SAE The Engineering Society For Advancing Mobility Land Sea Air and Space®
INTERNATIONAL
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AEROSPACE RECOMMENDED PRACTICE

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AIRCRAFT LANDING GEAR

1. SCOPE:

This SAE Aerospace Recommended Practice (ARP) applies to landing gear structures and mechanisms (excluding wheels, tires, and brakes) for all types and models of civil and military aircraft applications. All axles, wheel forks, axle beams, links, arms, mechanical and air-oil energy absorbers braces, lock assemblies, trunnion beams, etc., that sustain loads originating at the ground, and that are not integral parts of the airframe structure should be designed in accordance with this document. Hydraulic actuators (retraction, steering, positioning, and/or damping) should also be included in this coverage.

It should be the responsibility of the airframe manufacturer to determine the compatibility of these needs with the aircraft and to specify requirements in excess of these minima where appropriate.

1.1 Purpose:

This document defines minimum requirements for landing gear structure and mechanisms in civil and military aircraft applications.

2. APPLICABLE DOCUMENTS:

The following publications form a part of this specification 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, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

AS4052 Gland Design: Scraper, Landing Gear, Installation

2.2 U.S. Government Publications:

Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MS15000 - MS15004
MS28889
MS33559
MS33651
MS33675
MIL-L-22589
MIL-STD-805
MIL-STD-809
MIL-T-81259

2.3 ANSI Publications:

Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ANSI B46.1

2.4 Other Publications:

QQ-C-290
QQ-C-320

3. REQUIREMENTS:

3.1 Functional Requirements:

3.1.1 Energy Absorption: The landing gear should have sufficient capacity for energy absorption during the landing impact of the aircraft. This capacity should be demonstrated by the performance of drop tests in accordance with pertinent Federal Aviation Regulations (FARs), Military Specification Requirements, or procurement documentation. The drop tests should demonstrate the attainment of desired load/time/stroke characteristics for stress and loads analysis purposes.

3.1.2 Dynamic Stability: The springing and damping characteristics of the landing gear should be conducive to stable and even movement of the aircraft during taxiing, takeoff, and landing run-out.

3.1.3 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.

3.1.3.1 Extension to Touchdown Time: The internal construction of air-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.

3.1.4 Wear Characteristics: The durability of all working parts should be such that no significant diminishing of the landing gear performance occurs during their required life. The number of parts having a scheduled service life less than the rest of the landing gear must be minimized. The decay characteristics of these parts should be such that the need for their replacement is clearly apparent before it causes any significant malfunction of the landing gear. A suitable wear evaluation should be included in the development program.

3.1.5 Rebound Damping: Means should be provided to limit the re-extention velocity of the energy absorbing device so that the tendency of the aircraft to rebound after the initial landing will not significantly affect aircraft stability, control, or braking performance.

The strut extension stops should be designed to withstand the shock loads resulting from maximum re-extension velocity. Improper strut servicing (i.e., incorrect precharge, subsequent charge by gas only, lack of fluid, etc.) must be considered in this regard. An internal pressure equal to the closing pressure, or maximum dynamic pressure, whichever is the greatest should be considered.

3.2 Structural Requirements:

The landing gear should fulfill all the FARs, Military Specifications, or program structural requirements applicable to the type of aircraft for which it is designed.

3.2.1 Structural Capacity: The landing gear should have adequate structural capacity for all combinations of loads that can be encountered during landing impacts as defined by the pertinent drop test and crashworthiness requirements. The gear should be suitable to withstand all ground operational environments. All structural criteria should be verified during development.

3.2.2 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 contractor, 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.

3.2.3 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 shall be a consideration.

3.2.4 Structural Life Assurance: An analysis should be conducted to ensure an adequate life of the landing gear. The airframe contractor 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 when damage tolerant landing gear is a requirement.

Crack growth analysis should be performed for each critical location to determine damage tolerance life for the landing gear. 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.

3.3 Material and Process Requirements:

The selection of appropriate materials and processes should be made with thorough regard of all the pertinent factors. A complete history of material characteristics and corrosion inhibition should be available for review for the materials selected and the protection provided.

3.4 Requirements for Particular Elements and Features:

3.4.1 Air-Oil Energy Absorber Assemblies:

3.4.1.1 Orifices: An orifice mating with an unguided metering pin should be contoured such that the passage of oil during the primary stroke should be smooth. When the gas content of the oil passing through the orifice is negligible, or when the metering pin is mechanically guided (or nonexistent), 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.

3.4.1.2 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.

3.4.1.3 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 before the “unswept volume” upon which the design is based, when filled in accordance with the instructions stated on the nameplate.

3.4.1.4 Interconnection of Internal Chambers: In establishing the manner and degree of interconnection required between the various internal chambers of the shock absorber(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.

3.4.1.5 Servicing Provisions: Filler plugs and charging valves should be located so as to ensure practical access with the necessary standard equipment. Adjustment to gas 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.

For military aircraft 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.

3.4.1.6 Gas Charging Ports: The gas charging port(s) should be in accordance with MS33651 and be fitted with a valve in accordance with MS28889.

3.4.1.7 Drainage Provision: It should be a design objective to locate a drainage means within all shock absorbers having a substantial oil content, such that the bulk of this oil can be drained without retraction of the landing gear and prior to such major disassembly as the removal of the piston. When this is impractical, partial retraction to facilitate drainage is preferable to no drainage means at all.

3.4.1.8 Seals: The quantities of dynamic and static seals should be minimal, consistent with the remaining parts of this document, and their accessibility for replacement should be consistent with the severity of their operating conditions. Seal installations should be such as to preclude impairment from structural loading. The selection and installation of dynamic seals should be such as to resist the tendency of "spiral failure" of the seal. Similarly, the risk of extrusion failure should be assessed and any necessary anti-extrusion provisions made. Provisions should be made for adequate groove widths so that back-up rings may be used in severe service conditions.

O-rings are not recommended for use as dynamic seals due to their susceptibility to spiral failures and the resulting short service life. However, if O-ring dynamic seals are used, their installation should be in accordance with Table 1. Other forms of dynamic seals and/or installations may be preferable under severe service conditions. The materials of these other forms of dynamic seals shall be compatible with the hydraulic fluids specified.

No dynamic seal should require lubrication necessitating partial disassembly of the shock absorber.

TABLE 1 - Dynamic Seals and Hydraulic Fluids

Temperature Range	O-ring Dynamic Seal	Seal Material	Hydraulic Fluid	Gland Standard
-65 °F (-54 °C) to 275 °F (135 °C)	AS568	MIL-P-83461	MIL-H-5606 or MIL-H-6083	MIL-G-5514
-65 °F (-54 °C) to 275 °F (135 °C)	AS568	NAS1613	Phosphate Ester (e.g., Skydrol)	MIL-G-5514
-40 °F (-40 °C) to 275 °F (135 °C)	AS568	MIL-P-83461	MIL-H-83282	MIL-G-5514

3.4.1.9 Hydraulic Fluid: The use of a fluid as listed in Table 1 is preferred. In the event that phosphate ester based fluids are used, particular care is required to ensure that compatible elastomer seals are also used. The nameplate should list the acceptable fluid(s) with which the energy absorber should be filled.

3.4.1.10 Dynamic Seals Rubbing Surfaces: All sliding surfaces should have a polished finish of 8 to 16 µin in accordance with ANSI B46.1 and be so processed and protected as to minimize the deterioration of the finish and the seal during the life of the shock absorber. The proximity of the dynamic seal(s) to the sliding bearing(s) should be such that the lands flanking the seal groove(s) do not constitute bearing elements. Contact between these lands and the bearing engaging surfaces is to be precluded.

3.4.1.10.1 Seals Exposed Surfaces: Surfaces such as piston outside diameters that pass through dynamic seals or otherwise are exposed to corrosive and/or erosive environments should have the following minimum of chrome plating in accordance with QQ-C-320 after final grinding:

a. Land Based Aircraft: 0.003 in (0.076 mm)
b. Ship Based Aircraft and Amphibious Aircraft (Water and Land Alighting): 0.004 in (0.102 mm) with a nickel preplating of 0.0010 to 0.0005 in (0.025 to 0.013 mm) in accordance with QQ-N-290.

All plating should be free of surface imperfections that would impair the action of the seal. Other finishes and coatings which are proven to be environmentally friendly, may be used.

3.4.1.11 Scraper Ring: Scraper rings should be fitted to the lower end of the cylinder to protect the bearings and dynamic seals from abrasive contaminant damage. Nonmetallic scraper rings are preferred and are to be mounted in glands in accordance with AS4052 or with MS33675 as alternate. Scraper ring assemblies must be compatible with the hydraulic fluid used in the energy absorber as well as any grease or fluid contaminants likely to be encountered in the service area.

3.4.1.12 Sliding Bearings: The locations, proportions, materials, fits, and lubrication of the sliding bearings of all air-oil energy absorbers should be selected with due regard to the following factors:

a. The bending and/or column loading sustained by the telescopic members at the various degrees of closure.
b. The deflections resulting from (a).
c. Diametrical strain of mating members due to conditions of differential pressure.
d. Dimensional stability of bearing material with exposure to fluids and/or temperature.
e. The sensitivity of the performance, including re-extension of the energy absorber, to bearing friction and variations thereof.
f. Friction heat and "ladder cracks".

3.4.1.13 Gas Content: The compression ratio realized under the landing condition demanding most energy absorber 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 aircraft suspension the energy absorber 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 energy absorber after takeoff 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.

3.4.1.14 Full Travel Stops: Stops should be provided at the full travel stages of the energy absorber that would be capable of sustaining, without deterioration, all loads that can occur due to the engagement of the stops during the proper operation of the energy absorber.

3.4.2 Retraction Mechanism Elements:

3.4.2.1 Down-Locks: All retractable landing gear should have mechanical down-locks capable of sustaining the extended position of the gear under all loading (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 by a normal or emergency procedure. Release of the down-lock from its engaged state should occur automatically upon applying power to effect 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 or the lack of lubrication. The design of the down-lock should not permit the lock to be loaded by ground loads or to cause the lock to move 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.

3.4.2.1.1 Down-Lock 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 in line or overcenter per the design requirements. If internal locking actuators are used, a visual indication of lock condition should be provided.

3.4.2.1.2 Down-Lock Status Indication: Provision should be made for a means whereby the down-lock status ("engaged" or "less than fully engaged") may be indicated in the cockpit. Such means should be incapable of falsely indicating an "engaged" state.

3.4.2.2 Up-Locks: 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. Release of the up-lock from the engaged state should result from the cockpit selection of "gear down". The up-lock should be designed and protected to avoid the risk of malfunction due to corrosion, ice, and dirt accumulation, or lack of lubrication.

3.4.2.2.1 Up-Lock Status Indication: Provision should be made for means whereby the state of the up-lock(s) either "engaged" or "less than fully engaged" may be signaled to the landing gear control system.

3.4.2.2.2 Weight on Wheel Indicators: Provision should be made to indicate that the gear is being compressed (due to landing surface contact). This is to provide a signal to systems such as the antiskid system, which may require such indication. Indicator installations shall not be affected by corrosion, ice, de-icing or cleaning fluids, mud or dirt accumulation.

3.4.2.3 Retraction and Extension: Sizing of the retraction actuator (geometry and effective pressure areas) should be considered in the early stages of the landing gear design. Trunnion moments for retraction are established by the evaluation of the air loads, landing gear dead weight, and acceleration forces based upon retraction time requirements, and, in some instances, negative "g's" due to rapid ascent of the aircraft. For gear extension, all gears (nose and mains) should "free fall" and be powered down only in the case of an emergency. In cases where rearward retracting gears are found to be absolutely necessary, an independently powered extension device must be used.

3.4.2.3.1 Gear Control Action: All retractable landing gear should fully retract and complete their stowage and up-locking function in response to a single control action from the cockpit. Also, they should revert to the down and locked state in response to another single control action. Where a series of actions such as a down-lock release, bogie trimming, gear raising, and door actuation constitute the total retraction or extension cycle, all necessary sequencing should be accomplished either by positive mechanical means; or, if dependent upon electrical and/or hydraulic system(s), then system malfunction should be incapable of generating damage, or precluding return to the "gear down" state by both normal and emergency procedure.

3.4.2.3.2 Control Reversal: At all stages within the retraction and lowering cycles, the gear actuation should be responsive to a reversal of control selection. In the event that the retraction or lowering cycle is temporarily arrested or reversed by the occurrence of briefly applied dynamic or aerodynamic loads in excess of design operating values, the normal motion should resume thereafter without the need for further control action from the cockpit.

3.4.2.3.3 "Lost Motion" Mechanisms: 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 support structure.

3.4.2.4 Ground Safety Locking: Means should be provided to physically preclude gear retraction when or if hydraulic pressure is separately applied to each leg while the aircraft is ground borne. 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 be easily seen on a walk-around inspection.

3.4.3 Elements Interfacing With Other Units and Airframe:

3.4.3.1 Axle(s): 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 gripping 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.

3.4.3.2 Brake Mounting: The strength, stiffness, and orientation of the brake mounting means should be established by the airframe contractor.

3.4.3.3 Airframe Attachments: The airframe contractor should specify the orientation, size, and fit of all airframe attachment points and the distribution of loading sustained thereat.

3.4.3.4 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.

3.4.3.5 Towing: Each nose landing gear should provide 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. 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. For ship based aircraft, towing provisions shall be in accordance with MIL-STD-805.