AEROSPACE RECOMMENDED PRACTICE

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Superseding ARP1311B

(R) Landing Gear Structures and Mechanisms

RATIONALE

ARP1311C has been reaffirmed to comply with the SAE five-year review policy.

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1. SCOPE

This SAE Aerospace Recommended Practice (ARP) applies to landing gear structures and mechanisms (excluding wheels, tires, and brakes and other landing gear systems) for all types and models of civil and military aircraft.

All axles, wheel forks, links, arms, mechanical and gas/oil shock struts, downlock and uplock assemblies, braces, trunnion beams, and truck beams etc., that sustain loads originating at the ground, and that are not integral parts of the airframe structure, should be designed and validated in accordance with this document. Hydraulic actuators (retraction, main and nose gear steering, positioning, damping, etc.) should also be included in this coverage.

System level, non-structural components such as retraction/extension valves, controllers, secondary structure and mechanisms in the airframe (e.g., manual release mechanisms, slaved doors) as well as equipment that is located in the cockpit are not addressed in this ARP.

1.1 Purpose

This document establishes minimum recommended design requirements and validation for landing gear structure and mechanisms. In addition, recommended guidelines regarding priorities in landing gear structural design particularly in the early design stages is provided.

2. APPLICABLE DOCUMENTS

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

AS1241	Fire Resistant Phosphate Ester Hydraulic Fluid for Aircraft
AIR1494	Verification of Landing Gear Design Strength
AIR1594	Plain Bearing Selection for Landing Gear Applications
ARP1595	Aircraft Nosewheel Steering Systems
AIR1752	Aircraft Nosewheel Steering/Centering Systems
AS4052	Gland Design: Scraper, Landing Gear, Installation
AIR4566	Crashworthy Landing Gear Design
AS4716	Gland Design, O-ring and Other Elastomeric Seals
AS4832	Gland Design: Nominal 3/8 in Cross Section for Custom Compression Type Seals
AIR4894	Landing Gear Stability
ARP4912	Design Recommendations for Spare Seals in Landing Gear Shock Struts
ARP4915	Disposition of Landing Gear Components Involved in Accidents/Incidents

AS4941	Aerospace - General Requirements for Commercial Aircraft Hydraulic Components
AIR5358	Landing Gear Shock Strut Hydraulic Fluid
ARP5429	Landing Gear Fatigue Tests With Equivalent Damage Spectra
AIR5451	A Guide to Landing Gear System Integration
AIR5479	Environmentally Compliant Processes for Landing Gear
AIR5883	Landing Gears Shock Struts Bearing Selection
ARP5935	Use of HVOF Thermal Spray Coatings for Hard Chrome Replacement in Landing Gear Applications
ARP5936	Landing Gear Storage
AS6053	Tests, Impact, Shock Absorber Landing Gear, Aircraft
AS8860	Landing Gear Structural Requirements as Listed in the MIL-886X Series of Specifications
AMS-P-83461	Packing, Preformed, Petroleum Hydraulic Fluid Resistant, Improved Performance at 275 °F (135 °C)
AMS-QQ-N-290	Nickel Plating (Electrodeposited)
AMS-QQ-C-320	Chrome Plating (Electrodeposited)
PT-37	Aircraft Landing Gear Systems
PT-66	Emerging Technologies in Aircraft Landing Gear

2.2 U.S. Government Publications

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, http://assist.daps.dla.mil/quicksearch/.

MIL-T-6053	Tests - Impact Shock Absorbers (Inactive)
MIL-L-8552C	Landing Gear, Aircraft Shockstrut (Gas/Oil Type)
MIL-L-22589D	Launching System - Nose Gear Type Aircraft
MIL-T-81259B	Tie Downs - Requirements for Airframe Designs
MIL-A-8860B	Airplane Strength and Rigidity
MIL-A-8862	Airplane Strength and Rigidity (Canceled)
MIL-A-8863C	Airplane Strength and Rigidity
MIL-A-8867C	Airplane Strength and Rigidity

MIL-PRF-5606H	Hydraulic Fluid, Petroleum Base; Aircraft, Missile, and Ordnance
MIL-PRF-87257B	Hydraulic Fluid, Fire Resistant; Low Temperature, Synthetic Hydrocarbon Base, Aircraft and Missile
MIL-PRF-83282D	Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Metric, Nato Code Number H-537
NAS 1613	Seal Element, Packing, Preformed, Ethylene Propylene Rubber - Rev. 5; FSC 5330
MS 15000	Fittings - Lubrication - Hydraulic (Canceled)
MS 15001	Fittings - Lubrication - Hydraulic (Canceled)
MS 15002	Fittings - Lubrication - Hydraulic (Canceled)
MS 15003	Fittings - Lubrication - Hydraulic (Canceled)
MS 15004	Fittings - Lubrication - Hydraulic (Canceled)
MS 28889	Valve, Air, High Pressure Charging (5000 psi) (Inactive)
MS 33559	Adapter, Aircraft, Jacking Point, Design and Installation (Canceled)
MS 33651	Boss, Air Connection, Design and Installation (Inactive)
MS 33675	Scraper Installation - Packing Gland Ring (Inactive)
MIL-PRF-5503F	Actuators: Aero Linear Utility, Hydraulic, General Spec For
MIL-STD-805B	Towing Fittings and Provisions for Military Aircraft
MIL-STD-809	Adapter, Aircraft, Jacking Point, Design and Installation (Canceled)
AR-MMPDS-03	Metallic Materials Properties Development and Standardization
JSSG 2006	DOD Joint Service Specification Guide - Aircraft Structures

2.3 ANSI Publications

Available from American National Standards Institute, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org.

ANSI B46.1

2.4 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

FAR's Part 23, 25, 27 and 29

AC 25.571-1C Damage Tolerance and Fatigue Evaluation of Structure

AC 23-13A

2.5 EASA Publications

Available from European Aviation Safety Agency, Postfach 10 12 53, D-50452 Koeln, Germany, Tel: +49-221-8999-000, www.easa.eu.int.

CS-23, 25, 27 and 29

2.6 Other Publications

Aircraft Landing Gear Design - Principles and Practices, by Norman S. Currey

Landing Gear Design, by H. G. Conway

Airplane Design Part IV Layout Design of Landing Gear and Systems, by Dr. Jan Roskam

3. DESIGN REQUIREMENTS

The landing gear should fulfill all the regulatory and/or any airframe manufacturer's design requirements that are considered applicable to the aircraft being designed.

3.1 General Structural Requirements

3.1.1 Structural Capacity

The landing gear should have adequate structural capacity for all combinations of loads that can be encountered during takeoff, landing and ground handling conditions. The gear should be suitable to withstand all ground operational environments, including ambient temperature extremes and runway conditions.

3.1.2 Structural Analysis

An analytical assessment of the required structural capacity for all load carrying members, using the design ground loads as specified by the airframe manufacturer, should precede the release of the landing gear design for manufacture. The analysis should include finite element analysis as appropriate for complex structural components. This structural capacity should include strength without permanent deformation, ultimate strength, stiffness, and structural stability. More detail requirements are described in the following paragraphs.

3.1.2.1 Design Loads

Landing gear design loads for commercial aircraft are derived from requirements described in FAR/CS 25.471 through 25.519 or 23/27/29.471-511 as applicable. Design ground loads for military aircraft are governed by JSSG 2006 Aircraft Structures. Catapult, arrestment, and some ground handling or deck handling load conditions are unique to U.S. Navy applications. Those loads are treated as limit and ultimate in the same manner as loads for land based aircraft. However, landing loads for U.S. Navy aircraft are derived from a multivariate analysis of input conditions to establish nearly worst case conditions. To prevent prohibitive weight and envelope penalties, the predicted landing loads are treated as design loads and not as limit/ultimate loads.

The following are the load application locations for both static and fatigue conditions:

- For all ground operation conditions, excluding nose landing gear (NLG) towing and jacking condition loads, the loads should be applied at the tire contact point.

- For all landing conditions, drag and vertical loads should be applied at the axle and side loads applied at the tire contact point.

- For all towing conditions involving a tow bar attachment to the NLG axle, drag and side loads for the NLG should be applied at the axle of the NLG and vertical loads should be applied at the tire contact point. Similar conditions apply to main landing gear (MLG) towing.

The landing gear assembly should possess strength to withstand all static dynamic, and fatigue loading conditions listed in the commercial regulations or military specifications in accordance with the criteria specified herein. The design should be based upon the most critical of the requirements.

3.1.2.2 Design Factors

Design factors for bearing and/or joint sizing are used in the design of military landing gear, to provide added reliability and growth potential. All applicable loads are to be multiplied by these factors in the appropriate circumstance. Commercial landing gear typically do not use these factors with the exception of ground support interfaces.

FAR/CS 25.519 (or FAR/CS 23/27/29.519 as applicable) and all military applications require a joint design factor of 2.00 for all ground support interface features (jacking points, towing points, tie down rings, ground lock pins, etc.).

For information, Currey suggests a 1.15 factor be applied to ultimate loads for all joints. Also, some military applications have historically used bearing and joint design factors on specific load types or locations (i.e., US Navy design landing loads, bearings subject to overcenter loads). These factors are not standardized and vary among different airframe and landing gear manufacturers depending on their best practices. All landing gear design factors should be coordinated with the customer in those cases.

3.1.2.3 Deformations and Failure Criteria

Deformations from temperature, load, and other induced structural deformations/deflections resulting from any authorized use and maintenance of the air vehicle should not:

a. Inhibit or degrade the mechanical operation of the air vehicle or cause bindings or interference.

b. Affect the aerodynamic characteristics of the air vehicle to the extent that performance guarantees or flying qualities requirements cannot be met.

c. Result in detrimental deformation, delamination, detrimental buckling, or exceedance of the yield point of any part, component, or assembly which would result in subsequent maintenance actions.

d. Require repair or replacement of any part, component, or assembly.

e. Result in significant changes to the distribution of external or internal loads without due consideration thereof.

Limit Loads

For commercial airplanes, landing gear structure should not incur detrimental permanent deformation or strain levels producing residual stress that could result in insidious failure (rupture or collapse failure at a later time following exposure to normal loads and environments) or interference with the normal mechanical function, with the application of limit loads. For military airplanes, landing gear structure should not incur detrimental permanent deformation or strain levels producing residual stress that could result in insidious failure (rupture or collapse failure at a later time following exposure to normal loads and environments) at or below 115% of limit loading. Detrimental permanent deformation of a component is defined as any deformation that will hinder the continued safe usage of that component for its full designated life, both functional and structural.

Ultimate Loads

Ultimate loads, where they are applicable, are obtained by multiplying the limit loads by the ultimate factor of safety. Failure must not occur at the design ultimate load. The ultimate factor of safety to be used for the design of the structure is 1.50, except that in certain cases for considerations of added safety, rigidity, quality assurance, and wear, additional strength or multiplying factors of safety are specified.

Design Landing Loads

For the Air Force and commercial aircraft, landing loads are treated as limit/ultimate loads, like all other load conditions. For U.S. Navy carrier based aircraft, landing loads are design loads with no additional safety factor applied. The landing gear may have permanent deformation after exposure to the critical design landing loading conditions; however, the deformation should not interfere with the mechanical operation, nor require repair or replacement of parts. In addition, any yielding should not occur so as to precipitate a stress corrosion condition in the presence of a salt fog environment. The limit/ultimate load conditions should include loads due to attached actuators in powered or unpowered condition, whichever is more severe.

Sizing for critical piston bending from design landing loads should be based on ultimate bending rupture (Fbu) values with a MS agreed upon with the customer.

3.1.2.4 Material Properties

Static strength analyses should use A basis allowables (as defined by AR-MMPDS-03) where available. "S" basis design allowables will be acceptable for design until “A” or “B” basis allowables are available, provided they are specified in a governing industry/government document that contains quality assurance provisions at the heat, lot, and batch level in the as-received material condition. Appropriate test coupons should accompany the material in the as-received condition and be subject to testing for verification of minimum design properties after final processing, if required as indicated by the released design documentation.

All allowables used should be valid for the operational temperature requirements.

For U.S. Navy applications, steel alloys on parts within the main load paths must have a plane strain fracture toughness (Kic) value no less than 100 ksi $\sqrt{in}$ (longitudinal). This helps to ensure that any flaws will grow to an inspectable size before they reach the critical fracture point.

3.1.2.5 Margins of Safety

Margins of safety for both static and fatigue should be based on nominal dimensions. The static strength analysis must show no less than zero margin of safety, including appropriate design factors and rework allowables, for all critical static strength conditions. Static and fatigue checks of lugs or holes should be performed on the bore diameter plus 0.060 in for holes with bushings and bore diameter plus 0.120 in for holes without bushings. In addition, repair allowances of 0.030 in per lug face should be accounted for in the static and fatigue checks.

3.1.2.6 Fatigue

A safe-life fatigue evaluation is the assessment of a structure to ensure that the structure is able to withstand, without failure, the repeated loads of variable magnitude expected in service throughout its operational life. In general, commercial and Air Force aircraft employ the safe-life philosophy for landing gear fatigue to ensure that the crack initiation life is never reached.

Fail-safe is the attribute of the structure that permits it to retain its required residual strength for a period of unrepaired use after the failure or partial failure of a principal structural element. U.S. Navy requirements for fracture critical structure generally fall under this category.

For commercial fatigue, FAR/CS 25.571 (or FAR/CS 23/27/29.571 as applicable) state: “Compliance with the damage-tolerance requirements of this section is not required if the applicant establishes that their application for particular structure is impractical. This structure must be shown by analysis, supported by test evidence, to be able to withstand the repeated loads of variable magnitude expected during its service life without detectable cracks. Appropriate safe-life scatter factors must be applied.” Most or all airframe and landing gear manufacturers employ this approach, using a scatter factor of 4 or 5 over the design life of the aircraft for a minimum crack initiation threshold. (For determination of the scatter factor, use FAA Advisory Circular AC 25.571-1C or AC 23-13A as applicable.)

The standard military requirement for crack initiation performance is that the landing gear pass 2 lifetimes of fatigue testing without damage. For U.S. Navy nose tow launch airplanes, the NLG must pass 2 lifetimes of complete loads, plus an additional 1 lifetime of catapult loads. Airframe and landing gear manufacturers usually use design scatter factors which are double the test requirement to ensure that the LG meet the testing requirements. The U.S. Navy requires that fatigue analyses utilize strain life methodology. The failure criterion crack size is 0.01 in.

Some aircraft (i.e., prototypes, experimental, etc.) do not conduct landing gear fatigue testing for cost reasons. In those cases, the landing gear structure should be designed with a fatigue scatter factor of 8 applied to the expected life of the aircraft.

For U.S. military applications, the benefit of shot peening for fatigue life enhancement is prohibited for both analysis and test for all structural components, except where shot peening is used under chrome plating or HVOF (High Velocity Oxygen Fuel) spray coatings. For commercial applications, the benefit of shot peening is often accounted for both in analysis and test.

Lug fatigue analysis should include all bearing peaking, hole propping and secondary bending considerations.

An analysis should be conducted to ensure an adequate life of the landing gear. The airframe manufacturer should provide a design spectra to be used in the analysis. The most severely stressed areas should be determined from the structural analysis. Stress concentration values should be determined and fatigue life evaluated for these critical areas.

The fatigue analysis methods, and a positive margin life should be demonstrated.

Provision of a material reserve for gear repair purposes as well as future aircraft weight growth should be considered.

3.1.2.7 Damage Tolerance

As stated above, commercial equipment suppliers avoid damage tolerance analysis on landing gear. The Air Force also follows the safe life approach in that the landing gear is not considered ‘flight critical’. The U.S. Navy however, always imposes damage tolerance analysis on main structural components of the landing gear which are determined to be Fracture Critical. This should be accomplished through a part criticality classification, which is done by the airframe manufacturer at the component level. These classifications are: Fracture Critical Traceable, Fracture Critical, and Maintenance Critical. On carrier based aircraft, all NLG structure subject to launch loads and the entire arresting gear fall under the Fracture Critical or Fracture Critical Traceable categories. The typical requirement is that a starting flaw will not grow to critical size in less than 1 design lifetime. The starting surface flaw is 0.02 in long and 0.01 in deep (0.01 in corner flaw). Residual strength should be checked throughout the crack growth analysis using the Max Spectrum Load (MSL) or Limit Load, whichever is larger. The main landing gear is usually Maintenance Critical so damage tolerance and critical flaw size analysis is done for information purposes only with no explicit crack growth life imposed.

Damage tolerance analysis should be based on the average crack growth properties and minimum fracture toughness properties in either lab air or alternate immersion 3.5%NaCl environment, whichever is worse.

3.1.2.8 Stress Corrosion Cracking

Design and construction of the landing gear should not precipitate the occurrence of stress corrosion cracking due to a sustained stress condition in the presence of a salt fog environment. To support this recommendation, the stress intensity of sustained stresses due to straight and level flight or ground at-rest loads, and fabrication, assembly or load induced residual stresses in combination with a 0.10 in long surface flaw should not exceed the appropriate salt air K_{iscc} for high strength steel components. K_{iscc} values should account for the applicable grain flow orientation. Load induced residual stresses should be based on the worst case of 100% limit load, design landing loads, or the maximum load in the fatigue spectrum.

3.1.3 Spring Rates

The stiffness characteristics of the landing gear under all potentially critical loading conditions should be conducive to the on-ground dynamic stability of the aircraft. Suitable damping for stability in all modes should be demonstrated during development. Imbalance from worn tires and the adverse effects of tire cold set should be considered. In some instances, the air curve spring rate may be influenced by taxi ride comfort considerations. In other instances with 3 or more main landing gear, the air curve spring rate may be modified to minimize the effects of runway crown.

3.2 Energy Absorption

3.2.1 Capacity

The landing gear should have sufficient capacity for energy absorption during the impact of the landing according to the regulatory requirements (AC 23.727, 25.723, 27.727 or 29.727 as applicable), military specification requirements, AS6053 or procurement documentation.

3.2.2 Dynamic Stability

The stiffness and damping characteristics of the landing gear should be conducive to stable and even movement of the aircraft during taxiing, takeoff, and landing roll-out. The landing gear must be shown to be free from shimmy and show no damaging brake vibration within the operating speed envelope. (This may, in some cases, require the adoption of a shimmy damper, whose effectiveness should be validated during flight test.)

For helicopters, ground resonance damping should be considered.

3.2.3 Piston Diameter Sizing

The size of the piston rod of an aircraft landing gear should be determined by the ground reaction on one gear, and the internal pressure established in the shock strut under static conditions. This applies to gears where the total static ground reaction on one gear is essentially the same as the load in the shock strut. For this type of gear it is recommended that the piston be sized such that the initial static pressure be between 1500 and 1700 psi for a 1G maximum load allowing for growth in derivative models.

In the case of articulated gears, the load in the shock strut for the same ground reaction is increased by the mechanical advantage created by the trailing arm. Shock strut pressure in this type of gear are higher, not only because of the higher loads, but due to the need to minimize the shock strut piston rod diameter size to a point where the overall installation of the shock strut and articulating arm are of practical proportions, and weight is not a prohibiting factor.

With either type of landing gear it is recommended that the static pressure of the ultimate growth configuration not exceed 2500 psi to be compatible with 3000 psi nitrogen carts. The piston diameter may also be influenced by the bottoming load requirements. In applications where landing loads are critical (i.e., carrier aircraft), piston sizing should be as described in 3.1.2.3.

3.2.4 Piston Stroke Assessment

It is recommended that all landing gear shock strut strokes be checked for adequacy (in the early stages of design) in terms of shock absorbing capacity. This is achieved by equating the required kinetic energy for the design landing condition to the energy absorbed by the shock strut and tires. The shock strut maximum stroke is dependent on the maximum vertical reaction at landing and the shock strut efficiency. For shock struts with minimum travel capability, shock strut efficiencies up to about 90% are achievable. Lower efficiencies are sometimes desirable to lower the vertical loading during tire spin-up, thereby reducing loads transmitted to the airframe. Variable orifice devices may be used in order to control the damping performance, thereby tailoring the ground reaction throughout the compression cycle to optimize performance.

In addition to landing energy requirements, the shock strut stroke is also influenced by taxi design loads, bottoming load, and ride comfort. Shock strut bottoming should not occur below the design limit load for taxi, and some margin above this load is desirable to cover mis-serviced conditions (±5%). The slope of the air curve also affects ride comfort, and should be checked by dynamic analysis. The desired air curve is achieved by means of adjusting the maximum stroke, precharge pressure, reserve air volume, and the use of more than one air chamber if necessary.

3.2.5 Rebound Damping

Means should be provided to limit the extension velocity of the energy absorbing device to prevent overloading of the extension stop, and so that the tendency of the aircraft to rebound after the initial landing will not significantly affect aircraft handling, stability, control, or braking performance. When defining the damping design, several parameters must be considered: (1) The extend stop force must meet the design requirements (usually 20 G limit load); (2) the peak rebound chamber pressure must satisfy structural and seal requirements; and (3) the delta-pressure across the inner cylinder must satisfy cylinder buckling requirements. The first constraint tends to require more damping, while the latter constraints tend to require less damping, so the best solution is a balance of these requirements.

A dynamic analysis should be performed to simulate rebound characteristics during landing, takeoff, and in free extension tests. It is recommended that this analysis account for compressible flow due to the small oil volumes common to rebound chambers. Cylinder expansion effects may also influence the rebound damping performance. Care must also be taken concerning the design and function of any piston rings employed. Also, any leakage in the flow path due to nominal clearances should be accounted for.

3.2.6 Extension to Touchdown Time

The internal construction of gas/oil energy absorbing elements should be such that any transfer of the fluids while the landing gear is retracted, will be adequately returned to its functional chamber in the least time interval between "wheels down" and "touchdown" that is consistent with the operational requirements of the aircraft. Environmental effects should be included in this determination (especially cold temperature effects). Flow times may be significantly reduced by the use of small by-pass holes separated from the main damping orifice.

3.2.7 Orifices

An orifice mating with an unguided metering pin should be contoured such that the passage of oil during the primary compression phase is smooth. The orifice plate should have rounded edges and sufficient gap to prevent damage to the metering pin in the event of contact. When the gas content of the oil passing through the orifice is negligible, or when the metering pin is mechanically guided (or non-existent), sharp edged metering orifices may be used. Their edges should be without chamfers, radii, burrs, and irregularities. All metering passages should be so located, that their flow characteristics are unaffected by adjacent features. Velocity dependent (fixed orifices) and variable area fixed orifices may be used as passive damping techniques.

The specific orifice shape affects the flow discharge coefficient used in dynamic analysis. This coefficient must be validated by drop test. This value may be as low as 0.65 for square edge orifices to 0.97 for rounded edge orifices. It is important to have a good estimate of this value when performing dynamic landing analysis. For odd-shaped orifices, such as for flutted pins, the discharge coefficient may be difficult to predict, and the analysis and design should account for this uncertainty.

3.2.8 Metering Pins

Metering pin(s) should be located and retained in such a manner as to ensure that the intended relationship with its orifice is maintained throughout all conditions of operation. The gap between the pin and the orifice plate should allow for expected flexibility of the shock strut during landing. If the required orifice area is too small to allow for this gap, then a guided pin is preferable, such as a fluted pin.

The metering pin profile should be tailored to obtain the desired load versus stroke curve. This may be intentionally inefficient to minimize loads transmitted to the airframe. It is usually not desirable to enlarge the pin diameter at the beginning portion of compression, as this increases spin-up loads and may cause landing comfort issues. It also increases the possibility of pin contact with the orifice.

Lateral stiffness of metering pins should be considered to ensure no contact between metering pin and orifice plate.

3.2.9 Oil Content

The oil content and the manner of its containment should be such that metering action is not significantly impaired by either oil foaming during operation or a slight oil deficiency. When gas/oil separation is not provided, the metering passages in the extended position should be submerged by at least 125% of the diameter of the oil column, or 5 in, whichever is less. An oil deficiency approximating 10% of the swept volume should not cause a pronounced departure from normal functioning. It should not be possible to reduce oil quantity below the "unswept volume" upon which the design is based, when filled in accordance with the instructions stated on the nameplate. Cold temperature operation should also be accounted for.

Care should be taken to maintain an air to oil volume ratio that minimizes the effect of air entrainment (when separator pistons are not employed). It is recommended that this ratio be no less than 10 (with air at standard atmosphere).

3.2.10 Interconnection of Internal Chambers

In establishing the manner and degree of interconnection required between the various internal chambers of the shock strut(s), consideration should be given to all phases of servicing and operation, which, without such provision, could cause entrapped gas or misplaced oil to impair subsequent functioning. Proper functioning should be demonstrated during development.

3.2.11 Servicing

The following provisions are preferred:

1. Removal of wheels, tires, and brakes from multiple axle landing gears should be made without the jacking of the aircraft.

2. Spare seals (lower bearing-shock-absorber assembly) should be provided so that in the case of emergencies, the inner cylinder need not be fully removed when replacing seals.

3. Filler plugs and charging valves should be located so as to ensure practical access with the necessary standard equipment. Adjustment to nitrogen and oil content should be practical and without the need to jack the aircraft, or to disturb adjacent aircraft components. The time required for such servicing should be minimal and consistent with system maintenance limits. Good design practice dictates that the valves are located away from threat zones or are designed to prevent oil loss if the valve is damaged. The use of an oil drain valve at the bottom of the strut is recommended for ease in oil servicing.

4. For military aircraft which are required to operate in a chemical/biological environment, the landing gear design should allow the user the ability to accomplish flight critical servicing and maintenance tasks by personnel in chemical biological clothing as deemed necessary by the procuring activity.

3.2.12 Gas Charging Ports

The gas charging port(s) should be in accordance with MS33651 and be fitted with a valve in accordance with MS28889.

3.2.13 Static and Dynamic Seals

The number of dynamic and static seals should be kept to a minimum and their accessibility for replacement should be consistent with the severity of their operating condition. Seal installation should preclude impairment from structural loading. The selection and installation of dynamic seals should resist the tendency to “spiral” or roll in the gland. This problem is usually seen with O rings, which should not be used for dynamic landing gear applications. Custom geometry type seals are recommended for use in dynamic strut seals to resist these failures and assure a longer service life.

Gland configuration should be to AS4716 or to AS4832 where glands larger than 1/4 in cross-section are required. These larger glands and seals are recommended for piston diameters greater than 8 in or where significant ovalization and deflection is predicted.

A premium nitrile base elastomer should be specified for all mineral and synthetic base hydraulic fluids. AMS-P-83461 can be specified as a minimum requirement.

Recently most wide-bodied commercial aircraft have used elastomer seals with a filled PTFE cap on the dynamic surface. These seals have shown a much improved service life and are preferred for plasma spray coatings such as HVOF. Extra care is required to ensure smooth transitions where PTFE cap seals are installed as they are more susceptible to damage than elastomeric contact seals. PTFE cap seals are not amenable for use as spares.

Backup rings should be used whenever possible to prevent extrusion and the spiral type failures of some seals. Backup ring materials must be compatible with the fluid being used and of sufficient strength to eliminate shear failure with large extrusion gaps.

The use of spare seals stored in the strut or inactive seals, which can be easily activated, should be considered. Several methods of recommended spare seal storage are documented in ARP4912.

3.2.14 Hydraulic Fluids

MIL-PRF-5606H is the standard “red” oil that has been used for many years in shock struts. This fluid is rapidly being eliminated from the supply chain and is quickly being replaced by MIL-PRF-87257 or MIL-PRF-83282.

To assist in reducing the chances of “ladder cracking,” particularly in wide-bodied aircraft, AIR5358 has been issued. This fluid is a blend of either MIL-PRF-5606H or MIL-PRF-87257 with several EP extenders designed to reduce the high friction and resulting heat in the shock strut seal and bearing areas.

Seal compounds should be compatible with the hydraulic fluid used.

TABLE 1 - DYNAMIC SEAL SPECIFICATIONS

Temperature Range	Elastomer Material	Hydraulic Fluid	Gland Standard
-65 to 275 °F (-54 to 135 °C)	AMS-P-83461	MIL-PRF-87257 MIL-PRF-5606 AIR5358	AS4716 AS4832 (Optional)
-65 to 275 °F (-54 to 135 °C)	NAS1613	AS1241 Phosphate Ester (e.g., Skydrol)	AS4716 AS4832 (Optional)
-40 to 275 °F (40 to 135 °C)	AMS-P-83461	MIL-PRF-83282	AS4716 AS4832 (Optional)

3.2.15 Scraper Rings

Scraper rings should be fitted to the lower end of the cylinder assembly preferably in the gland nut to protect the bearing and dynamic seals from abrasive contamination damage.

Non-metallic scraper rings are preferred and are to be mounted in glands in accordance with AS4052. Scraper ring assemblies must be compatible with the hydraulic fluid used in the shock strut, as well as any grease or fluid contaminants encountered in this area.

3.2.16 Dynamic Sealing Surfaces

The proximity of the bearings to the dynamic seal should prevent the piston from contacting the lands flanking the seal groove.

Surfaces interacting with the seals should be hardened, typically by either chrome plating or with an HVOF coating. Stainless steel surfaces can be nitrided whereas aluminum surfaces can be hard anodized.

Chrome plating should have a minimum thickness of 0.003 in (0.076 mm) in accordance with AMS-QQ-C-320 after final grinding. All sliding surfaces should have a polished finish of 8 to 16 µin in accordance with ANSI B46.1. All plating should be free of surface imperfections that would impair the action and life of the seal.

HVOF coatings should meet the specifications of ARP5935.

3.2.17 Sliding Bearings

The locations, proportions, materials, fits, and lubrication of the sliding bearings of all gas/oil shock struts should be selected with due regard to the following factors:

a. The bending and/or column loading sustained by the telescoping members at the various degrees of closure.

b. The deflections resulting from a.

c. Diametral strain of mating members due to conditions of differential pressure.

d. Dimensional stability of bearing material with exposure to fluids and/or temperature variation.

e. The sensitivity of the performance, including extension of the shock strut, due to bearing friction and variations thereof.

f. Friction heat and its possible effects on the stability of mechanical properties of relevant exposed parts. Truck pivot pin joints should be designed so that the product of pressure-velocity (PV - psi-ft/min) due to operating on short wavelength runway roughness does not exceed the allowables of the joint materials used.

3.2.18 Full Travel Stops

Stops should be provided at the full travel stages of the shock strut that would be capable of sustaining, without deterioration, all loads that occur due to the engagement of the stops during the proper operation of the shock strut. An internal pressure equal to the closing pressure, or maximum dynamic pressure, whichever is the greatest should be considered.

The extension stop must withstand the expected (and required) out stop forces. For commercial aircraft, the required stop force is 20 times the unsprung weight (limit). In addition to this, fatigue loading should also be accounted for. Fatigue loads should account for nominal functioning of rebound snubbing devices.

3.2.19 Gas Content

The compression ratio realized under the landing condition demanding most shock strut stroke, should, whenever compatible with other requirements, be such that the unit is in no danger of compression ignition. When a higher compression ratio is deemed necessary, the nameplate should carry a notice: "SERVICE WITH DRY NITROGEN ONLY - DO NOT USE AIR".

The gas charge should be such that, working in conjunction with other elements of the aircrafts' suspension, the shock strut will not incur harmful travel stop loads during landing, taxiing, or ground handling. The gas charge should also affect full and prompt restoration of the unloaded state of the shock strut after take-off, and sustain it throughout flight, unless the airframe contractor can show that such action is unnecessary for stowage of the landing gear, and that the ensuing landing is not compromised by its omission. The static gas pressure should be limited to 2500 psi, wherever practical, to ensure compatibility with standard service equipment.

3.3 Retraction Mechanism Elements

3.3.1 Downlock Mechanisms

All retractable landing gear should have mechanical down-locks capable of sustaining the extended position of the gear under all loading conditions (air, ground, inertia, etc.) for which the gear is designed, and the structural deflections resulting therefrom. Engagement of the down-lock should be automatic upon completion of the gear extension, whether this extension is accomplished either by a normal or emergency procedure. Release of the down-lock from its engaged state should occur automatically upon applying power to affect landing gear retraction and after removal of ground safety provisions. The down-lock should be designed and protected to avoid the risk of malfunction due to corrosion, ice, and dirt accumulation. The design of the down-lock should not permit the lock to be unlocked by ground loads or cause the lock to move excessively due to either structural deflection, vibration, or any other means for which the gear is designed. When the down-lock has been "engaged", it should not change from that state as a result of any remote system function. Care should be taken in the design of the mechanism to ensure that classic failure modes (failure of a spring, failure of a actuator hose, hydraulic system, etc.) should not unlock the mechanism. The basic concept of a downlock design should fail safe (i.e., not unlock).

During the early design stages of an aircraft conceptual design some landing gear retraction mechanism design starts with a trade study on the merits of an external locking linkages versus internal locking actuator. In general, larger aircraft tend to use external locking linkages while small to medium aircraft use both internal locking actuators and externally locking linkages.

3.3.1.1 External Downlock Elements

External locking linkages such as over-center linkage, pin/cam, pin/hole, pin/hook and others have been used on landing gear downlock designs. The advantage of this design is the reliability of a mechanical linkage holding the struts on-center not influenced by deflections, friction or system failures. Also, the ground crew can usually see the state of the locking components from a safe distance. The disadvantage is the lock group is susceptible to dirt and ice contamination, and to impact from tire debris, birds, etc. Care should be taken to position the locking components in a protected area if possible. The lock links should be designed so that the weight of the members tend to lock the mechanism. Aiding springs should be designed to lock the mechanism. Springs used for critical functions should have redundant features. The design should ensure that if a spring breaks, the mechanism is not prevented from locking and if already locked not allowed to unlock. In addition, the broken spring parts (halves) should be designed to be captured and prevented from lodging in the downlock mechanism or other aircraft systems.

Some landing gear designs use the downlock mechanism as an up-lock mechanism also. Since the downlock design drives the design of the lock group the up-lock position might be over designed for the loads. However, this is a trade off between this and a separate up-lock design. The downlock is designed to fail and remain in the lock position. In the up-lock position this will require careful consideration of the mechanism failure modes. Since in a failure, the mechanism will tend to stay locked when we actually want it to release. In this case, the alternate release system will be required to be robustly designed to release the landing gear in the case of a failure.

3.3.1.2 Internal Locking Actuators

The internal locking actuator design concept offers an all in one solution which includes a retraction actuator and locking brace capable of holding the mechanism ground handling and landing loads. The internal lock concept may use segments, rings, collet or other concepts. The locking element must be "positive" (i.e., not dependent on friction) to prevent un-locking once the lock is set. The locking element must be capable to carry the required loads and operate correctly. One advantage of an internal locking actuator is the fact that the lock group is protected from the external elements (dirt, ice, etc.). The disadvantage is you can not directly see the locking components. However, various indication schemes have been made to work to provide external indication.

3.3.2 Gear Retraction and Extension

Sizing of the retraction actuator (geometry and effective pressure areas) should be considered in the early stages of landing gear design. Trunnion moments of retraction are established by the evaluation of the air loads, landing gear dead weight, friction and acceleration forces based upon retraction time requirements, and, in some instances, negative "g's" due to rapid ascent of the aircraft. It is important not to depend on gear inertial forces for either the gear retraction or extension cycle. For gear extension, all gears (nose and mains) should "free fall" in the event of an emergency. In cases where rearward retracting gears are found to be absolutely necessary, an independent means of extension must be used.

3.3.2.1 "Lost Motion" Mechanisms

A lost motion mechanism is defined as degree of freedom removed. A pin sliding in a groove is a good example. When "lost motion" mechanisms are adopted, studies should be made to ensure that the limited freedom of movement cannot occur to the detriment of the landing gear or its supporting structure. Analysis of the aerodynamic, inertia, friction, foreign object impact and contamination of the lost motion mechanism should be considered.

3.3.3 Downlock Position Verification

Means should be provided to inspect the position of lock components whose operation is sensitive to manufacturing tolerances such as overcenter type linkage locks. If overcenter type linkage locks are used, a positive means should be provided to measure or verify, during the rigging process, that the linkage pivot centers are overcenter per the design requirements. If internal locking actuators are used, a visual indication of lock condition should be provided.

3.3.4 Ground Safety Locking

Means should be provided to physically preclude gear retraction if hydraulic pressure is applied to retract the landing gear while the aircraft is on the ground. Such means should be independent of provisions to preclude "gear-up" selection in the event that any leg is in a loaded state. They should be provided with a warning indication that can easily be seen on a walk-around inspection.

Typically this is accomplished by a locking pin inserted into a lock member to prevent its inadvertent movement on the ground. Some small and/or older aircraft use a ground support equipment collar or sleeve mounted on a downlock release actuator to prevent gear retraction on ground. A red flag “Remove before flight” is usually attached to the locking pin.

3.3.5 Uplock

All retracting landing gears should have a means for sustaining the retracted state of the gear, either in conjunction with, or independently from, its stowage bay doors after retraction is complete, and until "gear down" is selected. Engagement of the up-locks should be automatic upon completion of the raising of the gear and, if interconnected, the closing of the doors. The up-lock should be designed and protected to avoid the risk of malfunction due to corrosion, ice, dirt accumulation and tire burst. Hydraulic and/or electric power should not be required to restrain the landing gear in the up and locked position.

3.4 Elements Interfacing with Landing Gear Systems, Airframe and Other Units

3.4.1 Axles

Axle ends mounting a wheel retaining nut should have provision for positive locking of the nut, with a position accuracy consistent with the need for correct preloading of the wheel bearings. All axles should be provided with protective means against undue wear from the engagement of the sealing element of the wheel anti-friction bearings and brake bushings. If internal wheel speed sensors are fitted, dimensional compatibility should be provided to ensure accurate mounting of such into the axle.

3.4.2 Brake Mounting

The strength, stiffness, and orientation of the brake mounting means should be established with brake system supplier and the aircraft manufacturer.

3.4.3 Airframe Attachments

The landing gear supplier and aircraft manufacturer should work together to specify the orientation, size, and fit of all airframe attachment points and the distribution of loading sustained therein.

3.4.4 Joint Lubrication

At all points where relative movement occurs (including that due to structural deflections), either permanently lubricated bearings or suitable lubrication means should be provided. Where journal bearings are of the lubricated type, the lubricators should be in accordance with MS15000 through MS15004 unless otherwise specified. Special consideration should be given to truck pivot pin joints when operating on rough runways. More frequent lubrication is required and in some instances, lubrication before and immediately after a rough runway visit is required in order to prevent bushing degradation and heat damage in the joint.

3.4.5 Towing

Each nose landing gear should have provisions for attaching suitable towing support equipment. This equipment should permit rapid towing or pushing of the airplane either forward or rearward with the aircraft under full control of the towing vehicle. The gear should be capable of withstanding the towing loads defined in the structural design criteria.

Towbarless towing should be considered in the design of NLG design.

Provision should be made on the main landing gear to permit emergency towing in deep snow, sand, or mud, and in either the forward or aft direction.

3.4.6 Jacking

Jacking points should be provided near the axle of each landing gear to permit wheel jacking at maximum aircraft weight. These points should be located such that standard jacks can be used when any single tire (or pair of tires) is deflated or destroyed. On larger braked wheels, the jacking points should be located such that standard jacks can be used when 3 in are ground off the wheel rim. Jacking points on the landing gear should be designed to MS33559 requirements, and for ship based aircraft, jacking provisions should be in accordance with MIL-STD-809.

3.4.7 Catapulting

For aircraft designed for catapult launching (using the nose landing gear) launching capability should be provided in accordance with MIL-L-22589.

3.4.8 Tie-Down

For ship based aircraft, tie-down provisions should be made in accordance with MIL-T-81259.

3.5 Material and Process Requirements

Complete history of material characteristics and corrosion inhibition should be available for review for the materials selected and the protection provided.

3.6 Environmental Compatibility

The performance of the landing gear should not be significantly affected by any combination(s) of environmental exposure for which the aircraft is required to be compatible, or those which the normal operation of the aircraft may generate. If the environment is adverse to the landing gear function, a compatibility demonstration should be conducted during development.

3.7 Miscellaneous Elements or Features

3.7.1 Interchangeability

All parts, sub-assemblies, and assemblies, should be physically and functionally interchangeable with all other parts, sub-assemblies, or assemblies produced to the same drawings, specifications, etc. To identify this interchangeability, such common parts, sub- assemblies, or assemblies should carry the same component number.

3.7.2 Adhesive Sealants

Joints that must be separated for servicing or for frequently needed maintenance operations should not be sealed with fused or adhesive materials.

3.7.3 Torsional Resistance of Locking Devices

The means of locking threaded joints such as may be used between a piston tube and piston nut, should have a liberal capacity to resist breakdown due to such action as torsional deflections, or relative rotation of other contacting parts. Five percent of the design torque loading of the gear strut should be considered minimal for gears with no abnormal factors prevailing.

3.7.4 Nameplate

The nameplate(s) complete with servicing instructions should contain the following or as agreed to with the airframer and/or contracting agency:

a. Manufacturer's name

b. Aircraft manufacturer's name

c. Design number and/or specification number

d. Order number

e. Serial number

f. Date of manufacture

g. Instructions for servicing

h. Warnings prior to disassembly, as applicable

i. Space to add modification numbers

The nameplate should be readily visible and the mode of attachment should be such as to resist the adverse effects of vibration, corrosion, foreign object damage (FOD), etc.

3.7.5 Standard Tools

The landing gear should be designed to minimize the need for special tools for servicing, repair, and overhaul operations, and to permit the use of standard commercially available tools whenever practical.

3.8 Hydraulic Actuators

MIL-PRF-5503 can be used as a guide for actuator design. External static seal glands should be per AS5857. Dynamic and internal static seals should be per AS4716. Load carrying features should be made from CRES or titanium to avoid corrosion.

3.8.1 Retract Actuators in Tension

3.8.1.1 Sizing

Operating area will typically be based on reacting maximum operating load at around 3/4 of the nominal system pressure. Over-sizing the actuator places an unnecessary flow demand on the hydraulic system and causes the supporting structure to be over-designed. In general, the lightest design will be achieved with the smallest actuator that can react the load at landing gear placard speed. Design weight is minimized if the stroke is longer (as compared to a short fat actuator) so if you can influence the moment arm of the system, try to make it as large as possible. This applies to tension actuators, not necessarily to compression designs.

Once the retract area is known the first detail to size is the piston rod to rod end joint. The lightest design is with an external thread on the piston rod but this requires a little more length. This will make a better fatigue detail of the rod end and the smallest possible diameter rod which assumes low column loading (usually not a problem with a free fall design). The thread diameter will be based on fatigue life (with a Kt of 3 at the thread root) so the load cycle needs to be developed. Don't forget snubbing pressures and flexure stresses due to bearing friction.

Landing gear retract actuators are best done as free fall designs where the head is connected directly to return.

Rod diameter must be slightly larger than the threads (1/16 to 1/8 in) so the rod gland seals will not be damaged at assembly. Now the cylinder bore can be calculated to provide the desired retract area.

3.8.1.2 Length

Be sure you have enough length to avoid poor structural details in the load path. This requires coordination with structures up front. A rule of thumb for sizing tension retract actuators for 3000 psi systems is for the retracted length (on the bench) to be equal to 3.5 times the bore plus the stroke. This assumes an internal rod end thread. Shorter designs are possible with external rod end threads and if the ports are brought out through the side of the barrel instead of through the glands.

Large actuators put out large forces which cause large deflections in the supporting structure and in the actuator itself. For this reason over-travel must be added to be sure it never bottoms out in service. For small actuators (lifting single axle landing gear) 3/8 in at both ends would be a starting point. Larger actuators must have more over-travel. Long load paths like walking beams also increase the deflection and tolerances.

Snubbers usually add additional length to the overall assembly for their operation.

To avoid fatigue problems don't overly reduce length where the rod end transitions from piston to bearing. If it looks like a like a very narrow rod with a large lug, it is likely a poor fatigue design.

3.8.2 Retract Actuators in Compression

Most of the above applies and then some. Compression actuators require large diameter piston rods to avoid buckling. Also must have greater bearing length at the rod gland to support the extended piston.

Their advantage is that you have the whole piston head area to react the load and the rod end seal is not subject to snubbing pressures. A disadvantage is the larger fluid exchange volume that increases the reservoir size. Snubbing is not as easy since both functions must be done at the head.

Since the rod end is mainly in compression the transition to the piston rod is not so important. Use an external thread on the rod end. If the rod diameter is large enough the rod bearing can be integral with the rod.

3.8.3 Internal Locking Design

The internal locking actuator is a hydraulic actuator that combines a traditional hydraulic actuator with a hydro-mechanical lock. Some actuators lock in the extended position, some in the retract position and others in both positions. The internal lock concept may use segments, rings, collet or other concepts. Depending on the design envelope and the external load the internal lock design may require a multiple stage lock design. Every stage reduces the load from the previous stage.

Internal failure modes and effects must be determined in the early phases of the design to ensure the design is “fail-safe” focusing on typical failures like seal failures, springs, lock members, etc during the initial design review studies.

Monitoring the lock group is one of the critical features in this design. Care should be taken to not only monitor the position of the actuator locking member. The “lock” indication should monitor the locking member to ensure that the actuator is in the correct “position” and “mechanically locked”. The sensor/switch has to have a minimal effect on the locking elements of the design function. In “closed cavities designs” care must be taken for condensation freezing cycles and frosting interfering with the locks function. In open cavities designs care must be taken to ensure contamination and impact by birds or ground handling personnel does not interfere with the normal function of the lock group. Varying system pressure should not cause any ill effects on the locking function or indication design.

It is recommended that the internal spring design be redundant due to the latent failure. If a spring fails it should not prevent the redundant spring from performing its intended function.

3.8.4 Lock Actuators

Size to unlock at 50% of system pressure. Must have less capacity than the alternate extend system so that the alternate system will always get the gear down. Actuator should extend to lock so return surges will not unlock it.

Downlock actuators are effectively a snubbing devise which should be restricted so that the stops of the lock links contact at about 4 in/s to limit noise.

Relief valves may be required if the geometry causes overdriving of the actuator. It is much better to design and test the actuator to the higher pressures since relief valves are undesirable in cost and complexity. The high loads generated must be made known to Structures.

3.8.5 Steering Actuators

Design case will be one of two: deflection control at flat tire spin-up or force required to maintain a maximum angle turn. Scrubbing loads may be a concern if steering when stopped is a requirement.

Must design for column loading although the control system should null out before the actuator bottoms to avoid noisy operation.

Special attention must be paid to the design of Structure's frangible tow lug which must be weaker than a single actuator piston since one actuator will be in tension if the tow vehicle over-steers.

3.8.6 Landing Gear Door Actuators

Snubbing length in the closed direction is affected by door warp. If controlling the final door velocity is important, usually for noise, then the snubbing must start before the door contacts the stop or the roller if applicable. The actuator is usually the door open stop. Air loads work to open the door for most of its travel which can lead to high rod end pressures during snubbing. One way around this is to restrict the flow into the head end so it cavitates until extend motion stops. Another method to limit pressure is to connect head and rod supplies together during opening. This requires a restrictor check upstream in the supply line to limit the rate.

Door actuators often must provide locking in the door closed position which requires the added complexity of internal mechanical locks. Current thinking is to lock the door closed using a hook mechanism at the front end of the door.

3.8.7 Truck Position Actuators

These have special requirements to hold the truck in a mid stroke position at landing. Must have over-travel in both directions to handle all possible landing attitudes and jacking for tire changing. Actuator should hydraulically lock in stow position so it is not loose in the wheel well. At landing there is a surge of fluid that must exit the unit rapidly, usually over a relief valve, so design for high pressures. During taxi there will be millions of small displacements which add to the fatigue damage. The simplest designs are single position actuators that are always pressurized to one position.

Some applications require a two position actuator when the landing position must be toes (front tires) up and the stow position must be toes down to fit in the wheel well. A toes-up attitude is generally preferred to minimize torsional vibration caused by the destabilizing nature of contacting the ground with the tires forward of the pivot point. Another reason for two position truck actuators is if the stow position does not provide enough truck angle with the runway to get a good truck on ground signal which is used by the auto spoiler system.

Truck actuators may benefit from having a bleed fitting. This is not so much to get air out of the actuator but to get air out of the pressure line at the time of fill and bleed. This should be a proper bleed fitting that a tube can be connected to, not just cracking a fitting which is a dangerous practice.

A loads analysis should be performed for the failure condition of landing with the truck in the stowed position.

4. DESIGN VERIFICATION

The following section provides recommendations for inspections and tests that are required to ensure the landing gears are designed, manufactured and assembled to meet their intended function and performance properties. Therefore, the scope of this chapter covers one-time activities (preproduction; qualification, flight testing, tooling verification) as well as recurring tests after final assembly that should be carried out in order to capture potential assembly discrepancies. It should be verified by inspection, analysis or test that the design meets all design requirements during development and qualification.

The actual requirements in terms of physical values, environmental conditions and other values are derived from the specific aircraft configuration and its operational necessities and are therefore to be specified by the aircraft manufacturer. Consequently, only some, all or even more verification activity may be required depending on the aircraft's specification, configuration and application.

4.1 Preproduction Testing and Inspections

To ensure the inherent capability in design, preproduction inspections should be applied to a sample, representative of the ensuing production units.

4.1.1 Examinations and Inspections

In addition to a First Article Inspection, which is a standard Quality Assurance measure, a thorough examination for compliance with drawing(s), correct identification, correct shock strut total travel, freedom from binding and correction of substandard workmanship should be conducted. It is advisable to split the inspections to various stages of the buildup process from subassembly level to fully dressed gears or actuators so that the examination can cover all features that are accessible only at various assembly stages.

Specific considerations for individual inspections are as follows (not exclusive):

- Drawing compliance examination should include proper engagement of threads, effectivity of locking features, main dimensions, torque versus locking feature adjustment capabilities (e.g., threaded gland nuts; wheel nuts; cross pin or cotter pin engagement in castellated nuts), accessibility of servicing/lubrication points, position and interface of undercuts/fillet radii/bearing lands, shape of assembly relevant features (chamfers, surface treatment transitions, guides, bearing lands, anti-rotation keys).

- Correct identification examination should include size and legibility of nameplates/stamps/engravings, visual obstruction of labels/markings, proper positioning of warning labels, correct color codes for nameplates as well as the colored markings of each lubrication feature (if applicable).

- An examination for correct shock strut total travel should include proper contact of intended mechanical stop and where accessible clearance checks for external/internal moving surfaces that are not supposed to be in contact with each other (if applicable). The A dimension[1] of the energy absorber should be defined and checked for the fully compressed and fully extended positions.

- Freedom from binding examination should include full shock strut travel in combination with full active and passive[2] steering travel where applicable. Clearance checks between suspended and non-suspended landing gear parts should include the actually measured deflections[3] under load. Clearance between paired torque links and harness guides in fully compressed and loaded condition. Verify actuator nominal travel, overtravel at each stop and overall travel. Check for clearance and free movement of spherical bearings, journal bearings, bushings and anti-rotation nibs (e.g., actuator rod end in clevis). Check for full truck tilt up and truck tilt down motion.

- An examination for correction of substandard workmanship should include optical appearance of finished surfaces, transitions from painted to non-painted surfaces, installation of non-standard locking features (e.g., fabricated tab washers), alignment and tie-down of dressing, application of sealants and corrosion inhibiting materials as well as retention of components that are installed with adhesives.

It is suggested that such engineering inspection is done by responsible design engineers and quality inspectors. Note that preproduction inspections of the landing gear installed in the airframe are listed in the Flight Testing section of this ARP.

4.1.2 Dynamic Leakage Tests

Shock strut elements should be correctly assembled, serviced, and stroked through not less than 100% of full travel. There should be no evidence of internal or external leakage causing degradation of performance as defined by the aircraft contractor. This may be done as part of the drop testing program and, depending on the gear configuration, in combination with or without lateral loads applied.

[1] A defined physical dimension on the shock strut used to measure stroke.
[2] With Torque links or other disconnecting/connecting/locking features engaged or disengaged as applicable.
[3] Actual deflections under loaded conditions are best to be derived from limit load tests. This is particularly important for but not limited to trailing arm type MLGs on fixed wing A/C and helicopters.

4.1.3 Static Leakage Tests

Correctly assembled and serviced shock struts should sustain the following test conditions without developing internal or external leakage causing degradation of performance as defined by the aircraft manufacturer.

a. Attitude, closure, and loading (except vibration) as appropriate to normal flight, for a duration of 6 h.

b. Attitude, closure, and loading as appropriate to aircraft standing on the ground for a duration of 24 h.

4.1.4 Development Drop Testing

In addition to qualification drop testing, the following tests might be carried out in order to establish the performance envelope at different servicing or temperature situations as well as to validate the simulation models, used in the design and certification process. The latter will provide substantiation data for correlating the gear to the simulation models which is then useful if special cases (incident investigation) or envelope extensions have to be simulated at a later stage.

Some of the development drop tests to consider include:

- Shock strut function and static strokes under cold (soaked) operation condition. Special configurations (e.g., when rubber or friction type damping elements/stops are in the load loop) might require high temp. drop testing as well.

- Static strokes at combinations of maximum/minimum vertical loads, maximum/minimum allowable servicing/mis-servicing conditions of both gas springs and damping fluids. Verify that gears don't bottom out or exceed desired extension stroke under these conditions.

A tear down visual inspection is recommended following testing.

4.1.5 Verification of Servicing Procedure

The initial servicing procedure as well as the re-servicing procedure should be tested.

If it is intended to avoid the load-stroke test for shock struts during each Production Acceptance Test, a servicing check should be designed to verify that the shock strut has the correct amount of oil/gas after applying the defined initial servicing or re-servicing procedures.

4.1.6 Verify Application of New Designs

It is recommended to conduct specific tests on new design items, processes, material combinations or mechanical features that are not based on previous design or for which little or no in-service experience exists. Testing such items for their suitability in this specific application as well as to ensure they meet the intended performance (e.g., endurance) can contribute a lot to avoiding costly in-service retrofits.

Safety related break-away features, crush-tubes, shear pins and other frangible design elements should be tested for function, break away force limits and to develop the required production process continuity. Final verification testing should be done with the actual component dimensions and correct interface materials, similar or identical to their production configuration.

Depending on the criticality of the application of such elements, the verification testing may have to be designed and recorded for use as substantiation material for subsequent landing gear qualification/certification. Claiming similarity to other programs, materials or design shapes is not advisable for frangible elements.

4.2 Qualification Testing

Qualification tests listed in this chapter are meant to be physical tests, not qualification by similarity, by analysis or by other acceptable means of compliance.

It is advisable to carefully evaluate if, for instance, similarity can be claimed. Experience shows that positive test results in the past are often invalid for application on a design or for a specific application that appears similar but is still different. As a precaution, qualification based on similarity should only be accepted when it goes back one component generation/application and the detail test specifications and results should be presented in a similarity matrix.

4.2.1 Examination of Product

Inspection and recording of components to substantiate production equivalent configuration of the test articles. This inspection is similar to the production acception tests defined in 4.3.

On structural type test articles, measure and record material dimensions of functional and/or critical areas. Measure and record clearances and free play of all relevant functional features of the landing gear before and after all qualification tests related to endurance, function and performance of the unit.

For qualification related electrical testing, a detail assembly record for all bonding and electrical performance related features should be established (e.g., actual value of torque applied to bonding strip fasteners).

4.2.2 Pressure Tests

The landing gear shock strut should be subjected to pressures not less than 1.25 times the maximum value that they are to accommodate during design landing for a period not less than 5 min. On completion there should be no leakage causing degradation of performance as defined by the contractor. To localize the test pressure distribution within energy absorption units, so as to statically simulate the pressures dynamically generated in usage, internal fluid passages may be blanked off for this test. End constraints of the energy absorbing units during this test should be applied when such means duplicate the loading and closure conditions occurring in service. The gas chambers of the shock struts should, whenever practical, be filled with oil in lieu of gas for the execution of this test.

4.2.3 Drop Testing

Energy absorption during landing should be demonstrated by analysis and the performance of drop tests in accordance with pertinent regulatory requirements, Military Specification Requirements, AS6053, or procurement documentation prior to first flight. The drop tests should demonstrate the attainment of desired load/time/stroke characteristics for stress and loads analysis purposes. This test is also used to validate the dynamic landing analysis used to develop certification design landing loads. (For derivative models, this may be demonstrated by analysis in lieu of testing, provided the analysis has been validated by prior drop test.) Some further drop testing, as a sampling procedure may be required by the aircraft manufacturer. Additional drops should be considered after the assembly has soaked at environmental extremes. Drop tests should be conducted with production fluid. Following the drop tests, inner and outer cylinders should be inspected for friction heat defects.

Particularly for inclined landing gears, the drop test setup should enable analytical extraction of the friction loads in order to distinguish between load distributed through the ground, tire, acceleration, gas spring compression and shock strut internal friction. The fraction of energy absorbed by friction should be kept to a minimum (e.g., preferably less than 15%).

Rebound damping performance should be verified during drop testing (reference 3.2.5).

For carrier based aircraft use full airframes for drop testing.