AEROSPACE INFORMATION REPORT	AIR1594™	REV. D
	Issued 1981-08 Revised 2018-04 Reaffirmed 2023-08 Superseding AIR1594C	
Plain Bearing Selection for Landing Gear Applications		

RATIONALE

AIR1594D has been reaffirmed to comply with the SAE Five-Year Review policy.

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 included herein was derived from bearing tests and service experience/reports. Airframe/landing gear manufacturers, commercial airlines, the U.S. Air Force and Naval Air Systems Command provided input for the document.

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

Base metal corrosion is a major cause of problems in bearing installations for landing gears. Therefore, methods of corrosion prevention are discussed.

Effort is directed toward minimizing maintenance and maximizing life expectancy of landing gear bearings. Lubricated and self-lubricating bearings are also 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 the 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.

Copper-Beryliium (Cu-Be) alloy material has been banned for new design by many airframers and government environmental agencies, therefore new designs are utilizing properly designed alternative bearing material such as Copper Nickel Tin (Cu-Ni-Sn) alloy.

Landing gear shock strut bearing design and selection criteria are covered in AIR5883 and, therefore, are not discussed in detail in this document.

1.1 Purpose

This document is to be used as a general reference for the aerospace community.

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For more information on this standard, visit
https://www.sae.org/standards/content/AIR1594D/

2. REFERENCES

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.

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)

AMS4598 Copper Nickel Tin Alloy,Tubes, 77Cu - 15Ni - 8Sn, Solution Annealed and Spinodal Hardened (TX 00)

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

AMS5643 Steel, Corrosion-Resistant, Bars, Wire, Forgings, Tubing, and Rings, 16CR - 4.0Ni - 0.30Cb - 4.0Cu Solution Heat Treated, Precipitation Hardenable

AIR5883 Landing Gear Shock Strut Bearing Selection

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

AS14101 Bearing, Plain, Self-Lubricating, Self-Aligning, Low Speed, Narrow, Grooved Outer Ring, -65 °F to +325 °F

AS14102 Bearing, Plain, Self-Lubricating, Self-Aligning, Low Speed, Wide, Chamfered Race, -65 °F to +325 °F

AS14103 Bearing, Plain, Self-Lubricating, Self-Aligning, Low Speed, Wide, Grooved Race, -65 °F to +325 °F

AS14104 Bearing, Plain, Self-Lubricating, Self-Aligning, Low Speed, Narrow, Chamfered Race, -65 °F to +325 °F

AS21230 Bearing, Plain, Self-Aligning, Grooved Outer Ringer TFE Lined, Wide

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

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

AS81934/1 Bearing, Sleeve, Plain, Self-Lubricating, -65 °F to 325 °F

AS81934/2 Bearing, Sleeve, Flanged, Self-Lubricating, -65 °F to 325 °F

AS81935 Bearings, Plain, Rod End, Self-Aligning, Self-Lubricating, General Specification For

AS81936 Bearings, Plain, Self-Aligning, (Cu-Be Ball, CRES Race), General Specification For

2.2 ANSI Accredited Publications

Copies of these documents are available online at http://webstore.ansi.org/

ANSI B4.1 Preferred Limits and Fits for Cylindrical Parts

2.3 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM E1417 Standard Practice for Liquid Penetrant Testing

ASTM E1444 Standard Practice for Magnetic Particle Testing

2.4 U.S. Government Publications

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

MIL-B-8942 Bearings, Plain, TFE Lined, Self-Aligning

MIL-B-8943 Bearings, Journal, Plain and Flanged, TFE Lined

MIL-DTL-83488 Detail Specification, Coating, Aluminum, High Purity

MIL-PRF-16173 Corrosion Preventative Compound, Solvent Cutback, Cold - Application

MIL-PRF-23827 Grease, Aircraft and Instrument, Gear and Actuator Screw

MIL-PRF-32014 Grease, Water Resistant, High Speed, Aircraft and Missile

MIL-PRF-81322 Grease, Aircraft, General Purpose, Wide Temperature Range

MIL-PRF-81733 Sealing and Coating Compound, Corrosion Inhibitive

MMPDS Metallic Materials Properties Development and Standardization

2.5 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.

A Main Landing Gear shock absorber will typically require bearings that can cope with sliding/axial translational movements (refer to AIR5883).

A Nose Landing Gear Shock Absorber will also typically require bearings that can cope with sliding/axial translational movements (refer to AIR5883), and also rotational/turning movements (during steering operations).

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 less 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. Figure 1 is an example of a typical landing gear journal bearing illustrating both a plain and flanged bearing on the same diagram.

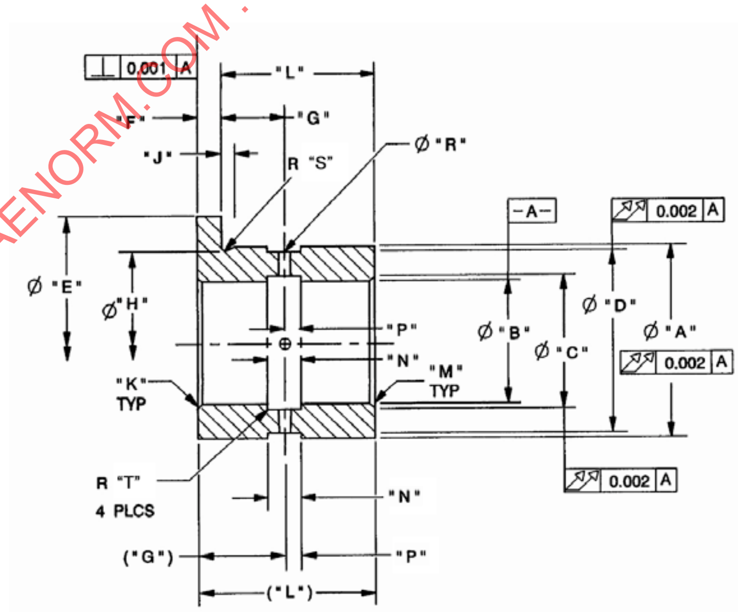

Figure 1 - Typical landing gear journal bearing

3.2 Spherical Bearings

This bearing configuration is an integral unit in which a spherically shaped (ball) inner race is free to rotate within the confines of the outer race. The spherical interface will provide for misalignment of joined members and allow for rotary motion about the balls vertical centerline (see Figure 2). The design will function under both radial and thrust loads. It is desirable for the material selection and rotary motion to take place between the ball and the outer race of the bearing (lower bearing stress) to avoid galling of the mating pin. To this end, the most common installation, the ball side faces (or bushing sleeve at the ball center) are clamped to the mating pin on small ball, but this may not be practical on large balls. The ball may be greased or lined with a low friction material.

Self-lubricating spherical bearings are also available.

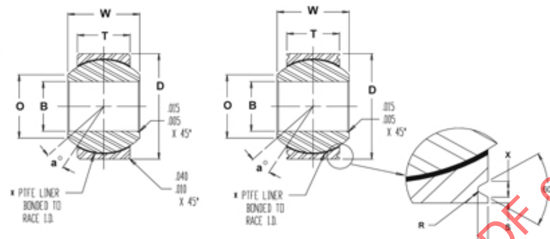

Figure 2 - Typical PTFE lined landing gear spherical bearing

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.

3.4 Bearing Material Options

There are many types of bearing materials available, both metallic and non-metallic. These can be used as lubricated or non-lubricated bearings, depending upon the application/operating conditions, and depending upon the exact composition of the bearing material and the mating counter surfaces.

A metallic type bearing can be used in a lubricated position and can generally carry higher loads/bearing pressures. These type of bearings can often achieve very low friction levels by utilizing a PTFE sintered layer on the contact face of the bearing ring. If this low friction coating wears off during use, then these metallic bearings can generate metallic wear particles. These metallic wear particles can be damaging to the component seals, and also to the sliding counter surfaces of the piston/gland.

A polymer type bearing can be used in a lubricated or non-lubricated position. Generally these polymer bearings cannot support such high loads/bearing pressures as the metallic bearing alternatives. The polymer bearings are typically homogenous, and do not rely on a coated layer to provide low friction performance. If these polymer bearings wear in use, then they will only generate soft polymer wear particles, which are not likely to damage the component seals and moving surfaces.

Consult the bearing suppliers of the respective bearings to determine the performance limits of the different types of bearing materials.

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 (and any associated risk of corrosion/chemical compatibility)

b. Applied loads and bearing stresses (radial, thrust, moment, static, dynamic, and shock)

c. Required service life or service time between overhauls

d. Velocity/pressure/duration of relative motion causing frictional heat buildup

e. Lubrication requirements

f. Misalignment possibilities (edge loading)

g. Envelope restrictions

h. Type of application (static, oscillatory, slow motion)

i. Retention methods (interference fit, swaging, staking, sealant)

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 (protection against galvanic action)

p. Same materials are avoided for bearings sliding in contact for frictional issues and galling potential

q. Material selection. Similar materials in contact (such as corrosion resistant alloys) are avoided for galling considerations. However, self-lubricating bearings and mating shafts can be made from corrosion resistant alloys since there is a lubricating barrier between the mating surfaces. Application of coating or plating on one of the mating flange faces is an effective way to address galling concerns with similar material bushings in rotating joints. Self-lubricating polymer bearings are also available. These will not suffer from the risk of metallic corrosion.

r. Temperature minimum and maximum

s. Housing material rigidity and stiffness.

t. Running fit per ANSI B4.1.

5. MATERIAL SELECTION FOR LUBRICATED BEARINGS

Based on experience and laboratory testing, the following materials are those used for bearing applications in landing gears (see Tables 1 and 2). The mating pin or shaft wear surface, in ideal cases, is steel with 0.003 inch (0.07 mm) minimum chrome plating or tungsten carbide (WC-Co or WC-Co-Cr) coating thickness.

NOTE: Copper-based alloys such as Aluminum-Nickel-Bronze (Al-Ni-Brz) and Aluminum-Bronze (Al-Brz) and Cu-Ni-Sn are all commonly referred to as “bronze,” and may be referred to as such herein unless the specific material reference is necessary.

5.1 Journal and Thrust Bearings

Journal and Thrust bearings (for lubricated positions) can be manufactured from metallic or polymer compounds.

There are several metallic materials suitable for lubricated journal bearing use such as Al-Ni-Brz. These journal bearings are often used in conjunction with high strength chrome plated or WC-Co/ WC-Co-Cr High Velocity Oxygen Fuel (HVOF) coated steel pins. Where two journal bearings move relative to one another, Al-Ni-Brz is often used in combination with Corrosion Resistant Steel (CRES), or and HVOF WC-Co/WC-Co-Cr coated surface or equivalent to prevent galling. It has been shown that coating and finish grinding both mating faces with WC-Co HVOF coatings produces excellent wear properties without galling and allows the use of Al-Ni-Brz for both journal bearings, Another typical application is to chrome plate one of the bearing flange faces and leave the mating bronze flange face bare. Also, laboratory tests and service usage indicate that unique journal bearing lubrication grooves improve lubrication properties and minimize wear in service.

Polymer bearings are manufactured from thermoset composite materials incorporating advanced polymer technologies. These consist of technical fabrics impregnated with thermosetting resins, evenly dispersed solid lubricants.

Because the polymer bearings have excellent corrosion performance and do not suffer from aging limitations, these can be used for long service life applications.

5.2 Spherical Bearings

There are several materials suitable for lubricated spherical bearing use such as softer metallic outer races with high strength-chrome plated steel balls. Some materials used are Al-Ni-Brz in combination with corrosion resistant steel (CRES) or low alloy steel heat treated to 275 ksi (1896 MPa). To reduce weight, titanium inner races with an HVOF coating have been used with various types of BNZ outer races.

Also, laboratory tests and service usage indicate that another satisfactory combination for spherical bearings in the landing gear environment is a Cu-Be ball with a 17-4 PH CRES outer race (reference AS81936, Be-Cu spherical bearing). As a lighter weight option, WC-Co HVOF coated titanium inner or outer race used in combination with Al-Ni-Brz or Cu-Be has been chosen for certain spherical bearing applications.

Polymer materials can also be machined to make spherical bearings, either as the outer race, or for the inner ball. These provide the normal benefits of polymer bearings, plus also weight saving capabilities compared to metallic alternatives.

6. WORKING PRESSURES FOR LUBRICATED BEARINGS

6.1 Working Bearing Pressure

The maximum suggested bearing pressures generally used for sizing bearings are listed in Table 1. The equation for calculating the bearing stress and for accounting for lube grooves is shown below (nomenclature for Figure 1) which is an average over the projected bearing area. Bearing surface roughness at sliding interfaces is commonly 16 to 32 µin (0.4 to 0.8 µm) Ra. Lower Ra values typically produce less wear in service as long as lubrication retention can be assured. Honing is a commonly used method to achieve superior surface finishes in small bearings. Additional bearing material information is given in Table 2. BNZ bearing materials have a higher coefficient of thermal expansion than steel. This characteristic has been considered during the bearing design at limit loads to prevent binding at adverse temperatures. Post installation sizing of the bearing inside diameter is often used to ensure adequate bearing to pin clearance.

<u>Average Bearing Stress</u> σ_B=A * L, minus the projected lube groove area (N)

6.2 Thermal Considerations

Where high velocity and pressure between the bearing surfaces develops frictional heat in excess of 500 °F (260 °C), detrimental impact to landing gear components may occur from frictional burning below a chrome plated journal. In this application, tests have shown that bearings with self-lubricated liners can be superior when compared with lubricated metal-to-metal sliding surfaces. Durability of these liners has been considered when used where high point loads and high PV (pressure/velocity) conditions may exist. The leading and trailing edges of such bearings is chamfered or beveled to prevent peaking or edge loading. Polymer bearings have proven to have good performance in edge loading situations due to the forgiving nature of the polymer structure.

HVOF coatings such as WC-Co and WC-Co-Cr have better thermal insulating properties than chrome and, therefore, may reduce the occurrence of frictional burning issues.

Table 1 - Bearing design guide (lubricated)

		Journal Bearings			Spherical Bearings (2)		
Materials		Aluminum Nickel Bronze (Al-Ni-Brz)	Copper Beryllium (Cu-Be)	Copper Nickel Tin Tin (Cu-Ni-Sn) (3)	Aluminum Nickel Bronze (Al-Ni-Brz)	Copper Beryllium (Cu-BE)	Copper Nickel Tin Tin (Cu-Ni-Sn) (3)
		AMS4640	AMS4533	AMS4596	AMS4640	AMS4533	AMS4596
		AMS4880	AMS4534	AMS4597	AMS4880	AMS4535	AMS4597
		AMS4590*	AMS4535	AMS4698	AMS4590*		AMS4598
		AMS4881*			AMS4881*		
Static Joint at Limit Load	Nonrotating movement under deflection, e.g., trunnion pivot joints under 1 g static load	50-80 ksi (414-552 MPa) (1)	60-90 ksi (414-620 MPa) (1)	60-90 ksi (414-620 MPa) (1)	47 ksi (324 MPa)	90 ksi (620 MPa)	90 ksi (620 MPa)
	Slight rotation movement under load, e.g., torsion links	45-60 ksi (310-414 MPa)	45-65 ksi (310-448 MPa)	45-65 ksi (310-448 MPa)	47 ksi (324 MPa)	90 ksi (620 MPa)	90 ksi (620 MPa)
Dynamic Joint	Rotating movement. Major portion of movement under normal operating pressure, e.g., actuator pins.	13 ksi (90 MPa)	13-15 ksi (90-103 MPa)	13-15 ksi (90-103 MPa)	15 ksi (103 MPa)	20 ksi (138 MPa)	20 ksi (138 MPa)
Dynamic Joint 1 g at Max Taxi Weight (MTW)	Rotating movement. All movement under 1 g loads at Max Taxi Weight, e.g., truck pivot joints.	10 ksi (69 MPa)	10 ksi (69 MPa)	10 ksi (69 MPa)	10 ksi (69 MPa)	10 ksi (69 MPa)	10 ksi (69 MPa)
Shock Strut Bearings	Upper and lower bearings under linear motion	Refer to AIR5883	Refer to AIR5883				

(1) Reference Table 2 remarks for rationale. Lower range is typically used for new design and higher range for derivatives/ redesign.
(2) Reference is for solid ball. Split and slotted entry designs use lower pressure.
* AMS4590 and AMS4881 have better material properties than AMS4640 and AMS4880. They are used when a higher allowable is warranted, but cost more.
(3) Higher design data allowables are available in MMPDS.

		Journal Bearings				Spherical Bearings (2)		
Materials		Aluminum Nickel Bronze (Al-Ni-Brz)	Copper Beryllium (Cu-Be)	Polymeric Bearings (Composite Thermoset)	Copper Nickel Tin Tin (Cu-Ni-Sn) (3)	Aluminum Nickel Bronze (Al-Ni-Brz)	Copper Beryllium (Cu-BE)	Copper Nickel Tin Tin (Cu-Ni-Sn) (3)
		AMS4640	AMS4533		AMS4596	AMS4640	AMS4533	AMS4596
		AMS4880	AMS4534		AMS4597	AMS4880	AMS4535	AMS4597
		AMS4590*	AMS4535		AMS4598	AMS4590*		AMS4598
		AMS4881*				AMS4881*		
Static Joint at Limit Load	Nonrotating movement under deflection, e.g., trunnion pivot joints under 1 g static load	50-80 ksi (414-552 MPa) (1)	60-90 ksi (414-620 MPa) (1)	13-15 ksi (90-103 MPa)	60-90 ksi (414-620 MPa) (1)	47 ksi (324 MPa)	90 ksi (620 MPa)	90 ksi (620 MPa)
	Slight rotation movement under load, e.g., torsion links	45-60 ksi (310-414 MPa)	45-65 ksi (310-448 MPa)	13-15 ksi (90-103 MPa)	45-65 ksi (310-448 MPa)	47 ksi (324 MPa)	90 ksi (620 MPa)	90 ksi (620 MPa)
Dynamic Joint	Rotating movement. Major portion of movement under normal operating pressure, e.g., actuator pins.	13 ksi (90 MPa)	13-15 ksi (90-103 MPa)	10 ksi (69 MPa)	13-15 ksi (90-103 MPa)	15 ksi (103 MPa)	20 ksi (138 MPa)	20 ksi (138 MPa)
Dynamic Joint 1 g at Max Taxi Weight (MTW)	Rotating movement. All movement under 1 g loads at Max Taxi Weight, e.g., truck pivot joints.	10 ksi (69 MPa)	10 ksi (69 MPa)	10 ksi (69 MPa)	10 ksi (69 MPa)	10 ksi (69 MPa)	10 ksi (69 MPa)	10 ksi (69 MPa)
Shock Strut Bearings	Upper and lower bearings under linear motion	Refer to AIR5883	Refer to AIR5883	Refer to AIR5883				

(1) Reference Table 2 remarks for rationale. Lower range is typically used for new design and higher range for derivatives/redesign.
(2) Reference is for solid ball. Split and slotted entry designs use lower pressure.
* AMS4590 and AMS4881 have better material properties than AMS4640 and AMS4880. They are used when a higher allowable is warranted, but cost more.
(3) Higher design data allowables are available in MMPDS.

Table 2 - Landing gear bearings

Bearing Material	Remarks
Aluminum-Nickel-Bronze (Al-Ni-Brz)	A very good bearing material of moderate strength and wear resisting properties when properly lubricated. Suitable for slow intermittent rotation and oscillatory motions. (Note: there is no design allowable data in MMPDS for Al-Ni-Brz.) Requires lubrication. Material will gall but not readily due to its moderate lubricity. More expensive than Al-Brz. Centrifugal castings are used in large bearing diameters to minimize costs, but due to equivalent properties are used in smaller diameters as well. Typically the housing interface surfaces of this material are cadmium plated, Zinc-Nickel (Zn-Ni) plated or IVD aluminum coated and primed and further protected with a corrosion preventative compound to minimize galvanic attack. Cadmium plating is not used in contact with titanium housings because of potential embrittlement. Oscillatory bearing wear testing indicates that these alloys offer equivalent wear characteristics to beryllium copper for loads up to 45 ksi bearing pressure, without the environmental concerns and global material restrictions of beryllium copper. AMS4590 and AMS4881 alloys offer improved strength properties over AMS4640 and AMS4880 and are used when envelope restrictions cause increased joint loading and for oversize repair bearings.
Copper Beryllium (Cu-Be)	This material has significant environmental impact and health issues, and is banned for use in many locations and, therefore, is not often used for new design . 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 significantly higher than Al-Ni-Brz or Al-Brz. It is used when dictated by size and envelope limitations such as exist in some redesign efforts. A-Basis design allowables are available in MMPDS. Typically the housing interface surfaces of this material are cadmium plated, Zn-Ni plated or IVD aluminum coated and further protected with a good corrosion preventative compound to minimize galvanic attack. Cadmium plating is not used in contact with titanium housings because of potential embrittlement.
Copper Nickel Tin (Cu-Ni-Sn)	This bearing material may offer an environmentally compliant replacement to beryllium copper of exceptionally high strength and properties. This material has been successfully used in combination with MIL-PRF-32014 grease to mitigate friction burns for large transport aircraft. The material should be suitable for slow, intermittent rotation and oscillatory motions, and tends to resist galling. Typically the housing interface surfaces of this material are cadmium plated, Zn-Ni plated or IVD aluminum coated and further protected with a good corrosion preventative compound to minimize galvanic attack. Cadmium plating is not used in contact with titanium housings because of potential embrittlement
17-4 PH CRES	This bearing material has exceptionally high strength. Suitable primarily for static joints and intermittent rotation and oscillatory motions where high load carrying capability is required while allowing relative motion against another high load bearing material such as beryllium copper. The material galls readily and in the absence of a lubrication film at high stress conditions galling will be excessive. Material costs are significantly higher than Al-Ni-Brz and may require some redesign efforts due to size, envelope and environmental considerations. A-Basis design limits are available in MMPDS. Typically bearings made from CRES material should not be installed in low alloy steel parts otherwise the joint will be subjected to galvanic corrosion under the more common protective plating finishes. If CRES bearings are used, nickel or chrome plating should be used in the housing to prevent galvanic corrosion and the design must allow for the degraded fatigue life which will occur as a result of the nickel/chrome plating used.

Bearing Material	Remarks
Polymeric bearings (composite bearings)	A very good bearing material of moderate strength and wear resisting properties and can be used lubricated or non-lubricated. Suitable for slow intermittent rotation and oscillatory motions. **Two types of bearing materials:** **Requires lubrication.** Material will not gall, but higher friction (if these are used without lubrication). Bearings are relatively cheap. Bearings are available in a wide range of sizes and often designed with thin walls to increase bearing stiffness. Composite bearings allow some misalignment. **Self-lubricating.** The bearing can operate in static and dynamic applications. Lubrication is achieved by creation of a transfer film from the bearing onto the shaft material. The bearings do not promote corrosion or galvanic reaction, which allows the use of a wide array of housing interfaces. Oscillating wear testing shows high wear performance up to 10 ksi, but with a lower overall weight of metallic bearings and no environmental concerns. Most polymeric bearings are chemically inert in the environment. Polymer bearings can be machined in a wide range of sizes or designs. Oversize bearings can easily/quickly be manufactured for maintenance and repair situations (where housing gland corrosion has to be machined away leading to a bigger/non-standard gland housing position)

7. INTERFERNCE FITS FOR JOURNAL BEARINGS

Journal bearings, plain or flanged, are installed with interference fits for retention in the housing. For example, the typical minimum interference fit for 2.00 inch (50.8 mm) bore diameter is 0.001 in/in (0.0254 mm/mm) with the maximum interference fit being minimum plus 0.002 to 0.003 inch (0.051 to 0.076 mm/mm) to provide for reasonable manufacturing tolerance on the bore and bushing. These values are determined prior to plating and finishing except on bores with chrome, nickel or HVOF coatings where the after plating/coating diameter should be taken into account. In addition when selecting an interference fit, consideration should be given to:

Hoop stresses generated by the interference fit (including temperature effects)

Temperature limitation during the installation process

Material temperature limitation (especially on aluminum)

Effect on shot peened surfaces (higher temperature may reduce the benefits of shot peening)

One method of assembly is the temperature differential method where the bearing is cooled with dry ice (-98 °F/-72 °C) or extreme conditions using liquid nitrogen to -320 °F (-196 °C). The housing may be heated up to 200 °F (93.3 °C) as required. If materials go through a transformation/phase change after freezing with liquid nitrogen, verify no degradation in material properties will occur. See Figure 2 for proper temperature for bushing and substrate material at different bearing sizes. 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, and to obtain the proper surface finish.

Proper tooling is required to perform assembly by temperature differential. Special consideration should be given to the warm-up time between removing the bushing from the cooling source and the installation to avoid jamming of the bushing before it is completely seated and to minimize damage to protective finishes during installation.

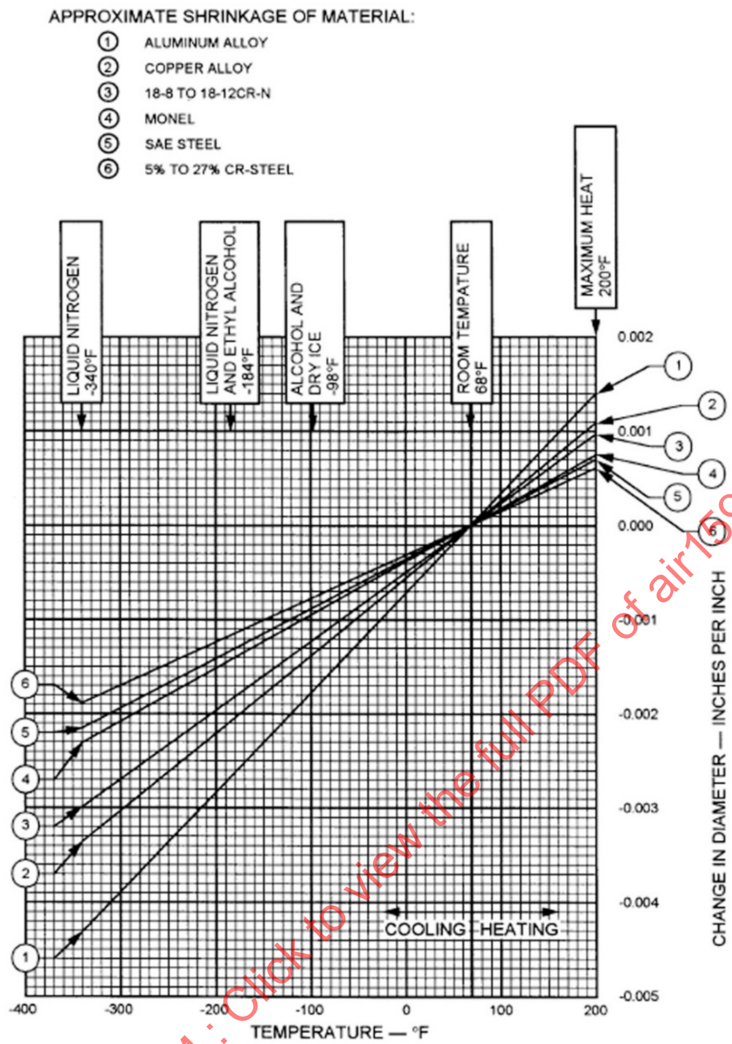

Figure 3 - Sub-zero installation of bearings

Some journal bearings to not require interference fit methods for installed and are merely press fit. Again as with interference fit journal bearings (bushings) the following conderations apply:

Hoop stresses generated by the press fit

Effect on shot peened surfaces

Damage to housing/journal bearing protective coating during installation process.

Polymer journal bearings can often be easily installed without an interference fit, into closed gland design housings

8. BEARING TO PIN CLEARANCES

The clearance between the pin or shaft and the bearing is commonly in the range defined by ANSI B4.1, RC5, or RC6 for landing gear applications. For self-lubricating bearings, the typical clearance between the shaft and bearing (bushing) is 0.003 inch (0.075 mm) maximum with a minimum of 0.001 inch (0.025 mm) of clearance.

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 assembled.

9.1 Potential Corrosion Causes

a. Entrapment of moisture between the mating surfaces of the lug and bearing. It is believed that fillet sealing bearings using fuel tank sealing compounds such as MIL-PRF-81733 promotes moisture entrapment if the sealing becomes brittle over time, although testing for this has been inconclusive.

b. Lug deflection or stretch ovalization during application of loads allowing moisture ingress.

c. Depletion of corrosion protection plating due to chemical action or wearing due to lug and bearing flange deflections or vibration fretting. This is especially true for split bearings that are not secured with an interference fit.

d. Residual installation stresses beyond the stress corrosion threshold of lug or fitting. Commonly accepted design criteria for 1G sustained stresses is less than one-half of Fty for the lug material at the bearing lug interface, however this does vary depending on the lug or fitting material selected.

e. Bushing rotation or migration.

f. Inadequate, and breakdown or lack of lubricant.

9.2 Potential Corrosion Prevention Methods

a. Titanium-cadmium, low hydrogen embrittlement LHE cadmium or LHE Zn-Ni plating 0.0002/0.0003 inch (0.0051/0.0076 mm) thick plus epoxy primer 0.0005 to 0.0007 inch (0.0013 to 0.0018 mm) on the lug or fitting face, bore and chamfer. Cadmium or Zn-Ni plating 0.0002/0.0003 inch (0.0051/0.0076 mm) thick on the bearing outside diameter and end faces. Cadmium or Zn-Ni plating and primer thickness, is not normally taken into consideration in the interference fit *sizing* as it is difficult to control in a production environment, although Zn-Ni is harder than cadmium which is often a consideration for interference fit sizing. Cadmium plated joint temperature is limited to 450 °F (232 °C) to avoid cadmium diffusion/embrittlement. Zn-Ni plated joint temperature is limited to 600 °F (316 °C) to avoid diffusion/embrittlement

b. IVD aluminum has been considered an equivalent corrosion protection to LHE cadmium or LHE Zn-Ni when applied per approved specification (2.1), yet IVD is more sensitive for re-embrittlement with maintenance materials/cleaners when in contact with an unprotected high strength steel substrate (>180 ksi).

c. Corrosion preventive compound MIL-PRF-16173 or equivalent covering housing bore before bearing insertion. Corrosion preventive compounds are widely used for this purpose and have proven to reduce corrosion versus sealing bearings with a sealing compound in high strength steel substrates. Ensure adequate corrosion preventive compound to fill cavity common to the bushing radius and lug chamfer.

d. Sealing compound equivalent to fuel tank sealant such as MIL-PRF-81733 is applied to housing face between housing and bearing flange for bearings that must not rotate, cannot have an interference fit, and are adhesively sealed in place. 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. In the event the bearing rotates, or the sealing compound becomes brittle and cracks, the joint is prone to more severe corrosion than if no sealant were used as it will entrap moisture in the joint. Sealant installations are normally discouraged for bushings with OD lubrication grooves. It is difficult to purge the sealant from the grooves after installation and some portion of the grooves could be blocked once the sealant has cured.

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 an environmentally compliant cleaning solvent before sealant adhesion can be effective.

e. Hard chrome plating or nickel plating of bores and faces of the housing results in good corrosion protection. Bores and faces of housings can be plated with plate to size chrome or nickel and polished to finished dimensions followed by wiping with epoxy primer and allowed to cure fully. The chrome or nickel plating replaces the cadmium plating on the bores and faces of the housings. The chrome or nickel plate thickness is 0.0015 to 0.0025 inch (0.0381 to 0.0635 mm) and should be accounted for in determining the interference fit values. 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. The design should be based upon fatigue data developed with the associated type of plating used.

f. The design should be based upon fatigue data developed with the associated type of plating used." Suggest: "The design should be based upon fatigue data developed with the associated plating.

g. Polymer bearing materials can be used where there is a risk of corrosion, as the polymer bearings themselves are resistant to the typical corrosion that metallic bearings can suffer from.

10. LUBRICATION

Bearing lubrication (when specified) 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.

Lubrication grooves should be arranged so pins or shafts are wiped with grease from the grooves. Lubrication paths in the housing should be arranged such that, if the bearing rotates, lubrication is not shut off from the sliding surfaces. Adequate grease paths need are designed to allow grease to flow properly throughout the bearing, without being blocked by old/dry grease, which promotes increased wear and corrosion.

All landing gear joints, both static and dynamic, should be considered for lubricating provisions (when a lubricated bearing is specified). A lubricator fitting should be provided for each surface to be lubricated. Service experience indicates that bearing/pin joins lubricated through grease passages in the substrate lug provide better lubrication than grease passages in the joint pin. If the lubricated surface is in close proximity to a nonmetallic seal, the lubricant and seal material compound must be checked for compatibility.

For critical applications it is common to dedicate one lubrication passage per joint. Having multiple passage greasing routes cannot always guarantee lubrication to all the joints. Multiple fittings per joint are usually avoided as the spare unused fitting may promote inservice corrosion. Note: For smaller landing gear, too many lubrication points can lead to missing one or two as it is easily missed due to the crowding of the too many grease fittings in a confined area

Care is excercised to ensure that different greases specified are not incompatible. This has even be an issue for greases meeting the same standard.

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 and low temperature performance. MIL-PRF-32014 is an example of synthetic grease that does not absorb moisture.

Landing gear joints that are extremely highly loaded benefit from a high molybdenum content grease. Care should be exercised in selecting a molybdenum grease. Molybdenum-disulfide grease such as MIL-G-21164 has excellent load carrying capability, but will absorb moisture in service and promotes joint corrosion.

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. Loads and motions are within the allowable range.

d. Lubricated bearings are not practical.

e. Applications with high levels of vibration and/or dithering motion.

f. Limited rotational movement (no ability to wipe grease around).

Self-lubricating bearings may not have the load carrying capability of lubricated bearings. The load carrying capability of various self-lubricating material vary widely. It is recommended to work with the self-lubricating bearing manufacturer to determine the appropriate load for a given material.

Performance of self-lubricated bearings can be 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 µin (0.2 µm) Ra and for larger bearings should be 16 µin (0.4 µm) Ra for practical manufacturing reasons in order to insure best bearing life. Likewise mating surface hardness can improve wear performance. It is recommended that the self-lube mating surface be Rc 40 or harder. The self-lube bearing manufacturer should be consulted for specific recommendations regarding mating surface condition at the design stage It should be kept in mind that the mating shaft for a self-lubricating bushing comprises one half of the bearing system, the bushing comprises the other.

Service experience indicates that self-lubricating bearings may tend to last longer than grease lubricated bearings. Grease lubricated bearings have corrosion issues, tend to damage mating shafts and migrate in housings. Self-lubricating bearings are made from corrosion resistant materials, and as long as care is taken on selection of materials to prevent galvanic corrosion, self-lubricating bearings tend to last longer.

In addition, self-lubricating bearings typically have a lower and more consistent coefficient of friction as compared to lubricated bearings (typically 0.03 to 0.08 (or higher) for self-lubricating as compared to 0.15 to 0.30 for lubricated bearings). This lower coefficient of friction is less likely to damage the mating shaft and also has a much reduced chance of having bearing migration in the housing. In applications where there is vibration or dithering motion, lubricated bearings normally have a greatly reduced life compared to self-lubricating bearings.