and Guidance: 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. Design life should be determined by analysis of the air vehicle mission and arrestment concepts. If no study results are available, it is suggested that a service life of 1000 landing engagements without replacment of components except that ground contacting elements may be replaced after each 15 landing engagements be used.

Performance Parameters: Hook point wear characteristics, attachment fatique characteristics, shank design and load levels, and hook materials, are parameters influencing the ability to meet this requirement.

Background and Source of Criteria: This is a new requirement. MIL-A-83136 required a replaceable hook point.

Lessons Learned: "Weak link" theory must be considered in design of an arresting hook system. Inadvertant overload is frequently a possibility due to the hostile environment in which the hook is loaded. Frequently, the most severe loads are dynamically applied, and these are the most difficult to calculate. Therefore, attachment structure is extremely critical for capacity and life. Attachment is usually integral with the structure or bulkhead of the fuselage.

Obviously, the hook life will be very low if the hook shank and hook point are integral. If life over 15 landings is desired, the hook point should be separate from the shank to minimize replacement cost.

The F-111/FB-111 hook shank and point were integral. During Category II testing, the average life for FB-111 hook was 6 or 7 landings. The F-111A average life was 10-12 landings. These are considered to be economically high. The replacement hook cost was $3,200.00 in 1966.

Verification (Paragraph 4.2.7.1): "Service life of the hook will be evaluated by laboratory tests for fatigue life and air vehicle tests for durability."

Verification Rationale: 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 Lessons Learned:

3.2.7.1 Auxiliary Deceleration Devices - Arresting hook Systems

3.2.7.1 - f "The retracted hook shall preclude ________________."

Rationale and Guidance: The objective of this requirement is to establish a safety requirement for landings where hook engagement is not desired. Rather than define a prescribed ground clearance at maximum tail down attitude, including compressed tires and struts, this requirement is a statement that the stowed hook shall not inadvertently engage the barrier or arresting system while in the most critical condition.

Performance Parameters: Physical details of the hook design, aft fuselage detail design, and high angle of attack flying characteristics impact meeting this design requirement.

Background and Source of Criteria: This requirement was previously contained in specification MIL-A-83136.

Lessons Learned: Generally, tail hooks have provided a minimum ground clearance of 14 inches in the stowed position at maximum tail down attitude. This rule of thumb has been to insure ground clearance for the cable which is rebounding from the main tires running over it. It may be conservative, but it represents lessons learned by the Navy after years of experience in arresting hook design and installation.

If such clearance cannot be provided, a fairing can provide suitable protection to preclude inadvertent hook-cable engagement. Considerable damage to the fairing was experienced on the F111 during Category II testing at Edwards Air Force Base. 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.

Verification (Paragraph 4.2.7.1): "The dynamic and design characteristics shall be evaluated by inspection."

Verification Rationale: No special tests can be conceived to evaluate inadvertent hook engagement on routine landings. This will become readily apparent by observation.

Verification Lessons Learned:

3.2.7.1 Auxiliary Deceleration Devices - Arresting Hook Systems

3.2.7.1 - g "Current position of the hook shall be indicated in the cockpit."

Rationale and Guidance: 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.

Performance Parameters: Cockpit design, arresting hook position display, position sensing circuit, redundancy of circuit, power sources, and switch design and location impact the ability to meet this operational need.

Background and Source of Criteria: This is a new requirement not previously contained in prior documentation.

Lessons Learned: Experience on recent air vehicle indicates that location of the arresting hook release lever is important. On the F111A and the F15A, 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.

Verification (Paragraph 4.2.7.1): "The dynamic and design characteristics shall be evaluated by inspection."

Verification Rationale: Observation from drawings, mock-up, or actual air vehicle confirm the adequacy of the arresting hook controls.

Verification Lessons Learned:

3.2.7.1 Auxiliary Deceleration Devices - Arresting Hook Systems

3.2.7.1 - h "For maintenance activity, the hook installation shall have ____________________."

Rationale and Guidance: Numerous features are available for arresting hook system designs. Each adds complexity and are cost drivers. If such features are known to be desired by the intended user, this requirement should reflect such choice.

Performance Parameters: Detail hook design, user's needs and maintenance procedures are influenced by this requirement.

Background and Source of Criteria: This requirement contains some previous requirements of specification MIL-A-83136 and has the potential of adding new requirements. The retraction/extension features were previously defined. AFSC DH 1-6 also contained a discussion of this item.

Lessons Learned: If the arresting hook extension is designed to be used only under emergency conditions, no retracting mechanism has been required in the past. However, a positive latching device, which prevents inadvertent extension in flight or on the ground, should be provided. If the system is electrically actuated, the controls from the cockpit to the uplock release mechanism should be totally redundant. In the past, extension time has been limited to two seconds or less. With electrically actuated release mechanisms, the ground safety pin should interrupt the electrical power to the release mechanism. This will prevent release mechanism damage if the cockpit switch is actuated with the ground safety pin installed.

In the interest of personnel safety, the release mechanism should prevent installation or removal of the ground safety pin with the arresting hook in any position other than fully up and locked.

Verification (Paragraph 4.2.7.1): "The dynamic and design characteristics shall be evaluated by inspection."

Verification Rationale: Design features are best reviewed by inspection of drawings and actual air vehicle installations.

Verification Lessons Learned:

3.2.7.1 Auxiliary Deceleration Devices - Arresting Hook Systems

3.2.7.1 - i "The hook shall be positioned by the following action: ______________________."

Rationale and Guidance: This requirement is to establish the design and performance requirements for the arresting hook control. Factors include location, actuation and design of the control switch. The following has been specified in the past by MIL-STD-203:

(Normal system operation) Single pilot/tandem pilot/ operable by pilot. Actuation - Direction of motion shall correspond to hook movement. Design - When an indicator light is used, it shall be located in the control handle, and shall be "ON" when the arresting hook is inconsistent with control position.

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 pushbutton switch or a guarded hook-shaped, coded toggle switch.

Performance Parameters: Type of arresting hook (normal or emergency), type of aircraft and number of crew influence this requirement.

Background and Source of Criteria: This requirement was formerly included in MIL-STD-203.

Lessons Learned:

Verification (Paragraph 4.2.7.1): "The dynamic and design characteristics shall be evaluated by inspection."

Verification Rationale: 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 Lessons Learned

3.2.7.2 Auxiliary Deceleration Devices - Drag Chutes

3.2.7.2 "For drag chute requirements, see MIL-"

Rationale and Guidance: Rather than duplicate the requirements expressed in the Parachute Systems Prime Document, reference is made to this document. It is intended to recognize the function that parachutes serve in this basic subsystem to assist in achieving air vehicle retardation.

Performance Parameters See MIL-___.

Background and Source of Criteria: MIL-D-9056, etc.

Lessons Learned: See MIL- ___.

Verification: See MIL- ___.

Verification Rationale: N/A

3.2.8.1 Ground Handling - Jacking

3.2.8.1 - a "Jacking provisions shall be provided by ______________________."

Rationale and Guidance: Jacking is classically achieved by jacking at the fuselage or on landing gear axles. This is a simple statement reflecting the desire for such accommodations.

Performance Parameters: Maintenance procedures and functions, jack attachment details and available jack equipment are influenced or are influential in meeting this operational need.

Background and Source of Criteria: A statement such as that proposed cannot be found specifically in any prior documentation. Each mention of jacks assumes jacking needs, but none specifically establish these needs. Generally, most air vehicle have fuselage and axle jacking capability, but design capacity is frequently inconsistent between air vehicle. MIL-STD-809 and MIL-A-8862 have jacking criteria for load factor. MIL-A-8860 requires axle jacking at maximum design gross weight and fuselage jacking at the same weight if they are used to change wheels and tires. The load factor criteria, tied to "design gross weight," dates back to ANC-2, dated 15 Oct 1941. It was carried in subsequent Air Force and Navy documentation until the present. The first notation of axle jacking for maximum design gross weight came in MIL-A-8860, dated 18 May 1960. The fuselage jacking was mentioned in 1960 as applicable at maximum design gross weight if this technique was used for changing tires or wheels. However, there are few air vehicle which utilize this technique. Therefore, for most air vehicle, the fuselage jacking design gross weight remains undefined.

Lessons Learned: It has become Industry practice to design each gear for individual jacking provisions. The installations permit each wheel to clear the ground and allow removal of the wheel or wheels for repair or replacement, without the necessity of removing the struts or any other part of the landing gear structure. The jacking pads are located so that there can be no interference between jacks and the operation of the landing gear system. It has been found that cradle jacks provide greater stability and versatility.

Figure 3.2.8.1 a-1 is a listing of jacking criteria as a function of air vehicle maximum design gross weight for axle and fuselage jacking.

Landing gear jacking pads should be located to preclude the contact of the jack head with any critical part of the landing gear. The jacking pads should be evident and easy to use. C-130 aircraft main landing gear torque struts have been destroyed by incorrect use as a jacking point. Low clearance of the aircraft with a flat tire requires that a special fixture be used for jacking. It may not be evident to maintenance personnel that special procedures are required.

Air vehicle	Axle Jacks	Fuselage Jacks
A-7		
A-10		
B-52		
B-57		
C-5		
C-7		
C-123		
C-130		
KC-135		
C-141		
F-4		
F-5		
F-100		
F-102		
F-104		
F-105		
F-106		
F-111		
F-15		
F-16		
A/T-37		
T-38		
T-39		

Figure 3.2.8.1 a-1. Jacking Weight as a Function of Max Design Gross Weight

Verification (Paragraph 4.2.8.1): "Jacking capability and provisions shall be evaluated on the air vehicle during the flight test program to the specified limits of the system."

Verification Rationale: Since there is considerable interface between the AGE, the air vehicle and the technique, this requirement is best verified with all parts operating as a system on the air vehicle.

Verification Lessons Learned:

3.2.8.1 Ground Handling - Jacking

3.2.8.1 - b *"Axle jacking system shall be capable of raising* __________ weight air vehicle high enough to perform required maintenance while exposed to __________ crosswind from any direction."

Rationale and Guidance: This requirement establishes axle jacking capability. Usually, the maintenance operations of the air vehicle dictate the need to jack a maximum design gross weight air vehicle. The crosswind limit is arbitrarily 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.

Performance Parameters: Air vehicle gross weight, c.g. location, strength of the jack pad and attachment are influences on meeting this operational need.

Background and Source of Criteria: This requirement is expansion of MIL-A-8860 criteria to include crosswind limits.

Lessons Learned: Figure 3.2.8.1 b-1 summarizes the prescribed jack capacity for current inventory air vehicle.

Figure 3.2.8.1. b-2 summarizes the crosswind limits for axle jacking on various inventory air vehicle.

Air vehicle	Main Gear	Nose Gear
A-7		
A-10		
B-52		
B-57		
C-5		
C-7		
C-123		
C-130		
KC-135		
C-141	35 ton	
F-4		
F-5		
F-100		
F-102		
F-104		
F-105		
F-106		
F-111	40 ton	15 ton
F-15		
F-16		
A/T-37		
T-38		
T-39		

Figure 3.2.8.1 b-1. Jack Capacities

Air vehicle	Crosswind Limit
A-7	
A-10	
B-52	
B-57	
C-5	
C-7	
C-123	
C-130	
KC-135	
C-141	
F-4	
F-5	
F-100	
F-102	
F-104	
F-105	
F-106	
F-111	
F-15	
F-16	
A/T-37	
T-38	
T-39	

Figure 3.2.8.1 b-2. Axle Jacking Crosswind Limits

Verification (Paragraph 4.2.8.1): "Jacking capability and provisions shall be evaluated on the air vehicle during the flight test program to the specified limits of the system. Crosswind compatibility shall be verified by analysis."

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

Verification Lessons Learned:

3.2.8.1 Ground Handling - Jacking

3.2.8.1 - c "Fuselage jacking system shall be capable of raising __________ weight air vehicle high enough to perform required maintenance while exposed to __________ crosswind from any direction."

Rationale and Guidance: This requirement establishes the system fuselage jacking capability. Frequently, the maintenance operations of the air vehicle dictate the need to jack a maximum design gross weight air vehicle. However, Using Command needs drive this requirement. The crosswind limit is arbitrarily set at a value which can be realistically expected in service usage and when the user would expect to still be performing maintenance functions requiring fuselage jacking. Arbitrarily, this value should be 15 knots to be consistent with structural design criteria, which shall contain the required load factors for design.

Performance Parameters: Air vehicle gross weight, c.g. location, strength of the jack pad and attachment are influences on meeting this operational need.

Background and Source of Criteria: This requirement is an expansion of MIL-A-8860 criteria to include crosswind limits.

Lessons Learned: Figure 3.2.8.1 c-1 summarizes the prescribed fuselage jack capacities for current inventory air vehicle.

Figure 3.2.8.1 c-2 summarizes the crosswind limits for fuselage jacking on current inventory air vehicle.

Air vehicle	Fuselage Jack Capacities
A-7	
A-10	20 ton
B-52	
B-57	
C-5	60/30 ton
C-7	
C-123	
C-130	
KC-135	
C-141	30/40 ton
F-4	20 ton
F-5	5 ton
F-100	
F-102	
F-104	
F-105	
F-106	
F-111	
F-15	20 ton
F-16	20 ton
A/T-37	
T-38	
T-39	

Figure 3.2.8.1 c-1. Fuselage Jack Capacities

Air vehicle	Crosswind Limit
A-7	
A-10	
B-52	
B-57	
C-5	
C-7	
C-123	
C-130	
KC-135	
C-141	
F-4	
F-5	
F-100	
F-102	
F-104	
F-105	
F-106	
F-111	
F-15	
F-16	
A/T-37	
T-38	
T-39	

Figure 3.2.9.1 c-2. Fuselage Jacking Crosswind Limits

Verification (Paragraph 4.2.8.1): "Jacking capability and provisions shall be evaluated on the air vehicle during the flight test program to the specified limits of the system. Crosswind compatibility shall be verified by analysis."

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

Verification Lessons Learned:

3.2.8.2 Ground Handling - Towing

3.2.8.2 - a "The air vehicle shall be capable of being pushed or towed at _____ gross weight up or down a ____________ slope on a __________ surface."

Rationale and Guidance: This is a maximum performance requirement for the towing system. Therefore, the blanks should reflect maximum design gross weight usage. The required slope is arbitrary and 3° is recommended. Towing under maximum conditions should probably be limited to dry concrete surfaces, but any special case can be reflected in this requirement. Towing at other angles than straight ahead is implied by the operational concept of the requirement.

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

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

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

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

Depending on the airbase, frequent use of the towbar is a possibility. Therefore, simple and reliable installation is a clear requirement.

Verification (Paragraph 4.2.8.2): "Performance of the towing system shall be demonstrated on the air vehicle during the flight test program."

Verification Rationale: Since there is considerable interface with the AGE and the air vehicle, this requirement is best verified with all the parts operating as a system on the air vehicle.

Verification Lessons Learned:

3.2.8.2 Ground Handling - Towing

3.2.8.2 - b "The main gear shall have the following provisions for emergency towing: _______________."

Rationale and Guidance: There are options available for emergency towing of the main and nose landing gear. Each is a cost driver and the Using Command should state their preference in sufficient time for inclusion in the Type I specification. Normally, this requirement is used for identifying towing lugs.

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

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

Lessons Learned: Some recent large air vehicle 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, etc., 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.

Verification (Paragraph 4.2.8.2): "Performance of the towing system shall be demonstrated on the air vehicle during the flight test program."

Verification Lessons Learned:

3.2.8.2 Ground Handling - Towing

3.2.8.2 - c "The interface between the air vehicle and tow vehicle shall be as follows: ______________________."

Rationale and Guidance: This requirement is to define configuration or performance requirements to insure compatibility of the air vehicle towing fittings and the tow bar or tow vehicle. Other areas to be considered include steering of the air vehicle during towing and communications between the towing crew members. Figure 3.2.8.2 - c-1 and c-2 provides dimensions of towing fittings that are the subject of an international agreement. Air vehicles intended for world-wide operation should comply to insure compatibility with towing equipment in foreign countries. Consider requiring that the tow fittings be compatible with the appropriate standard towbar. This requirement must be coordinated with ground equipment specification requirements.

Normally it should be required that the air vehicle be designed to permit the air vehicle to be steered by the tow vehicle, it may be desirable to require that this be done without disconnect of the air vehicle steering system. Communication between the tow vehicle operator and the tow crew member at the air vehicle crew station should be maintained during all towing operations.

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

Background and Source of Criteria: Most of the items covered by this requirement were included in MIL-STD-805 and Design Handbook 2-1.

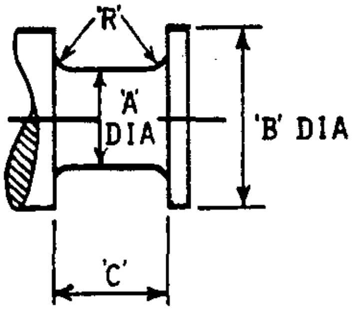
Lessons Learned:

(1) Most existing air vehicle 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 must 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 five degrees inside of absolute mechanical limits.

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

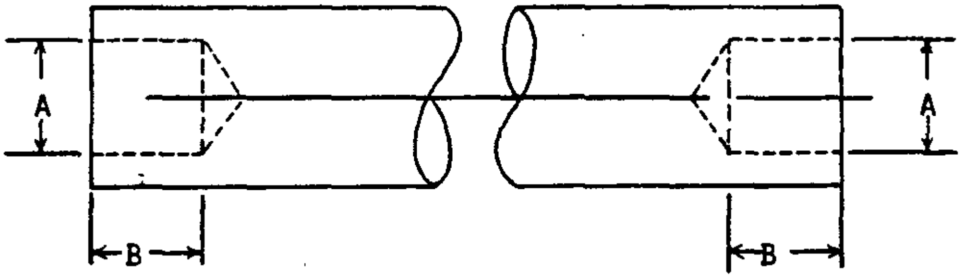
(3) The method used to disconnect the steering is very critical. If frequently used, the resultant wear may increase free play to the point that nose gear shimmy becomes a problem. Failure to reconnect the steering or incorrect connection have been problems on some past designs. Automatic disconnect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

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



AIRCRAFT WEIGHT POUNDS (lbs) (kg conversions in brackets)	DIAMETER OF SPOOL IN INCHES (mm conversions in brackets) A	DIAMETER OF FLANGE IN INCHES (mm conversions in brackets) B	WIDTH OF SPOOL BETWEEN FLANGES IN INCHES (mm conversions in brackets) C	RADIUS AT SPOOL FLANGE INTERSECTION IN INCHES (mm conversions in brackets) R
0-195,000 (0-88,450)	0.875 (22.23)	1.500 (38.10)	1.000 (25.40)	0.125 (3.18)
195,000 - 495,000 (88,450 - 224,527)	1.500 (38.10)	NOT YET DETERMINED		

FIGURE 3.2.8.2.c-1



Aircraft Weight Pounds (lbs) (kg in brackets)	Axle inside diameter (inches) (mm in brackets) A	Minimum depth of Hollow Axle (inches) (mm in brackets) B
0-195,000 (0-88,450)	0.750 - 0.000 + 0.016 (19.05 - 0.00) + 0.40	1.000 (25.40)
195,000 - 495,000 (88,450 - 224,527)	1.250 - 0.000 + 0.031 (31.75 - 0.000) + 0.79	1.500 (38.10)

FIGURE 3.2.8.2.c-2

Verification (Paragraph 4.2.8.2) "Performance of the towing system shall be demonstrated on the air vehicle during the flight test program.

Verification Rationale: Due to the complex interaction of the air vehicle and support equipment verification must be accomplished by demonstration.

Verification Lessons Learned:

3.2.8.3 Ground Handling - Mooring

3.2.8.3 - a "Mooring arrangement shall be compatible with ______________."

Rationale and Guidance: Air vehicle mooring compatibility with the standard mooring pattern is described in MIL-T-81259 and notification is the objective of this requirement. Since the airfields are equipped with mooring attachments in a standard pattern, the intended air vehicle should be compatible.

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

Background and Source of Criteria: This requirement has always existed as piecemeal inputs from various documents. This should clarify the intended installation.

Lessons Learned: Several recent air vehicle have waived the mooring requirements. But this basically is a Using Command decision. If the mooring is not to be used to survive in adverse weather, it may be more expedient to dispatch te air vehicle to other bases rather than to take the risk of weather damage.

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

Verification (Paragraph 4.2.8.3): "The air vehicle shall be moored to __________ during the flight test program. Design characteristics and component compatibility will be evaluated."

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

Verification Lessons Learned:

3.2.8.3 Ground Handling - Mooring

3.2.8.3 - b "The mooring arrangement shall be capable of withstanding ______ _____ with all surfaces locked, at _____________ gross weight."

Rationale and Guidance: 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.

Performance Parameters: Mooring fitting strength and mooring loads control meeting this requirement.

Background and Source of Criteria: The strength requirement is derived from specification MIL-A-008865A. This indicates mooring in a 70 knot crosswind. The MIL-A-008865A requirement is a direct derivative of ANC-2, dated October 1952, which requires mooring in a 75 mph wind.

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

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

Verification (Paragraph 4.2.8.3): "The air vehicle shall be moored to ________ during the flight test program. Design characteristics and component compatibility will be evaluated."

Verification Rationale: Interface between AGE and landing gear are best demonstrated on the air vehicle. Analysis does not lend itself to evaluation of this type of arrangement.

Verification Lessons Learned:

3.2.9 Specialized Subsystems

3.2.9.1 Specialized Subsystems - General

3.2.9.1 "The air vehicle shall have special subsystems or characteristics as follows: ____________________."

Rationale and Guidance: This requirement is to provide definite requirements for specialized subsystems. The blank is filled with te name of any specialized subsystem desired from the development program. Examples are: skis, croswind positioning systems, kneeling systems, etc.

Performance Parameters: Variable depending on the system in question.

Background and Source of Criteria:

Lessons Learned:

Verification (Paragraph 4.2.9.1): "The ____________ system shall be evaluated by ____________."

Verification Rationale: This requirement cannot be defined until the equipment in question is identified.

Verification Lessons Learned:

3.3 Reliability

"The landing gear system reliability requirments shall be as follows: ____________________."

Rationale and Guidance: The landing gear ststem reliability is an integral part of the reliability requirements for the total Air Vehicle. Therefore, proper allocation of reliability with the associated confidence level should be generated for the system. This then must be further distributed to the major components or subsystems as described by the basic prime specification (Section 3.1). In order to achieve high overall system performance, the allotted reliabiity of each system must be proportionately higher. It is conceivable that landing gear component reliability could be better expressed in desired Mean Cycle Between Failure (MCBF). The overall system Reliability Monitor should assist in establishing these requirements. For details of the overall Reliability Program consult MIL-STD-785.

Performance Parameters: Mean Cycle Between Failure

Background and Source of Criteria: Prior Reliability requirements were previously included in the overall program of MIL-STD-785. Most landing gear component specifications implied that completion of the qualification testing described in the individual specifications represented satisfactory completion of the Reliability requirements.

Lessons Learned: Component or subsystem performance, in terms of reliability, is impacted by many factors. Examples include basic design, material selection, production processing, installed environment, subsystem or component interfaces, accuracy of predicted load, and maintenance. Therefore, all modes of failure must be anticipated and analyzed. Figure 3.3-1 shows the distribution of accidents and incidents for the C5A during FY72 through FY75. This illustrates the distribution of failures which can contribute to the overall reliability of the system. Figure 3.3-2 illustrates the same information for the KC-135 and Figure 3.3-3 illustrates the information from the C-141A.

Component	Incidents	Minor Accidents	Major Accidents
Struts	2	0	0
Tires	2	0	0
Brakes	1	0	1
Actuators	9	0	0
Electrical	1	0	0
Hydraulic	1	0	0
Wheels	4	0	0
Steering	1	0	0
Anti-Skid	3	0	0
Crosswind Computer	1	0	0
Structure	10	0	0
Undetermined	2	0	0

Figure 3.3-1. C5A Landing Gear Accident & Incident Summary (FY72-FY75)

Component	Incidents	Minor Accidents	Major Accidents
Struts	3	0	2
Tires	26	0	0
Brakes	5	0	0
Anti-Skid	15	0	0
Hydraulic	20	0	0
Gear handle Mech.	1	0	0
Electrical	7	0	0
Actuator	1	0	0
Wheel	6	0	0
Structure	4	0	0
Undetermined	7	0	0

Figure 3.3-2. KC-135 Landing Gear Accident & Incident Summary (FY72-FY75)

Component	Incidents	Minor Accidents	Major Accidents
Struts	2	0	1
Tires	19	0	0
Brakes	6	0	0
Actuators	10	0	0
Wheels	14	0	0
Steering	2	0	0
Hydraulic	3	0	0
Anti-Skid	4	0	0
Structure	9	0	0
Undetermined	3	0	0

Figure 3.3-3. C-141A Landing Gear Accident & Incident Summary (FY72-FY75)

1. Additional Reliability data can be obtined from monthly reports produced by AFLC. Examples of suitable data are the RCS:LOG-MMO(AR)7170 entitled "Maintenance Actions, Manhours, and Aborts by Work Unit Code," which provides historical information pertaining to each assigned WUC. You have to identify the air vehicle and 13000 series Work Unit Codes for Landing Gear. The most pertinent data produced is the monthly MTBF and MTBM for each item, RCS:LOG-MMO(AR)7220 entitled "Maintainability Reliability Summary," which provides 12 months summary by air vehicle and includes "on" equipment maintenance action occurrences and manhours and "off" equipment units and manhours as reported on AFTO Form 349. These reports are obtainable from AFLC/MMOMA upon request.

2. The following reports provide a summary of Air Force aircraft landing gear failures and problems for the period: 1970 - 1976. The summary is much more detailed than data presented in this handbook.

"Aircraft Landing Gear Failure and Problem Analysis," Udell S Albrechtsen, AFLC, Ogden Air Logistics Center, Hill AFB, Utah, 1976. (Covers 1970 - 1973).

"Aircraft Landing Gear Failure and Problem Analysis", Udell S. Albrechtsen, AFLC, Ogden Air Logistics Center, Hill AFB, Utah, May 1977. (Covers 1974 - 1976).

Verification (Paragraph 4.3): "The reliability requirements of paragraph 3.3 are verified as follows: ______________."

Verification Rationale: Most landing gear components are tested in a variety of environments during the development program. Individual components are exposed to a series of qualification tests to vendor specifications as installed, the various components are tested in the system simulator and on the air vehicle during various phases of flight testing. The composite of all testing constitutes the total reliability testing.

Verification Lessons Learned:

3.4 Maintainability: "The landing gear system maintainability requirements shall be as follows: ____________."

Rationale and Guidance: The landing gear system maintainability is an integral part of the maintainability requirements for the total Air Vehicle. Therefore, limits on maintainability tasks and the associated times to accomplish should be generated for the landing gear system and its components. In order to achieve low overall system maintainability, the allotted taskes must be individually considered. The overall System Maintainability monitor should assist in establishing these requirements. For details of the overall Maintainability Program consult MIL-STANDARD---.

Performance Parameters:

Maintenance Tasks

Background and Source of Criteria: Prior Maintainability requirements were described in MIL-STD-470 and MIL-STD-471. The landing gear was included in those times and tasks allotted to the overall Air Vehicle.

Lessons Learned:

1. Component or subsystem performance in terms of maintainability is influenced and impacted by many factors, including, complexity of design, intended AGE, design life, servicing requirements, and bulk of the hardware.

2. Maintainability performance data can be obtained from monthly reports produced by AFLC. Examples include: RCS:LOG-MMO(AR)-7170 entitled "Maintenance Actions, Manhours, and Aborts by Work Unit Code." This report produces monthly MTBF and MTBM for each component or WUC. Another report is RCS:LOG-MMO(AR)-7220 entitled "Maintainability Reliability Summary," which provides 12 months summary by air vehicle and includes "on" equipment maintenance action, occurrences, and manhours. It also includes "of" equipment and manhours as reported on AFTO Form 349. These reports are obtainable from AFLC/MMOMA upon request.

3. Components that require frequent removal should be attached to the primary structure with easily removable hardware.

The hydraulic swivel assembly for the nose gear actuator on the A-10 is fastened to the aircraft structure with "Hi-Lock" fasteners. The "Hi-Lock" fastener, by design, is semi-permanent and must be removed by drilling or splitting the retaining collar. Time repair would be significantly reduced by use of a fastener that is easier to remove and install.

4. Landing gear system maintainability is significantly enhanced by designing for maximum interchangeability of components. In so far as practical, design the landing gear units for installation at any position (left or right, fore or aft) as built-up units. Where this is not practical, provide a minimum number of designated parts for installation at the required position.

5. Components should be designed for adjustment and repair at the lowest level of maintenance as so far as is practical. Adequate technical data is vital to efficient performance of all required adjustment and repair. Technical data distribution must be consistent with the intended level of repair.

6. A void adjustment or repair on the air vehicle if such action is difficult to accomplish due to access or environment. Consider use of replaceable modules or components that can be adjusted or repaired in a field shop as an alternative.

Verification (Paragraph 4.4): "The maintainability requirements of paragraph 3.4 are verified as follows: ______________."

Verification Rationale: Maintenance of landing gear equipment is accomplished at various levels. Depending on the units, the LRU will vary depending on the subsystem. The task allocation should reflect the overall logistic plan and be consistent with the intended inventory practices.

Verification Lessons Learned:

3.5 System Safety: "The landing gear system safety requirements shall be as follows: _______________.

Rationale and Guidance: System Safety requirements for the landing gear system should be consistent with these requirements for the total Air Vehicle. The subsystem and component designs must take into consideration the hazards generated by various modes of failure and insure redundancy within the systems to avoid those modes which potentially can create Class III and IV hazards. Class I and Class II hazards, although qualitalively of less consequence than Class III or Class IV, may impact the design because of their anticipated frequency of occurrence. The safety analysis and design change process involves identification of all potential hazards, hazard reduction and minimization techniques, and a closed loop procedure established to assure design change, as appropriate.

Background and Source of Criteria: System Safety for the landing gear system tie directly to MIL-STD-882 and the subsequent system generated by that program. Specific designations related to system safety were also included in AFSC Design Handbooks 2-1 and 1-6.

Lessons Learned: Figure 3.5-1 illustrates the safety record for landing gear systems over the last five years in terms of accidents and incidents:

Air vehicle	Total Number of Landings	Total LG Incidents	Total LG Major & Minor Accidents
A-7			
A-10			
B-52			
B-57			
C-5			
C-7			
C-123			
C-130			
C-135			
C-141			
F-4			
F-5			
F-15			
F-16			
F-100			
F-102			
F-105			
F-106			
F-111			
A/T-37			
T-38			
T-39			

Figure 3.5-1. Accidents & Incident Summary

Verification (Paragraph 4.5): "The system safety requirements of Paragraph 3.5 are verified as follows: ______________."

Verification Rationale: System safety assessment is an integral part of the system safety program for the total air vehicle.

Safety is generally verified by analytical methods, which involve preliminary hazard analysis, subsystem hazard analysis, system hazard analysis, and operating hazard analysis. Fault hazard analysis is an inductive tool and fault tree analysis is a deductive tool to identify hazards. Finally, recognition should be made of the fact that if hazards, especially catastrophic or critical, cannot be controlled to an acceptable level, then ground or flight test should include measures to verify the safety of the landing gear system.

Verification Lessons Learned:

3.6 Environmental Conditions: "The landing gear system equipment shall be capable of withstanding or operating under the following conditions:

Environment	Requirement
Temperature	
Humidity	
Fungus	
Vibration	
Dust	
Salt Fog	
Explosion Proof	
Acceleration	
Shock	
Electromagnetic	

Rationale and Guidance: The intent of this requirement is to provide a suitable definition of environmental conditons from which the various landing gear components must operate periodically and continuously. Some components are sensitive to environmental considerations and some are not. With the environment defined, this judgment can be logically made on a component by component basis. If a certain environmental characteristic varies from one location on the airplane to another, the variation should be noted in the blank and the equipment evaluated accordingly.

Performance Parameters:

Background and Source of Criteria: Environmental requirements were contained in the various subsystem and component specifications. Each usually assumes the most adverse environment and much of the development efforts have been expanded trying to satisfy arbitrary conservative criteria. With the environment defined, the development cycle can be tailored to meet the application. The risk is the ability to accurately assess the true environment.

Lessons Learned: Typically, the most critical environmental factors for landing gear are temperature, vibration, and acceleration. The other factors affect some of the components but are not universally critical.

Some of the temperature problems are generated by the landing gear in various means of energy absorption. But temperature in the wheel well generated by high speed flight can be critical to all components.

The landing gear also creates vibratory problems as well as being critical to external sources such as sonic input.

The most critical accelerations are self-generated but certain flight maneuvers to load locks and other critical components.

"The landing gear and associated structure should be designed to eliminate or minimize the ingress of water or fluids, from the runway or aircraft washing operations with special attention to gear boxes and other drive mechanisms."

Verification (Paragraph 4.6): "Environmental testing shall be conducted to verify the requirements of paragraph 3.6 as follows: __________."

Verification Rationale: Depending on the component, the environmental tests should be tailored to evaluate the critical characteristics of the component. The classical methods of environmental testing are presented in MIL-STD-810. These should be utilized whenever they can be determined to be applicable or near the operational duplication. The following standard methods are applicable:

Environment	Method
Temperature	501,502
Humidity	507
Fungus	508
Vibration	514
Dust	510
Salt Fog	509
Explosion Proof	511
Acceleration	513
Shock	516
Electromagnetic	

Verification Lessons Learned:

3.7 Interface Requirements

3.7.1 Related Systems: "The landing gear system shall interface with other air vehicle systems as follows: ______________."

Rationale and Guidance: The landing gear system must interface with several other air vehicle systems. As a minimum the interface with the air vehicle structure and secondary power systems must be defined. Normally this is accomplished by the air vehicle contractor as part of the air vehicle integration task. In some cases it may be desirable for the government to define some interface characteristics. An example might be the fitting of a modified landing gear system to an existing air vehicle. In this case, the blank would contain a reference to documents that describe characteristicsof the air vehicle that must be considered in design of the new landing gear system. In the case of an entirely new development, it may be desirable to include a statement such as: "The landing gear system shall provide the performance required herein without degradation of other air vehicle systems performance below their specified performance requirements. The landing gear system shall provide the performance specified herein while installed in the air vehicle and operated with interfacing systems as required by all missions defined for the air vehicle."

Performance Parameters:

Background and Source of Criteria: This is a new requirement in that it is applied to the total landing gear system. In the past some landing gear component military specifications provided general interface requirements with air vehicle structure and secondary power subsystems.

Lessons Learned: Detailed interface requirements for new air vehicles should be minimized. Very frequently the detailed requirements must be changed after contract award as a result of contractor design studies and development test. If the contractural interface definition is minimized the contract changes and related cost will be minimized.

Verification (Paragraph 4.7.1): "Characteristics of the landing gear system interface with other air vehicles systems shall be verified by __________."

Verification Rationale: Verification of interface requirements can be accomplished only be installation of the landing gear system, functinal test and flight test. The final proof is flight test of the air vehicle to the required missions.

Verification Lessons Learned

3.7 Interface Requirements

3.7.2 Ground Support Equipment: "The landing gear system shall interface with the following ground support equipment as follows: ____________."

Rationale and Guidance" Usually it is desired that the landing gear system be compatible with common ground support equipment or facilities. Examples include nitrogen servicing equipment, tow bars, jacks, tie down fixtures, and test stands. It may be necessary to define permissible modification of standard ground support equipment. This paragraph should provide necessary contractual coordination between air vehicle development and ground equipment modification. It may also be desirable to identify specific ground equipment to be defined and/or developed by the contractor.

Lessons Learned:

Verification (paragraph 4.7.2): "The interface of the landing gear system with specified ground support equipment shall be evaluated by _________."

Verification Rationale: Usually the only suitable method is demonstration of the compatibility of ground support equipment with the air vehicle during the flight test program. In some cases, demonstration may be supplemented by analysis to adequately determine suitability under the most adverse conditions. The blank should identify the specific verification method for each item of ground support equipment.

Verification Lessons Learned

3.7.3 "International standardization: Where applicable, utilize standard parts from international standardization lists, including NATO and ISO documentation."

Rationale and Guidance: Since considerable effort has been expended on developing NATO and ISO standards and participating countries have agreed to utilize these configurations, the Air Force is obligated to conform in all instances where the system is not significantly penalized. Standard valve caps and cores, jack pads, towbar, etc. should be utilized wherever possible.

Performance Parameters:

Background and Source of Criteria: The use of standard components is defined in AFSC DH 2-1.

Lessons Learned:

Verification (Paragraph 4.7.3): "Use of NATO or ISO standard parts should be verified by ______________."

Verification Rationale: Verification of the use of NATO and ISO standard parts are best achieved by observation and discussion with the airframe manufacturer.

Verification Lessons Learned:

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