SAE Aerospace
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AEROSPACE INFORMATION REPORT

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(R) Selection, Testing, Lubrication, and Sealing of Single Row Tapered Roller Bearings for Aerospace Wheel Applications

1. SCOPE:

This SAE Aerospace Information Report (AIR) describes available technology and current aerospace industry practices used for the selection, testing, lubrication, and sealing of single row tapered roller bearings to reduce bearing damage as a problem in the aircraft industry.

2. REFERENCES:

2.1 Military Publications:

Available from Standardization Documents Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-A-8863	Airplane Strength and Rigidity Ground Loads for Navy Procured Airplanes
MIL-A-18717	Arresting Hook Installations, Aircraft
MIL-PRF-81322	Grease, Aircraft, General Purpose, Wide Temperature Range

2.2 Other Publications:

ANSI/ABMA Std 19.1 Tapered Roller Bearing Radial Metric Design

ANSI/ABMA Std 19.2 Tapered Roller Bearing Radial Inch Design

ANSI/ABMA Std 11 Load Ratings and Fatigue Life for Roller Bearings

SAE Technical Paper Series 841121 Rating and Life Formulas for Tapered Roller Bearings

Federal Aviation Administration Technical Standard Order C26d (FAA TSO-C26d)

Federal Aviation Administration Technical Standard Order C135 (FAA TSO-C135)

(reference: Federal Aviation Regulation Pt . 21 Subpart O)

3. SELECTION:

3.1 Bearing Quality Classification:

Aircraft quality tapered roller bearings are available for aerospace landing wheel applications. Currently, bearings made to Anti-Friction Bearing Manufacturers Association (ABMA) standard/commercial precision class 2 (IS0 metric class N or K) are used for aerospace landing wheel applications. Manufacturers have developed customized requirements for aircraft landing wheel applications. A typical bearing part number includes the information to signify the aircraft quality features. The bearing part number should include all information to order the correct part and prevent usage of similar base part number yet not equivalent parts. For example, bearing cone 13889 2-629 is commonly used.

3.2 Analytical Sizing:

3.2.1 Bearings are sized using the design wheel load requirements. Wheel radial loads and side (thrust) loads as well as the load application points (influenced by tire vertical and lateral deflection) are resolved for each bearing for each radial/side load condition. Bearing life and stress criteria are then evaluated for one or more bearing candidates at each position. Existing parts are considered prior to developing new bearings. Historical L10[1] rating data, corrected for changes in bearing rating that have improved over the years, can also be used to approximate the size of the axle and bearings required. The solution method assimilates wheel and tire requirements, brake envelope, and landing gear strength requirements. Optimizing the diameters and capacity of the bearings along with the adjacent components results in a minimum weight assembly having adequate landing gear stiffness and adequate component life. See Figure 1.

3.2.2 The bearing size and rating evaluation considers both the desired fatigue life of the bearing and the anticipated tire tread life. The anticipated tire tread life will determine the practical inspection period for the bearings and the normal frequency for bearing relubrication. Due attention is given during the design to the possible failure modes of the bearing such as roller end scoring, etching (corrosion) damage, or fatigue spalling and the frequency of inspection. In the design of the wheel/bearing system, consideration is given to the prevention of mis-installation of bearing cups or cones by differing the inboard and outboard bearing diameters.

3.2.3 Bearing fatigue life calculations (described in vendor catalogues or software, also see 2.2) can be made to assess the static and dynamic load capacity of the bearings so that the landing gear assembly will perform adequately. Similarly, refined fatigue life calculations can also be made for a load spectrum which includes due accounting for load, speed, reliability, environment, temperature, alignment, and lubrication. Catalogue fatigue life calculations do not encompass bearing failures emanating from misalignment or roller end scoring. These are addressed in design with due accounting as noted above to check for acceptable contact stresses for the bearing elements and adequate lubrication parameters. Bearing contact stress calculations, including roller end contact stresses, require review by the bearing supplier for a detail understanding of wheel design loads' effects on the bearings. Adequate lubrication is addressed by grease selection and seal design to contain and protect the bearing and grease. Preload is important to achieve desired bearing life.

[1] The L10 life is a laboratory test life at which 10% of the test bearings will have failed under controlled conditions. Refer to the ANSI/ABMA Standards and SAE paper referenced above.

3.2.4 Spacers may be considered in the wheel design adjacent to the bearings to locate the wheel assembly on the landing gear axle. The use of separate loose spacers is discouraged to prevent their possible omission during wheel installation. Integral extensions to the bearing cones or relocation of the axle shoulders should be considered as alternatives to using separate loose spacers.

3.2.5 The availability of salvage bushings and larger OD cups for oversize wheel bearing bore repairs are a consideration. The bearing cup loading and press-fit is maintained at levels that minimize cup rotation. Consideration for hub stresses as a result of the press fit as well as temperature exposure are made.

3.2.6 Deflection analyses can be used to assess the impact of wheel and axle bending on the load distribution between and within the bearings. The effect of the deflected wheel and axle on the cup and cone alignment, the effect of the imposed side load[2] on the load zones of the 2 indirect mounted bearings and the effect of variation in bearing preload setting via axle nut torque can also be evaluated.

3.2.7 The wheel bearing system axle nut torque and the resulting preload application procedure is defined commensurate with the bearing fatigue calculations. This includes evaluating the axle nut torque needed to attain the targeted bearing preload. This preload application procedure includes wheel rotation throughout the installation procedure. There is an initial torque value capable of adequately seating the wheel bearing components, usually twice the targeted final torque value followed by relaxation of the axle nut torque and then advancement to final torque value and next available (tighter) locking feature position. Selection of the final or targeted torque (preload) value by the wheel builder considers the calculated operational axle loads, wheel system axial stiffness, lubrication, and landing gear configuration (bogie or single axle). The final torque value provides for normal preload loss (due to subsequent dynamic seating of bearing system components), and dynamic preload variations so that resultant preload losses do not result in bearing damage. Excessive preload can also result in bearing damage.

3.2.8 Differences in bearing components, materials, finishes, and/or geometric tolerances can adversely affect bearing fatigue performance. Changes in internal bearing geometry can have pronounced effects on bearing performance. In light of this, the mixing of ABMA bearing components from different suppliers in a given assembly is definitely not recommended.

[2] All loads are in aircraft coordinates unless specifically noted. Local coordinate system origins are the axle centerline and the wheel/tire cross section centerline intersection.

3.2.9 Bearing configuration for aerospace landing wheel application is the indirect mounting arrangement. See Figure 1. Bearing cups are tight (interference) fitted to the wheel hubs. Some wheel builders recommend a brief soak in liquid nitrogen to ease the tight fit cup installation. This is not recommended for the bearing cones or other high strength steel components due to the possible formation of martensite. Bearing cones are a slip fit onto the aircraft axle to facilitate repeated installation, removal, and assembly preload (bearing setting) requirements. See Figure 2.

3.3 Fatigue Life Analysis:

Fatigue life calculations are made for the bearings using appropriate factors (load, speed, shock load, vibration, contamination, etc.) derived from the analysis of the deflected system. Several fatigue spectra exist as derived for specific applications (military, commercial transport, commuter, business, and general utility) based on experience. Speed, radial and side load conditions[2] can be estimated by the wheel or landing gear builder based on anticipated aircraft usage. Bearing fatigue life is typically targeted to be a portion of wheel design fatigue life and varies per application and wheel builder preferences.

3.4 Operating Conditions:

The operating conditions to which the bearings are exposed will affect the selection of the bearing as well as the sealing method and lubricant selection. The following considers operational and environmental concerns for aircraft landing gear wheel bearings that influence system design:

3.4.1 Allowances are made for load, speed, and time duration conditions during landing, takeoff, and ground maneuvering with due regard for the characteristics of the anticipated operating surfaces, including runway crown, variation in tire wear, tire growth, and inflation pressure. For carrier based aircraft, the operating surface includes landing on and/or running over cross deck pendants, centerline lights, and PLAT (pilot landing aid television) heads, See documents MIL-A-8863 and MIL-A-18717.

3.4.2 Allowances are made for deflection of the landing gear and load variation for each bearing within a wheel and between wheels on a gear. This is due to deflection, the selection, and retention of lubricant and the influence to the bearings for the deflection and fit effects of false axles and sleeves.

3.4.3 Allowances are made for installation torque variation on bearing preload due to machining tolerances, lock nut design, burnishing-in of the bearing, and compressive set of components. If applicable, lubrication variances on the axle nut threads, nut and spacer faces, and the outer bearing face will also affect the installation preload. As such, the targeted bearing preload from the axle nut torque procedure is a minimum value for the completed assembly.

3.4.4 Allowances are made for environmental factors including extreme ambient temperature and temperature change during operation, brake and bearing system induced heat, and grease temperature during transient loads.

The effect of brake and bearing induced heat is a consideration when determining the fatigue strength of the bearings and the lubricating qualities of the grease. The effect and control of the lubricant quantity is also a consideration (see also 4.2).

3.5 Lubrication:

3.5.1 Typically, aircraft wheel bearings are installed with grease packed by hand or machine. Bearing cones should be fully packed with the specified grease between the cage and cone raceway surfaces as well as all external surfaces. Bearing inspection or replacement is usually only performed at tire removal and, therefore, the system is designed and grease specified so that the lubricant is retained in the bearing and the grease performance life exceeds the predicted tire tread life. Some of the commonly used greases meet specifications MIL- PRF-81322 (Military requirement), MIL-G-3545 (cancelled) or similar requirements. Performance levels may vary between different brands of grease qualified to the same specification, therefore, wheel and/or airframe manufacturers may specify other greases based upon test and field service experience.

3.5.2 Bearing components should remain lubricated at all times to prevent corrosion. Bearing components should be degreased to clean out old grease and facilitate visual inspection. Light oil or other transparent coatings are suggested for the inspection interval. They should be re-greased immediately following inspection. Greased and unassembled (open) bearing components should be covered or packaged with clean, lint free materials to prevent contamination, grease loss or damage prior to assembly and installation.

4. BEARING SEALING:

4.1 Design:

4.1.1 The objective of sealing is to maintain an adequate amount of grease in and around the bearing and prevent contamination from entering the bearing cavities.

4.1.2 Some of the factors that influence the design are the choice of dynamic sealing surfaces, their size, speed, the contacting materials, their surface finish requirements, fit with adjacent bearing and wheel hub components and their susceptibility to heat and wear. The method of seal retention is critical to grease retention within the bearing and the prevention of contaminant ingress.

4.1.3 The bearing seal design includes consideration of the movement or flow of the grease during its tire change cycle. This includes centrifugal force and pumping action on the grease from wheel rotation or movement within the bearing cavity from a change in axle orientation when the gear are stowed in flight. If internal (cone front face) grease dams or seals are used, lubricant circulation may be improved. The natural pumping action of the grease toward the cone back face is considered in seal design. Seal design should encourage recirculation of the lubricant back into the bearing.

4.2 Environment:

4.2.1 The type of potential contaminant, be it dirt, brake dust (carbon/steel), water (steam/condensation or water spray), cleaning solvents, fuel, hydraulic fluid, or corrosive atmosphere (for ship based aircraft) is a consideration in seal selection. The contaminant ingress direction, velocity, and pressure influence the seal design as well as the chemical compatibility of the seal material with the lubricant and all possible contaminants over the expected operating temperature range. The effect of high pressure cleaning with hot fluids and vapors thereof and high volume rinsing is a consideration.

4.2.2 The effect of airflow on the seal during gear retraction, extension, and steady flight under all conditions is a consideration when not protected by a wheel hub cap.

4.2.3 The requirement to vent the cavity between bearings to allow for expansion of trapped air should be considered. Venting of the cavity should not jeopardize the configuration's grease retention capability.

4.2.4 The effect of temperature and repeated temperature excursions on the properties of the seals, grease dams or other nonmetallic materials is a consideration.

5. TESTING:

5.1 Laboratory Testing:

5.1.1 The fatigue life of the bearing is substantiated to FAA TSO-C26d, TSO-C135 or military requirements such as ARP1493; wheel assembly roll tests with radial and combined radial and side load conditions. The criterion for success is absence of loose bearing cups or fatigue damage on the bearings. Typically, the roll requirements are supplemented by accelerated roll tests to confirm the expected long term service life of the wheel.

5.1.2 The wheel system can also be tested to show that the design is not susceptible to roller end scoring. This is typically done on a dynamometer or a special wheel bearing test machine where the properties of the actual aircraft installation are accurately reflected. The critical factors are axle deflection, wheel configuration, temperature (including brake heat and/or extreme cold), speed, load (vertical, side, and drag), axle nut torque - including variation due to locking method, grease, grease retention, and seal wear. The artificial application of contaminant can be used to assess the sealing method. The criterion for success is the absence of loose bearing cups or other bearing damage after a specified or arbitrary multiple of the anticipated tire tread life.

5.1.3 Ground load data, if available, can be used to determine actual static and dynamic wheel loads to confirm the fatigue analysis and test spectrum.

Measurement can be made via instrumented struts or wheels during ground operations.

5.2 Aircraft Monitoring:

5.2.1 Aircraft monitoring is useful to confirm general conditions, axle nut torque relaxation, grease retention, ease of installation, and operating temperatures. Field evaluation can be carried out to evaluate the nominal axle nut torque value, rib roller end scoring resistance, grease selection, operating temperatures and resistance to cage pocket damage. Confirmation of expected temperatures in the vicinity of braked wheel bearing assemblies can be verified during flight testing or in-service evaluation as needed.

PREPARED UNDER THE JURISDICTION OF
SAE SUBCOMMITTEE A-5A, WHEELS, BRAKES, AND SKID CONTROLS OF
COMMITTEE A-5, AEROSPACE LANDING GEAR SYSTEMS