



AEROSPACE RECOMMENDED PRACTICE

ARP1311™

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Superseding ARP1311C

Landing Gear Structures and Mechanisms

RATIONALE

This document defines the Aerospace Recommended Practice (ARP) for the design and verification of landing gear structures and mechanisms. This ARP revision corrects testing inaccuracies in the Static Leak Section of previous revisions.

ARP1311D 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 +1 724-776-4970 (outside USA), www.sae.org.

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)
AIR1494	Verification of Landing Gear Design Strength
AIR1594	Plain Bearing Selection for Landing Gear Applications
AIR1752	Aircraft Nosewheel Steering/Centering Systems
AIR4566	Crashworthy Landing Gear Design
AIR4894	Landing Gear Stability
AIR5358	Landing Gear Shock Strut Hydraulic Fluid
AIR5451	A Guide to Landing Gear System Integration
AIR5479	Environmentally Compliant Processes for Landing Gear
AIR5883	Landing Gears Shock Struts Bearing Selection
ARP1595	Aircraft Nosewheel Steering Systems
ARP4912	Design Recommendations for Spare Seals in Landing Gear Shock Struts

ARP4915	Disposition of Landing Gear Components Involved in Accidents/Incidents
ARP5429	Landing Gear Fatigue Tests with Equivalent Damage Spectra
ARP5935	Use of HVOF Thermal Spray Coatings for Hard Chrome Replacement in Landing Gear Applications
ARP5936	Landing Gear Storage
ARP6408	External Hydraulic Fluid Leakage Definition for Landing Gear Shock Absorbers
AS1241	Fire Resistant Phosphate Ester Hydraulic Fluid for Aircraft
AS4052	Gland Design: Scraper, Landing Gear, Installation
AS4716	Gland Design, O-ring and Other Elastomeric Seals
AS4832	Gland Design: Nominal 3/8 in Cross Section for Custom Compression Type Seals
AS4941	Aerospace - General Requirements for Commercial Aircraft Hydraulic Components
AS6053	Tests, Impact, Shock Absorber Landing Gear, Aircraft
AS8860	Landing Gear Structural Requirements as Listed in the MIL-886X Series of Specifications
PT-37	Aircraft Landing Gear Systems
PT-66	Emerging Technologies in Aircraft Landing Gear

2.2 U.S. Government Publications

Copies of these documents are available online at <http://quicksearch.dla.mil>.

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-L-8552C	Landing Gear, Aircraft Shock Absorber (Gas/Oil Type)
MIL-L-22589D	Launching System - Nose Gear Type Aircraft
MIL-PRF-5503F	Actuators: Aero Linear Utility, Hydraulic, General Spec For
MIL-PRF-83282D	Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Metric, Nato Code Number H-537
MIL-PRF-87257B	Hydraulic Fluid, Fire Resistant; Low Temperature, Synthetic Hydrocarbon Base, Aircraft and Missile
MIL-STD-805B	Towing Fittings and Provisions for Military Aircraft
MIL-STD-809	Adapter, Aircraft, Jacking Point, Design and Installation (Canceled)
MIL-T-6053	Tests - Impact Shock Absorbers (Inactive)

MIL-T-81259B	Tie Downs - Requirements for Airframe Designs
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)
AR-MMPDS-03	Metallic Materials Properties Development and Standardization
JSSG 2006	DOD Joint Service Specification Guide - Aircraft Structures

2.3 ANSI Accredited Publications

Copies of these documents are available online at <http://webstore.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, Ottoplatz, 1, D-50679 Cologne, Germany, Tel: +49 221 8999 000, www.easa.europa.eu.

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 (F_{bu}) 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 (K_{Ic}) value no less than 100 ksi $\sqrt{\text{in}}$ (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 inch for holes with bushings and bore diameter plus 0.120 inch for holes without bushings. In addition, repair allowances of 0.030 inch 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 two lifetimes of fatigue testing without damage. For U.S. Navy nose tow launch airplanes, the NLG must pass two lifetimes of complete loads, plus an additional one 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 inch.

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 eight 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 one design lifetime. The starting surface flaw is 0.02-inch-long and 0.01-inch-deep (0.01-inch 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-inch-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 three or more main landing gears, 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.