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(R) Landing Gear Shock Strut Bearing Selection

RATIONALE

This Aerospace Information Report (AIR) is intended for aircraft landing gear shock strut designers and is being updated as part of the Five-Year Review process and is intended to provide normally utilized criteria of aircraft landing gear shock strut bearing selection.

TABLE OF CONTENTS

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1. SCOPE

This document defines the criteria used for the selection and placement of landing gear shock strut upper and lower bearings (see Figure 1).

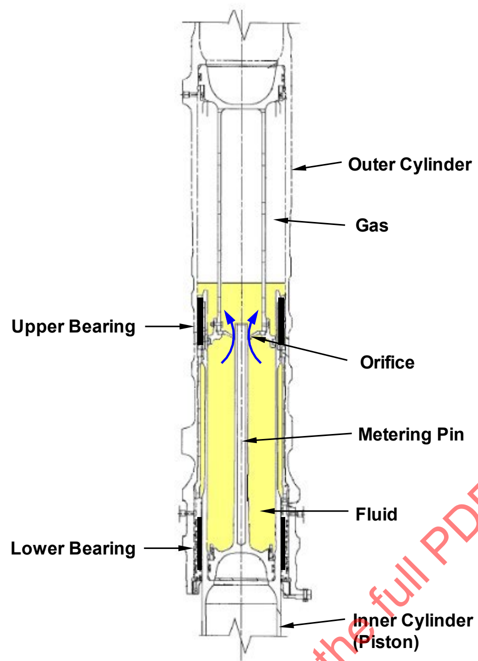

Figure 1 - Typical landing gear shock strut diagram

Common problems associated with shock strut bearings are presented herein.

2. REFERENCES

2.1 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.

2.1.1 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.

AMS4533 Copper-Beryllium Alloy, Bars and Rods, 98Cu - 1.9Be, Solution and Precipitation Heat Treated (TF00, formerly AT)

AMS4534 Copper-Beryllium Alloy, Bars and Rods, 98Cu - 1.9Be, Solution Heat Treated, Cold Worked, and Precipitation Heat Treated (TH04, Formerly HT)

AMS4535 Copper-Beryllium Alloy, Mechanical Tubing, 98Cu - 1.9Be, Solution and Precipitation Heat Treated (TF00, formerly AT)

AMS4590 Extrusions, Nickel-Aluminum Bronze, Martensitic, 78.5Cu - 10.5Al - 5.1Ni - 4.8Fe, Quenched and Tempered (TQ50)

AMS4596 Copper Nickel Tin Alloy, Bars and Rods, 77Cu - 15Ni - 8Sn, Solution Annealed and Spinodal Hardened (TX 00)

AMS4597 Copper-Nickel-Tin Alloy, Bars and Rods, 77Cu - 15Ni - 8Sn, Solution Annealed, Cold Finished and Spinodal Hardened (TX TS)

AMS4640 Aluminum Bronze, Bars, Rods, Shapes, Tubes, and Forgings, 81.5Cu - 10.0Al - 4.8Ni - 3.0Fe, Drawn and Stress Relieved (HR50) or Temper Annealed (TQ50)

AMS4880 Aluminum Bronze Alloy, Centrifugal and Continuous-Cast Castings, 81.5Cu - 10.3Al - 5.0Ni - 2.8Fe, Quench Hardened and Temper Annealed (TQ50)

AMS4881 Nickel-Aluminum-Bronze, Martensitic, Sand, Centrifugal and Continuous Castings, 78Cu - 11Al - 5.1Ni - 4.8Fe, Quench Hardened and Temper Annealed

AIR5913 Landing Gear Component Heat Damage

AIR6280 Overview of Aircraft Landing Gear Shimmy Analysis Methods

ARP4912 Design Recommendations for Spare Seals in Landing Gear Shock Struts

ARP5935 Use of HVOF Thermal Spray Coatings for Hard Chrome Replacement in Landing Gear Applications

AS81820 Bearings, Plain, Self-Aligning, Self-Lubricating, Low Speed Oscillation

AS81934 Bearings, Sleeve, Plain and Flanged, Self-Lubricating

2.1.2 U.S. Government Publications

Copies of these documents are available online at https://quicksearch.dla.mil.

MIL-L-8552 Landing Gear, Aircraft Shock Absorber (Air-Oil Type)

2.2 Definitions

2.2.1 ALLOWABLE LINER WEAR (LINED BEARINGS)

A lined bearing is considered no longer serviceable when a portion of the wear coating has been worn to a degree that could affect the shock strut operation. Wear definition of the liner material is usually related to the maximum allowable clearance between the bearing and the cylinder or the bearing and the inner cylinder (piston).

2.2.2 LADDER CRACKING

Lateral cracks found on the chrome surface of the shock strut inner cylinder (piston). Refer to AIR5913.

2.2.3 LINER DELAMINATION (LINED BEARINGS)

The separation of the liner material from the metallic backing.

2.2.4 SLIP-STICK (STICTION)

The buildup of static friction between stationary surfaces being released to dynamic friction, which results in sliding and stopping as load is being applied to, or removed from, mating surfaces. Also referred to as ratcheting.

2.2.5 BEARING OVERLAP

As defined in MIL-L-8552, the bearing overlap is the distance between the lower edge of the lower bearing to the upper edge of the upper bearing (see dimension “C” in Figure 2). With landing gear fully extended, a distance of at least 2.75 times inner cylinder (piston) outside diameter (OD) for cantilevered gears and 1.25 times inner cylinder (piston) OD for articulated gear configurations have been used as a design limit. Maintaining this overlap has been shown to ensure smooth operation and reduce the impact of bearing stiction. Based on historical data, large cantilevered gears typically have an optimized bearing center-to-center spacing (see dimension “A” in Figure 2) based on the configuration of the landing gear (braked versus non-braked). Main landing gear (MLG) typically have brakes and are subjected to higher drag loads during a loaded, static stroke, braked-roll condition, when the bearing spacing is near the maximum distance. Nose landing gear (NLG) typically do not have brakes and are subjected to higher drag loads during an unloaded, nearly fully extended landing spin-up condition, when the bearing spacing is near the minimum distance.

Based on historical data for cantilevered gears, typical bearing spacing ratios (B/A) from Figure 2 are 1.5 for MLGs at static stroke and 3.0 for NLGs at the spin-up stroke.

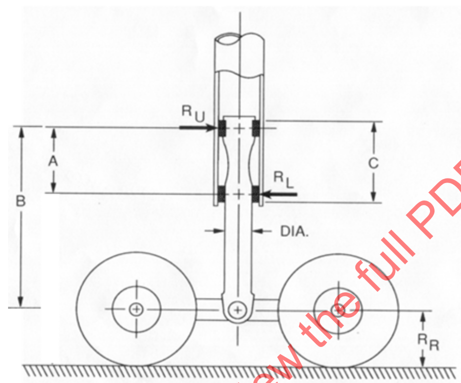

Figure 2 - Typical landing gear shock strut diagram with bearing spacing

3. BEARING MATERIALS SELECTION

The following criteria are commonly considered for selecting a bearing material:

3.1 Wear

Depending on the type of aircraft and its intended utilization, suitable materials will be selected. Wear is also a function of the mating surface material and surface finish (roughness).

3.2 Friction

Although the material with the lowest friction is desired, consideration should be given to other aspects such as tendency to shimmy, which can be less likely with a higher friction material. Generally, it is not advisable to use shock absorber bearing friction as a means to control shimmy, with independent means being preferred. However, if changing from a high friction material to a low friction bearing material, shimmy stability and steering system perfomance may be impacted.

Other friction characteristics to be considered when selecting the type of bearing are summarized as follows:

- The liner behavior with the contact material of the landing gear shock strut, as well as the type of plating/coating used. Contact materials can be steel, chrome-plated steel, high velocity oxygen fuel (HVOF), WC-Co/WC-Co-Cr-coated steel/titanium, aluminum, hard anodized aluminum, plasma-coated aluminum, and/or titanium.

- Some bearing materials exhibit increasing friction under light loads, then reverse that behavior as the load is increased up to a limit.

- Polytetrafluoroethylene (PTFE) lubricated bearing materials normally require a slight break-in period to start the lubrication process. Therefore, these types of bearings can have a different coefficient of friction in their newly installed condition compared to their broken-in condition.

- Heat caused by friction can be detrimental to bearing interfacing components as well as the elastomeric component in sealing assemblies, particularly to those that are direct elastomeric contact seals.

3.3 Heat Dispersion

The heat dispersion characteristics of the selected bearing material are typically evaluated. Generally, materials with good dispersion properties are used. Composite and nonmetallic materials are inherently nonconductive. In this case, the cooling is provided through the contact materials/running face and by the fluid environment in the landing gear shock strut (wet bearing applications only).

3.4 Cost

Depending on the type of aircraft and its intended utilization, the material selection is considered for the lowest life cycle cost.

3.5 Weight

Bearings with a liner usually are lighter than an all-metal bearing, but wear can be an issue. Careful selection of the liner and contact material for the application is considered such that component integrity is not affected by wear.

3.6 Bearing Capacity

A higher bearing capacity will result in a shorter bearing, hence resulting in a lower weight. A bearing operating with high unit stresses (pressure loading or PV [pressure times velocity]) will result in a shorter life.

3.7 Bearing Materials

Bearing materials can be categorized into three categories: metal, lined, and nonmetallic resins.

3.7.1 Metal

The most common material used for metal bearings is Al Ni bronze (refer to AMS4640, AMS4590, AMS4880, and AMS4881). Some applications historically made use of copper beryllium (refer to AMS4533, AMS4534, and AMS4535); however, copper beryllium is not often used in new designs for environmental reasons. Newer materials, such as Cu-Ni-Sn (refer to AMS4596 and AMS4597), offer high strength and good wear characteristics and may be an adequate replacement for copper beryllium without environmental restrictions; however, structural analysis is typically accomplished before use for replacement applications.

3.7.2 Lined

Since liners are nonconductive materials, consideration is typically given for gear electrical bonding requirements. Several types of liner are available for use:

3.7.2.1 PTFE Impregnated Cloth Type

This bearing type is a resin/PTFE with a fabric reinforcement bonded to a metal shell or sleeve. This lining type has been problematic when the fabric becomes un-bonded, or wears through to the metal shell, and affects the shock strut performance. Consider use of a bearing material for the metal shell to reduce the negative impacts resulting from loss of the liner material.

3.7.2.2 Phenolic Cotton Fabric Bearing

This type is used on some shock struts for weight savings. However, it is customary in design considerations to pay attention to the environment for this type of bearing as some early designs have experienced swelling and other dimensional instabilities, resulting in binding or slip-stick (stiction) behavior. Bearing manufacturers are often consulted to validate compatibility of the bearing material to the operating environment.

3.7.2.3 Sprayed or Molded

This bearing type is a composite matrix that includes a structural resin system, self-lubricating fillers such as PTFE, and possibly other fillers applied to a metallic or composite substrate without need of a fabric base. Sprayed or molded liners are generally able to be machined after liner application to close tolerances.

3.7.2.4 PTFE Coating on a Metal Shell

This bearing type is a resin/PTFE wear coating applied to a metal shell or sleeve in such a manner that it can be machined if necessary and does not require or make use of a fabric base.

3.7.2.5 Porous Bronze Matrix Impregnated with PTFE on a Backing Shell

This bearing type is a combination of a porous bronze matrix impregnated with a PTFE/high strength filler bearing material on a steel or bronze backing shell. These bearings are typically thin-walled bearings that are installed into a grooved bearing carrier. Carrier material is usually aluminum or titanium for the purpose of weight savings. This type of shock strut bearing material has proven to reduce friction binding or slip-stick (stiction) and friction burns (refer to AIR5913) in many commercial and military applications. Lead-free options of this bearing type are also available for consideration, although fleet experience with the lead-free versions is currently limited. Both the leaded and lead-free versions are compatible for wet or dry applications.

3.7.3 Nonmetallic Resins

Several bearing-grade, homogenous nonmetallic resins can be molded and fit into existing gland standards. Such designs may reduce the potential threat of wearing through a bearing liner but have not historically been used for landing gear shock strut bearings.

3.7.3.1 Fabric Reinforced Resin Bearings/Composite Bearings

This bearing type is a combination of organic resins and man-made fibers. Added solid lubricants, such as graphite or PTFE, improve the coefficient of friction in dry or oil lubricated applications. The organic resin shows little or no swell in fluids. With a low specific weight, these bearings can be applied as a weight-saving solution. The use of thermosets avoids risk of creep. These types of bearings have shown reliable performance in oil-immersed upper bearing locations and have been introduced into service in lower bearing locations as well.

3.8 Contaminants

Selected bearing liner systems are usually qualified to either AS81934 or AS81820. However, additional testing to verify the bearing performance under extended contamination levels is often considered since these specifications are not appropriate for landing gear shock strut bearings. The type of contamination and its level will vary depending on the application. Therefore, it is important to understand the environment under which the shock strut will operate in order to define the contamination testing. Bearing materials may change the surface of the counter face (e.g., by polishing) or cause localized surface defects. Foreign particle contamination may further contribute to damage of the counter face. The hardness and stiffness of the bearing material in relation to the hardness of the counter face is an indicator allowing a prediction of what may occur in service. The shape, size, and hardness of any contamination present will also affect the performance of the bearing system. Contaminants can become embedded in the bearing surface and score or scratch the mating part (counter) surface, resulting in leakage indications.

3.9 Fluid Compatibility

Fluids may have a positive or negative effect on friction and wear, load capability, and dimensional stability (e.g., swell). Requirements are typically set in the context of fluid temperature and duration of exposure (e.g., permanently submerged or only incidentally).

4. COMMON PROBLEMS ENCOUNTERED WITH SHOCK STRUT BEARINGS

4.1 Ladder Cracking

Ladder cracking is found on chromed diameters and suggests heat has been generated between the shock strut bearing and its mating diameter. When friction is accompanied by rapid motion and high localized contact stresses, heat is generated, which causes distress to the chromed surface. Severe ladder cracking can be seen by the naked eye; however, it is usually detected by nondestructive inspection methods. When streaks on the chromed surface are present, cracks may occur and are oriented like "rungs of a ladder" 90 degrees to the direction of the streaks. Refer to AIR5913.

While the severity of the problem varies between different types of shock absorbers and can be exacerbated by high rake angles, the use of PTFE-based self-lubricating lower bearings has been shown to minimize the issue in service.

4.2 Localized Heat Damage

Heat generated by shock strut bearings to their mating surface (see 4.1) may locally increase temperatures to the base metal sufficient to change its microstructure. Increased temperature can cause local phase changes to the base metal, forming over-tempered martensite (OTM) or, at higher temperatures, un-tempered martensite (UTM). Refer to AIR5913. Heat damage from shock strut bearings can be found on the ODs of inner cylinders (piston) or IDs of outer cylinders. Potential causes for heat damage include:

- Partial contact of the upper bearing carrier onto the ID of the outer cylinder (base metal in the case of lined bearing).
- Pressure times velocity (PV) exceeding the thresholds of the bearing material(s).
- Relative structural deflection between the inner cylinder (piston) and the outer cylinder analyzed as a cantilever beam.
- Structural interference between an ovalized inner cylinder (piston) passing through a relatively stiff round-tubed lower bearing and outer cylinder.

4.3 Slip-Stick (Stiction)

Stiction occurs during low-speed taxi or during towing by producing a bumpy and noisy ride. Braking stability is also affected since one shock strut could be at a significantly different stroke position than the other one. Bearings with stiction problems might cause the aircraft to suddenly drop during loading or during or after fueling. Stiction is mostly present with cantilevered and semi-articulated gear configurations, where the bearings are subject to radial loads induced by the ground loads.

It is believed that stiction is caused by:

- A difference between the static and dynamic friction coefficients of the strut bearings. The larger the difference, the more stiction-prone the gear becomes.
- Inner cylinder (piston) ovalization, for which the inner cylinder (piston) would tend to socket in the bearing, has been identified as another potential source for the stiction. Therefore, inner cylinder (piston) radial stiffness (or the diameter over thickness [D/t] ratio) may also be considered to avoid stiction.
- Periods of standstill during which the lubrication condition deteriorates.

Cases where stiction problems have been observed on large landing gears at high rake angles that used bronze lower bearings have been resolved by changing to self-lubricating, PTFE-based, or a porous bronze matrix impregnated with PTFE on a backing shell lower bearings.