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Plain Bearing Selection for Landing Gear Applications

RATIONALE

This document has been reaffirmed to comply with the SAE 5-year Review policy.

FOREWORD

Information included herein was derived from bearing tests and service reports. Inputs were made by airframe, landing gear manufacturers, airline companies, the U.S. Air Force and Naval Air Systems Command.

1. SCOPE:

This document is intended to give advisory information for the selection of plain bearings and bearing materials most suitable for aircraft landing gear applications.

Information is given on bearing installation methods and fits that have given satisfactory performance and service life expectancy.

Corrosion is a major cause of problems in bearing installations for landing gears. Therefore, methods of corrosion prevention are outlined.

Effort is directed toward minimizing maintenance and maximizing life expectancy of bearing installations. Lubricated and self-lubricating bearings are discussed.

There are wide ranges of bearing load and motion requirements for applications in aircraft landing gears. For this reason, it is the responsibility of the designer to select that information which pertains to his particular application.

Anti-friction bearings, defined as rolling element bearings generally used in wheel and live axle applications, will not be discussed in this document.

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

AMS 4533	Copper-Beryllium Alloy Bars and Rods 98Cu 1.9Be Solution and Precipitation Heat Treated (TF00, formerly AT)
AMS 4534	Copper-Beryllium Alloy, Bars and Rods 98Cu 1.9Be Solution Heat Treated, Cold Worked, and Precipitation Heat Treated (TH04, formerly HT)
AMS 4535	Copper-Beryllium Alloy, Mechanical Tubing 98Cu 1.9Be Solution and Precipitation Heat Treated (TF00, formerly AT)
AMS 4590	Extrusions, Nickel-Aluminum Bronze, Martensitic, 78.5Cu 10.5Al 5.1Ni 4.8Fe, Solution Heat Treated and Tempered
AMS 4640	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)
AMS 4880	Aluminum Bronze Alloy, Centrifugal and Continuous-Cast Castings 81.5Cu 10.3Al 5.0Ni 2.8Fe Quench Hardened and Temper Annealed
AS14102	Bearing, Plain, Self-Lubricating, Self-Aligning, Low Speed, Wide, Chamfered Outer Ring, -65°F to 325°F
AS14103	Bearing, Plain, Self-Lubricating, Self-Aligning, Low Speed, Wide, Grooved Outer Ring, -65°F to 325°F
AS14104	Bearing, Plain, Self-Lubricating, Self-Aligning, Low Speed, Narrow, Chamfered Outer Ring, -65°F to 325°F
AS21230	Bearing, Plain, Self-Aligning, Grooved Outer Ring TFE Lined, Wide
AS81820	Bearings, Plain, Self-Aligning, Self-Lubricating, Low Speed Oscillation, General Specification For
AS81934	Bearings, Sleeve, Plain and Flanged, Self-Lubricating, General Specification For
AS81935	Bearing, Plain, Rod End, Self-Aligning, Self-Lubricating, General Specification for
AS81936	Bearings, Plain, Self-Aligning, (BeCu Ball, CRES Race), General Specification For

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2.1.2 U.S. Government Publications: Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-B-8942
MIL-B-8943
MIL-B-81819
MIL-PRF-16173
MIL-PRF-23827
MIL-PRF-81322

2.2 Definitions:

A landing gear bearing is a component which, when installed between two or more landing gear structural members having relative motion, can perform the following functions:

- a. Transmit loads between those members (moving or stationary).
- b. Control the friction coefficient of the joint.
- c. Control the wear of the joint.
- d. Protect the primary component - act as a sacrificial part.

3. PLAIN BEARING CONFIGURATIONS:

Plain bearings are those bearings whose interface motions are sliding actions between two parallel surfaces. Bearings falling within this classification can carry radial and/or thrust loads and accommodate motion. The bearing configurations most widely used in landing gear applications are journal, spherical, and thrust. These bearings can be lubricated or self-lubricating configurations.

3.1 Journal Bearings (Bushings):

This configuration consists of a cylindrical shell (with or without a flange) installed in a housing in conjunction with a mating pin or bolt. These bearings are used in pinned joints of landing gear mechanisms and structures. They can be highly loaded when there is no joint rotation and lesser loaded when oscillatory motion is present such as during landing gear retraction and extension. Axially sliding sleeve journals are used in shock struts and hydraulic actuators.

3.2 Spherical Bearings:

This bearing configuration is an integral unit in which a spherically shaped (ball) inner race is free to rotate and misalign within the confines of the outer race. The design will function under both radial and thrust loads. For some installations the ball is clamped in place and all motion is accommodated at the spherical surface-to-outer race interface. Another normal bearing installation method consists of clamp up on a sleeve (or shoulder bolt) through the ball bore. In this configuration the spherical interface will provide misalignment and (because of the shorter moment arm to the sliding surface) the rotary motion will occur at the ball bore-to-sleeve interface. With this arrangement, unit loads are higher at the ball bore than at the spherical surface and lubrication (or self-lubricating material) is required to prevent excessive wear. The choice of material for the pin and bearing is important.

3.3 Thrust Bearings:

Thrust bearings, as the name implies, are designed to carry thrust loads. Although they may be a separate bearing, they are frequently integrated into a journal bearing as a flanged face.

4. LANDING GEAR BEARING CONSIDERATION:

In the selection of any landing gear bearing or bearing material, the following application parameters must be considered.

- a. Environmental conditions including exposure to dirt, water or other contaminants
- b. Applied loads (radial, thrust, moment, static, dynamic, and shock)
- c. Required service life or service time between overhauls
- d. Velocity of relative motion causing frictional heat buildup
- e. Lubrication requirements
- f. Misalignment
- g. Envelope restrictions
- h. Type of application (static, oscillatory, slow motion)
- i. Retention methods
- j. Position accuracy (radial and axial)
- k. Maintenance (must be lubricated, repaired or replaced)
- l. Installation (expansion characteristics, allowable looseness, pre-load requirements)
- m. Friction, torque (starting and dynamic)
- n. Weight
- o. Dissimilar materials (avoid galvanic action)
- p. Same materials are generally avoided

5. MATERIAL SELECTION FOR LUBRICATED BEARINGS:

Based on experience and laboratory test, the following materials are those used for bearing applications in landing gears (Reference Tables 1 and 2). The mating pin or shaft wear surface, in most cases, is steel with 0.003 in (0.07 mm) minimum chrome plating thickness.

- a. There are several materials suitable for bearing use such as softer metallic outer races with high strength-chrome plated steel balls or pins. Some materials used are aluminum bronze or aluminum nickel bronze in combination with 440C or 15-5 stainless steel or 4340 steel heat treated to 260 ksi (1790 MPa). Also, laboratory tests and service usage indicate that another satisfactory combination for spherical bearings in the landing gear environment is a copper beryllium ball with a 17-4 PH stainless steel outer race (Reference AS81936, BeCu spherical bearing).
- b. Where high velocity and pressure between the bearing surfaces develops frictional heat in excess of 500 °F (260 °C), detrimental cracking may occur in chrome plated steel pins or shafts. This feature is exhibited in the "ladder" and "smile-frown" cracking of the chrome plated shock strut piston surface. In this application, tests have shown that bearings with self-lubricated liners are superior when compared with metal-to-metal sliding surfaces. Durability of these liners needs to be considered when used as shock strut bearings. The leading and trailing edges of shock strut bearings should be chamfered or radiused to prevent end loading. Copper beryllium has better heat transfer characteristics than aluminum-nickel-bronze and would tend to prevent the high temperature spikes that cause the cracking.
- c. Shock strut friction caused by transverse or offset loading results in binding or heeling between the upper and lower bearings. This frictional force can be reduced by the use of self-lubricating bearings.

6. WORKING PRESSURES FOR LUBRICATED BEARINGS:

The maximum recommended bearing pressures at limit loads generally used for sizing bearings are listed in Table 1. Bearing surface roughness at sliding interfaces should be 16 rms except for special cases. For example, 32 rms may be acceptable for large bearings. For 8 rms finishes, lubricant retention must be assured. Additional bearing material information is given in Table 2. Aluminum-bronze and copper beryllium have a higher coefficient of thermal expansion than steel. This characteristic should be considered during the bearing design to prevent binding at adverse temperatures.

TABLE 1 - Bearing Type (Lubricated)

Materials: (3)	Plain Bearings		Spherical Bearings (2)	
	Aluminum Nickel Bronze (AMS 4590 / AMS 4640 / AMS 4880)	Copper Beryllium (AMS 4535 / AMS 4533)	Aluminum Nickel Bronze (AMS 4640 / AMS 4880)	Copper Beryllium (AMS 4535 / AMS 4533)
a) Static Joint	Non-rotatable, movement under structural deflections only, e.g. trunnion pivot joints	60,000 to 90,000 psi (414 to 620 MPa) (1)	47,000 psi (324 MPa)	90,000 psi (620 MPa)
	Rotatable, slight movement under load e.g. torsion links	45,000 to 60,000 psi (310 to 414 MPa)	45,000 psi (310 MPa)	90,000 psi (620 MPa)
b)	Normal operating pressure. Major portion of movement under load - e.g. Retraction actuation pin joints.	13,000 psi (90 MPa)	15,000 psi (103 MPa)	20,000 psi (138 MPa)
c)	Normal operating pressure. All portion of movement under load - e.g. Truck pivot pin joints.	10,000 psi (69 MPa)	10,000 psi (69 MPa)	10,000 psi (69 MPa)
d)	Shock Strut Bearings	6,000 psi (41 MPa)	N/A	N/A

(1) Use low end of range for new design, higher for derivatives

(2) These capacities are for solid balls. Split ball and slotted entry designs use lower loads.

(3) Good performance has been achieved with corrosion resistant steels, Chrome plate, and Tungsten carbide thermal spray coatings as mating surfaces.

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TABLE 2 - Landing Gear Bearings

Bearing Material	Remarks
Aluminum-Nickel-Bronze AMS 4590, AMS 4640, AMS 4880	A good bearing material of moderate strength and wear resisting properties suitable for slow intermittent motions. Requires lubrication. Will gall but not readily due to moderately smearable characteristic. More expensive than aluminum bronze.
Copper Beryllium AMS 4535, AMS 4533(TF00), AMS 4534(TH04)	A good bearing material of exceptionally high strength and wear resisting properties when properly lubricated. Suitable for slow, intermittent rotation and oscillatory motions. It has good heat transfer properties. It tends to resist galling; however, in the absence of a lubrication film at high stress conditions galling is probable. The full high strength tempers (TF00 and TH04) offer the greatest load capability with limited ductility. Higher ductility tempers are available for journal bearings which are mechanically formed into place during installation. Material costs are generally higher than aluminum nickel bronze or aluminum bronze but may offer better value due to higher performance characteristics.
Aluminum-Bronze	A good bearing material possessing low strength properties. Suitable for slow intermittent motions. Requires lubrication; however, its low shear characteristics provide a smearable feature which makes galling unlikely in the event a lubrication period is overlooked. Aluminum-bronze is susceptible to wear and deformation, particularly at high unit loads and in the absence of a lubricating film.
17-4 PH Stainless Steel	A good static bearing material. However, with this material corrosion protection must be provided between the housing and outer race if the materials are dissimilar.

7. HOUSING FITS FOR JOURNAL BEARINGS (BUSHINGS):

Journal bearings, plain or flanged, are installed with interference fits for retention in the housing. The interference for 2.0 in (50.8 mm) dia. and greater is 0.001 in/in (0.0254 mm/mm) diameter plus 0.002 in (0.051 mm) disregarding bore or bushing plating thickness up to 0.0003 in (0.008 mm) per plated surface. For diameters less than 2.0 in (50.8 mm) the interference should be 0.001 in/in (0.0254 mm/mm) diameter and the 0.002 in (0.051 mm) should be proportionally reduced until it is eliminated for a 1 in (25.4 mm) diameter.

One method of assembly is the temperature differential method where the bearing is cooled with dry ice (-65 °F/-54 °C) or liquid nitrogen (-325 °F/-198 °C) for extreme conditions to -325 °F (-198 °C) minimum and the housing is heated up to 212 °F (100 °C) as required. Maximum temperature differential is 537 °F (281 °C). Provisions for holding the bushings in position during temperature stabilization are required. Usually bearing inside diameters require sizing after temperature stabilization for good alignment and clearance conditions.

8. BEARING TO PIN CLEARANCES:

The clearance between the pin or shaft and the bearing is recommended to be a medium fit (0.003 to 0.007 in (0.076 to 0.178 mm) for sizes to 1 in (25.4 mm) diameters and 0.005 to 0.009 in (0.127 to 0.229 mm) for larger bearings) for rotations at less than 600 rpm. Shake or wobble between mating parts should not be noticeable, except on parts with very short bearing width.

9. CORROSION PREVENTION:

On modern aircraft landing gear installations, the most frequent damage found in service and at landing gear overhaul is corrosion in lugs and fittings in which bearings are fitted.

9.1 Some causes of corrosion are as follows:

- a. Entrapment of moisture between the mating surfaces of the lug and bearing.
- b. Lug deflection or stretch ovalization during application of loads.
- c. Depletion of corrosion protection plating due to chemical action or wearing due to lug and bearing flange deflections.
- d. Unit loading beyond the stress corrosion threshold of lug or fitting.
- e. Lug or housing sectional strength discontinuity.

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9.2 Corrosion prevention methods to overcome the above conditions are as follows:

- a. Titanium-cadmium or non-embrittlement cadmium plating 0.0002/0.0003 in (0.0051/0.0076 mm) thick on the lug or fitting face and bore. Cadmium plating 0.0002/0.0003 in (0.0051/0.0076 mm) thick on the bearing outside diameter and end faces. These platings can be as much as 0.0005 in (0.0127 mm) thick if the plating is considered in the interference fit sizing.
- b. Bore and faces of housings treated with epoxy primer and allowed to cure fully.
- c. Corrosion preventive compound MIL-PRF-16173 or equivalent covering housing bore before bearing insertion.
- d. Sealing compound equivalent to fuel tank sealant applied to housing face between housing and bearing flange. Care should be taken to prevent moisture from being trapped in the sealed joint. Also, with some joint designs it is feasible to coat the housing bore with sealant prior to inserting the bushing. Sealed joints must not be allowed to rotate.

NOTE: Some corrosion preventive compounds and the sealants are not compatible materials. Surfaces that have had a corrosion prevention compound applied must be thoroughly cleaned with a dry cleaning and degreasing solvent before sealant adhesion can be effective.

- e. Hard chrome plating of bores and faces of the housing results in good corrosion protection. The chrome plating replaces the cadmium plating on the bores and faces of the housings. The chrome plate thickness is 0.0015 to 0.0025 in (0.0381 to 0.0635 mm). However, the structural fatigue lives of the high heat treated steel lugs and housings are reduced when compared with cadmium plated parts. The reduction in fatigue life can be as much as 60% unless the material process control includes such preventive measures as shot peen, bake, etc.

10. LUBRICATION:

Bearing lubrication has three basic functions: To provide a means of resisting adhesion between mating surface protrusions; to provide a low shear film to minimize the coefficient of friction and to provide a corrosion resisting medium.

Provisions must be made so that lubrication of the landing gear can be accomplished with the weight of the aircraft resting on the landing gear.

Greasing grooves should be arranged so that during retraction and extension or other excursions, the surface of the pins or shafts are wiped with grease from the grooves. Grease paths in the housing should be arranged such that, if the bearing rotates, lubrication is not shut off from the sliding surfaces.

10. (Continued):

All landing gear joints, both static and dynamic, should be considered for lubricating provisions. A lubricator fitting should be provided for each surface to be lubricated. If the lubricated surface is in close proximity to a non-metallic seal, the lubricant and seal material compound must be checked for compatibility.

The lubricants most widely used are aircraft greases according to MIL-PRF-23827 and MIL-PRF-81322 or equivalents. These are general purpose greases for landing gears and other systems and mechanisms of the aircraft requiring periodic lubrication. In addition, new generation greases are being/have been developed that provide superior properties for this type of application such as better corrosion protection. An example is Aeroshell Grease 33.

11. SELF-LUBRICATING BEARINGS:

11.1 Applications:

Self-lubricating bearings are used in application where:

- a. No scheduled maintenance is a requirement.
- b. The bearing joint is inaccessible for lubricating purposes.
- c. Some joint looseness is acceptable.
- d. Loads and motions are within the allowable range.
- e. Lubricated bearings are not practical.

Self-Lubricating bearings may not have the load carrying capability and service life of lubricated bearings. Down time and cost of removal and replacement should be considered when evaluating self-lubricating bearings for applications. During the self-lubrication process this type of bearing experiences some wear and therefore joint looseness is usually aggravated by foreign particle contamination between the sliding surfaces, and excessive surface speeds which result in heat. Seals may be used to prevent contamination. However, the seals can trap the contaminants in the bearing resulting in additional bearing surface damage. Experience indicates that bearing wear life is increased with better finishes on the surface that mates with the self-lubricating material. For example, small to medium size bearings should have a finish of 8 rms and that for larger bearings may be 16 rms or greater for practical manufacturing reasons.

General information regarding the amount of looseness to expect can be obtained from the following military specifications: MIL-B-8942 and AS81820 for spherical bearings, and MIL-B-8943 and AS81934 for journal bearings.