SAE Aerospace
An SAE International Group

AEROSPACE RECOMMENDED PRACTICE

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Aircraft Landing Gear

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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 including all aircraft with vertical landing and crash attenuation requirements.

All axles, wheel forks, axle beams, links, arms, mechanical and nitrogen/oil energy absorbers, lock 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 in accordance with this document. Hydraulic actuators (retraction, main and nose gear steering, positioning, and/or damping) should also be included in this coverage.

1.1 Purpose:

This document establishes minimum design requirements along with guidelines regarding priorities in landing gear design, and is recommended for use particularly in the early design stages of all aircraft concepts. These priorities should be approved by the aircraft manufacturer's program management as early in the program as possible, along with any deviation which may be deemed necessary. It is also the aircraft manufacturer's responsibility to specify requirements in excess of these minima where appropriate.

2. APPLICIABLE 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, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

ARP4912	Design Recommendations for Spare Seals in Landing Gear Shock Struts
ARP4915	Disposition of Landing Gear Components Involved in Accidents/Incidents
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.

MIL-T-6053	Tests - Impact Shock Absorbers
MIL-L-8552	Landing Gear, Aircraft Shockstrut (Gas/Oil Type)
MIL-L-22589	Launching System - Nose Gear Type Aircraft
MIL-T-81259	Tie Downs - Requirements for Airframe Designs
MIL-A-008860	Airplane Strength and Ridgidity
MIL-A-008862	Airplane Strength and Ridgidity
MIL-A-008863	Airplane Strength and Ridgidity
MS 15000	Fittings - Lubrication - Hydraulic
MS 15001	Fittings - Lubrication - Hydraulic
MS 15002	Fittings - Lubrication - Hydraulic
MS 15003	Fittings - Lubrication - Hydraulic
MS 15004	Fittings - Lubrication - Hydraulic
MS 28889	Valve, Air, High Pressure Charging (5000 psi)
MS 33559	Adapter, Aircraft, Jacking Point, Design and Installation
MS 33651	Boss, Air Connection, Design and Installation
MS 33675	Scraper Installation - Packing Gland Ring
MIL-STD-805	Towing Fittings and Provisions for Military Aircraft
MIL-STD-809	Adapter, Aircraft, Jacking Point, Design and Installation

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

Aircraft Landing Gear Design - Principals and Practices, by Norman S. Curry
Emerging Technologies in Aircraft Landing Gear (SAE PT-66)
Landing Gear Design, by H. G. Conway

3. LANDING GEAR DESIGN REQUIREMENTS:

3.1 General Structural Requirements:

The landing gear should fulfill all the FAR's, and/or any airframe manufacturer's program requirement that is considered applicable to the aircraft being designed.

3.1.1 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 requirements. The gear should be suitable to withstand all ground operational environments. All structural criteria should be verified during development.

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 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.

3.1.3 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.

3.1.4 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 of 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.

3.2 Energy Absorbtion:

3.2.1 Capacity: The landing gear should have sufficient capacity for energy absorbtion during the impact of the landing. This capacity should be demonstrated by the performance of drop tests in accordance with pertinent Federal Aviation Regulations (FAR's), Military Specification Requirements, MIL-T-6053, or procurement documentation. The drop tests should demonstrate the attainment of desired load/time/stroke characteristics for stress and loads analysis purposes.

3.2.2 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.

3.2.3 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 absorber both under static conditions. This applies to cantilevered gears where the total static ground reaction on one gear is the same as the load in the shock absorber. In the case of articulated gears, the load in the shock absorber for the same ground reaction, being increased by the mechanical advantage created by the trailing arm.

Shock absorber pressure in this type of gear are higher, not only because of the higher loads, but due to the need to minimize the shock absorber piston rod diameter size to a point where the overall installation of the shock absorber and articulating arm are of practical proportions, and weight is not a prohibiting factor.

3.2.4 Piston Stroke Assessment: It is recommended that all main landing gear shock absorber strokes be checked for adequacy (in the early stages of design) in terms of shock absorbing capacity. This is acheived by using the appropriate portion formula for the conservation of energy, including the aircrafts' design sink speed, maximum allowable ground reaction factor (n), together with the shock absorber and tire efficiencies.

3.2.4.1 This mathematical formula reduces to the following:

$$WV^2 / 2g = (W\,n\,T\,\delta so) + (W\,t\,\delta t) \qquad \text{(Eq. 1)}$$

where:

- W = Maximum static load on one gear (lb)
- V = Maximum sink speed of aircraft (ft/s)
- T = Total vertical axle stroke (inch minimum)
- t = Tire deflection (inch) resulting from the load W
- n = Ground reaction factor. A unitless value obtained by dividing the anticipated vertical dynamic load by the static load W. The range of this value is usually between 1.0 and 8.0 as applicable for commercial and deck landing aircraft respectively.
- δso = Shock absorber efficiency (85% approx)
- δt = Tire efficiency (47% approx)
- V^2 = 2g (n T δso) + (δt)

3.2.4.1 (Continued):

Hence:

$$\text{Minimum Shock Absorber Stroke (T)} = \frac{6V^2/\ g - (t\ \delta t)}{n\ \delta so} \quad \text{(Eq. 2)}$$

3.2.4.2 From the above equation, it can be seen that the shock absorber minimum travel requirement consists primarily of the square of the sink speed of the aircraft (V), and the inverse of the ground reaction factor (n).

For large commercial aircraft, where excessive shock absorber strokes are usually available, variable orifice devices may be used in order to control the damping performance, thereby developing the maximum ground reaction at any desired position within, or at any time during the stroke.

3.2.5 Shock Absorber Efficiency (δso): Low shock absorber efficiencies may be tolerated in the cases where shock strut travels exceed those defined in 3.2.4. For shock absorbers with minimum travel capability, shock absorber efficiencies up to 92% are acheivable.

3.2.6 Tire Efficiency (δt): For most aircraft appplications, tire efficiencies of 47% (approximately), and straight line load/deflection graphs may be assumed. The amount of damping in a tire is considered negligible.

3.2.7 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.

3.2.8 Extention 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. Enviromental effects should be included in this determination.

3.2.9 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 non existant), 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.

3.2.10 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.

3.2.11 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.

3.2.12 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.

The locations, proportions, materials, fits, and lubrication of the sliding bearings of all gas/oil energy absorbers, 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 re-extention of the energy absorber, due to bearing friction and variations thereof.

f. Friction heat and its possible effects on the stability of mechanical properties of relevant exposed parts.

3.2.13 Servicing: The following provisions should apply:

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.

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.

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

3.2.15 Static and Dynamic Seals: The number of dynamic and static seals should be minimal, 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. 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, O-rings may be used as energizers in dynamic seal assemblies where other materials provide the rubbing and sealing surfaces. Their installation should be in accordance with Table 1, and 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.

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

TABLE 1 - Dynamic Seal Hydraulic Fluid Specifications

Range	Dynamic Seal	Material	Fluid	Standard
-65 to 275 °F (-54 to 135 °C)	AS568	MIL-P-83461	MIL-H-5606 MIL-H-6083	MIL-G-5514 AS4832 (Option)
-65 to 275 °F (-54 to 135 °C)	AS568	NAS1613	Phosphate Ester (e.g., Skydrol)	MIL-G-5514 AS4832 (Option)
-40 to 275 °F (40 to 135 °C)	AS568	MIL-P-83461	MIL-H-83282 MIL-H-	MIL-G-5514 AS4832 (Option)

3.2.17 Scraper Rings: Scraper rings should be fitted to the lower end of the cylinder assembly (more specifically in the gland nut assembly) to protect the bearings and dynamic seals from abrasive contamination damage. Spiral scraper rings (beryllium copper) are preferred, and are to be mounted in glands in accordance with AS4052 (or MS33675 as an alternate). Scraper ring assemblies should 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.

Non-metallic or elastomer scraper rings are not recommended, as they have the tendency to imbed sand (and other) particals in the sliding surface area causing excessive wear and moisture penetration.

3.2.18 Rubbing Surfaces - Dynamic Seals: All sliding surfaces should have a polished finish range 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. Higher pressure shock absorbers such as liquid springs may need finishes as good as 4 µin. 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 should be avoided.

3.2.19 Exposed Surfaces - Dynamic Seals: Surfaces such as piston outside diameters that pass through the dynamic seals, or are otherwise exposed to corrosive and/or erosive environments, should have a minimum of 0.003 in (0.076 mm) thickness of chrome plating in accordance with QQ-C-320 after final grinding.

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

3.2.20 Sliding Bearings: The locations, proportions, materials, fits, and lubrication of the sliding bearings of all gas/oil energy absorbers, 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 re-extention of the energy absorber, due to bearing friction and variations thereof.

f. Friction heat and its possible effects on the stability of mechanical properties of relevant exposed parts.

3.2.21 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 occur due to the engagement of the stops during the proper operation of the energy absorber. Improper strut servicing (i.e., incorrect precharge, subsequent charge by gas only, lack of fluid, etc.) should be considered in this regard. An internal pressure equal to the closing pressure, or maximum dynamic pressure, whichever is the greatest should be considered.

3.2.22 Gas Content: The compression ratio realized under the landing condition demanding most energy absorber stroke, should, wherever compatible with other requirements, be such that the 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 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 take-off, and 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 Down-Locks: 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 extention, whether this extention 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 loaded by ground loads or 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.

3.3.1.1 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.

3.3.1.2 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.

3.3.1.3 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 should not be affected by corrosion, ice, de-icing or cleaning fluids, mud or dirt accumulation.

3.3.2 Up-Locks: All retracting landing gears should have a means for sustaining the retracted state of the gear, either in conjuntion 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 cockpit selection of "gear down". The up-lock should be designed and protected to avoid the risk of malfuntion due to corrosion, ice, and dirt accumulation. Hydraulic and/or electric power should not be required to restrain the landing gear in the up and locked position.

3.3.2.1 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 indicated to the cockpit via the landing gear control system.

3.3.3 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, and acceleration forces based upon retraction time requirements, and, in some instances, negative "g's" due to rapid ascent of the aircraft. For gear extention, all gears (nose and mains) should "free fall" and be capable of being powered down in the event of an emergency. In cases where rearward retracting gears are found to be absolutely necessary, an independently powered extention device must be used.

3.3.3.1 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, truck assembly trimming, gear raising, and door actuation constitute the total retraction or extention 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.

3.3.3.2 Gear 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 occurance 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.

3.3.3.3 "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 supporting structure.

3.3.4 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 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.

3.3.5 Elements Interfacing with Airframe and Other Units:

3.3.5.1 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 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.

3.3.5.2 Brake Mounting: The strength, stiffness, and orientation of the brake mounting means should be established by the aircraft manufacturer.