SECTION 7

ENGINEERING SECTION II

Bearing Installation and Retention

Installation and retention details are important considerations when designing a bearing. Features such as pins or bolts, housings, corrosion resistance, installation method, and retention methods must be considered to ensure optimum bearing performance.

38 This typical bearing installation, which is staked into the housing, is assembled with a mating clevis, bolt, nut, washers, and plain and flanged bushings.

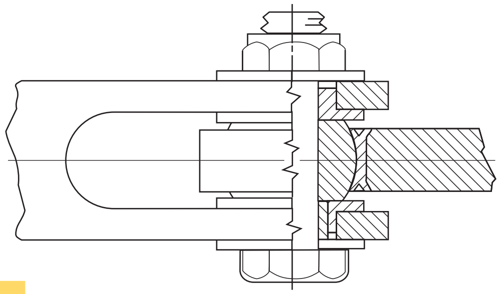
In most applications, the bolt is preloaded with the nut to clamp up the ball and force the ball to rotate on the race I.D. Caution must be exercised when clamping the ball. Excessive force expands the ball and will bind it in the race. If the ball is not clamped up, motion will usually take place on the bore, in which case the bolt, the bearing bore, or both must have suitable surfaces for this motion.

THE PIN OR BOLT

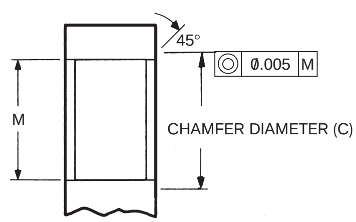
In addition to carrying the structural loads through the joint, the pin or bolt may function as a journal, and must therefore meet the multiple requirements of adequate strength, minimum wear, low friction, and corrosion resistance. In these instances, the following provisions for relubrication should be made:

1. TEFLON® line the bearing bore or the pin or bolt O.D.
2. Dry film the bearing bore and/or the pin or bolt O.D.
3. Introduce lubrication holes and grooves in the pin or bolt or the ball members

Suggested pin materials are 17-4PH and PH13-8Mo stainless steel, and 4130/4340 steel chrome plated .002 thick. Pins, either bare or plated, should be heat treated to the required shear strength (108,000 psi Ref.) and ground and polished to the required dimensions with a surface finish of 8 R_a or better. The recommended fit between the pin or bolt and the bearing bore is line-to-line to .001 loose.



38 *Typical Bearing Installation*



39 *Chamfered Size Calculation for V-Groove Retention*

Chamfer Dia.

(C) = M + [T - H + (2 X E)]

(Tolerance + .008/ - .007)

T = average housing thickness

H = average outer race thickness

E = average V-groove depth in race, depending on groove.

V-Groove Size*	Avg. Groove Depth (E)
A	.023
B	.033
C	.053
D	.073

*See **46** for groove dimensions, page 75.

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Bearing Installation and Retention

HOUSINGS

The housing into which the bearing is mounted must be designed to ensure the structural integrity of the bearing. The recommended housing dimensions are as follows:

1. Bearing-to-housing fit: .0002 tight to .0008 loose.
2. Bore finish: 32 R_a.
3. Round within the bore diametral tolerance.
4. Bore aligned perpendicular to housing faces within .002 for sleeve bearings only.
5. Housing width: .005 tolerance (for staking purposes).
6. For V-groove retention the housing bore is chamfered. Chamfer size is calculated as shown in 39, page 71.
7. For housing stake and bolted plated retention, break edges .005 max on both sides.

The recommended shaft and housing sizes are based on an operating temperature range of -65° to 350°F. At elevated temperatures, allowances must be made for different coefficients of expansion for the various shaft, bearing, and housing materials. In general, the mating components should be adjusted to provide the recommended fit at operating temperature. In addition, internal bearing fit-up between the ball and race may be required (either additional internal clearance or decreased torque) to ensure proper operation over a broad temperature range.

The use of heavy interference fits between a bearing and housing is not generally recommended because it reduces internal clearance. If the application requires a heavy interference fit, the assembly of the bearing and housing must be accomplished by use of temperature differentials to prevent galling of the bearing or housing. The temperature differentials are dependent on the amount of press fit. After assembly, the bearing usually cannot be replaced because of galling during pushout. When using interference fits, the internal ball to race fit-up must allow for the contraction of the race (which can be up to 100% of the interference fit, depending on housing material, heat treatment, and size). For fit-ups on sleeve bearings see pages 47 and 49.

CORROSION RESISTANCE

A bearing, housing, or shaft interface is a likely place for various forms of corrosion to develop. Corrosion may be initiated or accelerated by wear (fretting) or caused by the galvanic action of dissimilar metals in the presence of an electrolyte. Control of galvanic corrosion can be established by isolating and protecting the active metal surfaces. When corrosion resistant materials are used for bearings, pins or bolts and housings, there is little problem with galvanic corrosion. When dissimilar, noncorrosion resistant materials are used, precautions must be taken to protect bearings, shafts, and housings used in contact with other metals or with the atmosphere. Table 6 shows various bearing, shaft, and housing materials, with finishing precautions necessary to combine them to make a complete design. In addition to these recommendations, the bearing O.D. and housing bore are sometimes coated with zinc chromate primer according to TT-P-1757, epoxy primer according to MIL-PRF-23377, or sealant according to MIL-PRF-81733.

TABLE 6: Treatments to Prevent Galvanic Corrosion

Bearing Material (Bore and O.D. Surface)	Housing or Shaft Material				
	Aluminum Alloys	Low Alloy Steels	Titanium	Corrosion Resistant Steels	Super-Alloys
Aluminum alloys	A	A, C	A	A, C	A, C
Bronze and brass	A, C	C	S	S	S
Bronze and brass cadmium plated	A	C	—	S	S
52100 and low alloy steels	A, C	C	—	C	C
440C stainless steel	A, C	C	S	S	S
440C with wet primer	A	C	S	S	S
Corrosion resistant steels, 300 series (17-4PH, 15-5PH, PH 13-8Mo, etc.)	A, C	C	S	S	S
Superalloys (Rene 41®, etc.)	A, C	C	S	S	S

— = Incompatible   A = Anodize aluminum per MIL-A-8625, Type II, or Alodine per MIL-C-5541   C = Cadmium plate per Fed-Spec QQ-P-416   S = Satisfactory for use with no surface treatment required

INSTALLATION

The installation of a bearing or sleeve into a housing bore is a simple operation when done properly. Alignment of the bearing or sleeve to the housing bore is critical to prevent a cocking motion during insertion, which can damage or ruin the bearing or housing. Temperature differential installation is recommended.

SPHERICAL BEARING INSTALLATION

Use of an arbor press or hydraulic press is recommended. Under no circumstances should a hammer or any other type of shock-inducing impact method be used. A suitable installation tool (as shown in 40) is advised. A guide pin aligns the ball in a 90° position, but all force is applied to the outer race face only. A lead chamfer or radius on either the bearing or housing is essential.

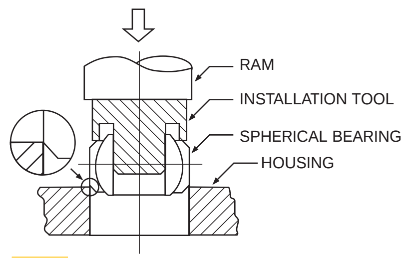
LINED SLEEVE BEARING INSTALLATION

The same general procedure as outlined for spherical bearings should be followed (see 41). In the case of fabric lined bores, however, it is mandatory that both the insertion tool guide pin and the mating shaft have ends free of both burrs and sharp edges. A .030 (min.) blended radius or 15° lead (as shown in 41) is recommended, since it is virtually impossible to install a sharp edged shaft without inflicting some damage to the fabric liner. For maximum support of the fabric lined bore, the effective length of the insertion tool guide pin should exceed the sleeve bearing length.

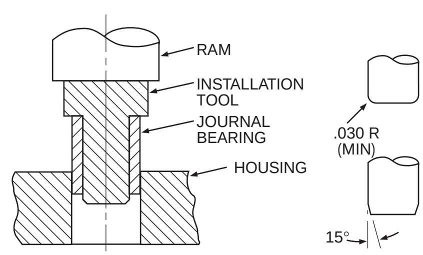
RETENTION METHODS

Bearing retention in a housing can be accomplished by any one of the methods listed in table 7. To determine the best method, several factors must be taken into account, such as effect on bearing internal clearance and torque, effect on housing residual stress, thermal expansion, added space and weight, retention capability, housing damage during bearing replacement, and number of times a bearing can be replaced.

The four retention methods listed in table 7 are the most commonly used. Other methods do exist, such as adhesive bonding, snap rings, and threaded cover plates, but they should be used only as a last resort.



40 *Spherical Bearing Installation*



41 *Sleeve Bearing Installation*

TABLE 7: Characteristics of Recommended Retention Methods

Method	Effect on Bearing Internal Clearance	Effect on Housing Residual Stress	Added Space and Wt.	Retention Capability Requirements	Can Replacement Damage Housing?	Possible No. of Replacements
Threaded Bearing Retainer	None	None	None	Medium	No	No limit
Bolted Retainer	None	None	High	High	No	No limit
V-Groove Stake	None	None	None	Medium	No	No limit
Housing Stake: Continuous or Interrupted	High	High	None	Low	Yes	None

Bearing Installation and Retention

THREADED RETAINER RETENTION

Threaded bearing retainers, as shown in 42, offer an excellent bearing retention method due to ease of bearing replacement, high axial thrust load capabilities, and ease of assembly in areas where accessibility to conventional staking would be difficult.

BOLTED PLATE RETENTION

For high retention capability and ease of bearing replacement, the bolted plate method, as shown in 43, is recommended. However, space requirements and weight will increase.

HOUSING STAKE RETENTION

Housing stake retention, as shown in 44, has many shortcomings when compared to V-groove staking. The major consideration is race contraction, which adversely affects internal fit-up. Housing stake retention should be used only when there is insufficient space on the race face for a V-groove or the race material is not ductile. When mounting, the bearing and its housing are supported by an anvil while the staking tool is forced into one side of the housing near the edge of the bearing. This action displaces a small amount of the housing material over the race chamfer. The opposite side of the housing is then staked in the same manner.

V-GROOVE RETENTION

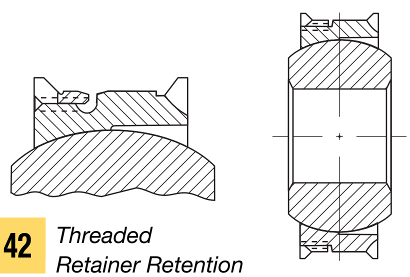
V-groove retention, as shown in 45, is the most widely used and recommended. The bearing outer race has a small groove machined into each face, which leaves a lip on the race O.D. corners. With the use of staking tools, these lips are swaged (flared) over the chamfered edges of the housing.

The prerequisites for good V-groove staking are proper size housing chamfers, staking tools that match the V-groove size, and the availability of a hydraulic or pneumatic press capable of applying the staking force. To use V-groove staking successfully, the following conditions must be met:

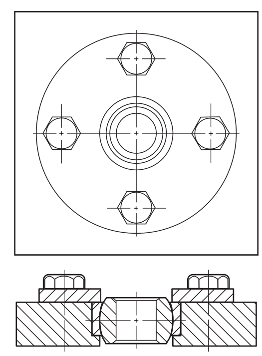
1. Race hardness: R_C40 max.
2. Sufficient space on the race face for machining a groove. For V-groove sizes, see 46.
3. V-groove size capable of carrying the axial load, see 47.

STAKING PROCEDURE

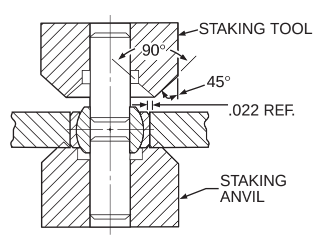
1. Install bearing into housing per 40 and position it symmetrical about housing centerline within .005.
2. Mount bearing and top anvil over bottom anvil guide pin as shown in 45.
3. A trial assembly should be made for each new bearing lot to determine the staking force necessary to meet the axial retention load required. Excessive force should be avoided since this may result in bearing distortion and seriously impair bearing function and life. (See table 8 for recommended Staking Force, page 75).
4. Apply the staking force established by trial assembly, rotate assembly 90° and re-apply force.
5. After staking, a slight gap may exist between race lip and housing chamfer as shown in detail in 45. This gap should not be a cause for rejection providing the bearing meets the thrust load specified.



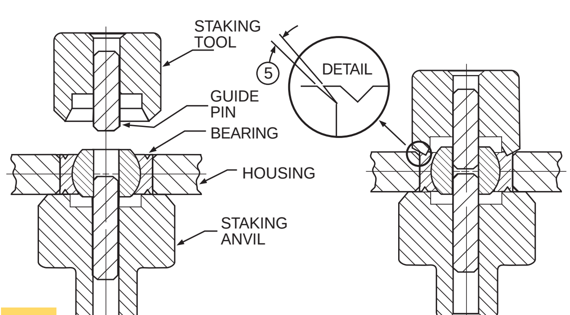
42 *Threaded Retainer Retention*



43 *Bolted Plate Retention*



44 *Housing Stake Retention*



45 *V-Groove Staking Method*

STAKING FORCE

The staking force equals the product of the bearing O.D. and a constant for each groove size (see table 8). For example, a bearing with a "B" size V-groove and 1.500 O.D., the staking force will be 1.500 X 12,000 lbs. = 18,000 lbs.

These staking forces are valid for outer race materials having an ultimate tensile strength of 140,000 psi.

Staking forces for other materials are proportional to the ultimate tensile strength or the materials as compared to 140,000 psi.

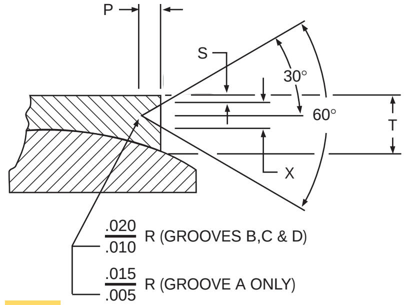
These staking forces should be used as a general guide to establish a starting point. Lower forces may be adequate or higher forces may be necessary depending on staking technique and axial load requirements.

As a rule, only the amount of force required to get the desired amount of retention should be used.

The use of proper fits and staking techniques should not cause significant changes in bearing preload.

As a minimum, the first and last article staked should be proof-tested. 48 shows a method for proof-testing staked bearings for axial retention. This is the generally accepted method for checking retention used by bearing and air frame manufacturers.

47 shows allowable design thrust loads for bearing O.D.'s The loads shown should be obtainable using staking tools with 45° outside angles.



46 *V-Groove Sizes*

V-Groove Sizes

Groove Size	P +.000 -.015	S +.000 -.010	X +.000 -.010	T Min.*
A	.030	.020	.045	.075
B	.040	.030	.055	.125
C	.060	.030	.080	.156
D	.080	.045	.105	.188

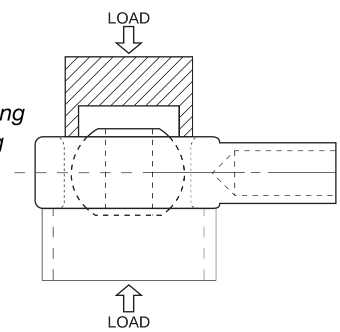
*For TEFLON® lined bearings, add single liner thickness to "T Min."

TABLE 8: Staking Force

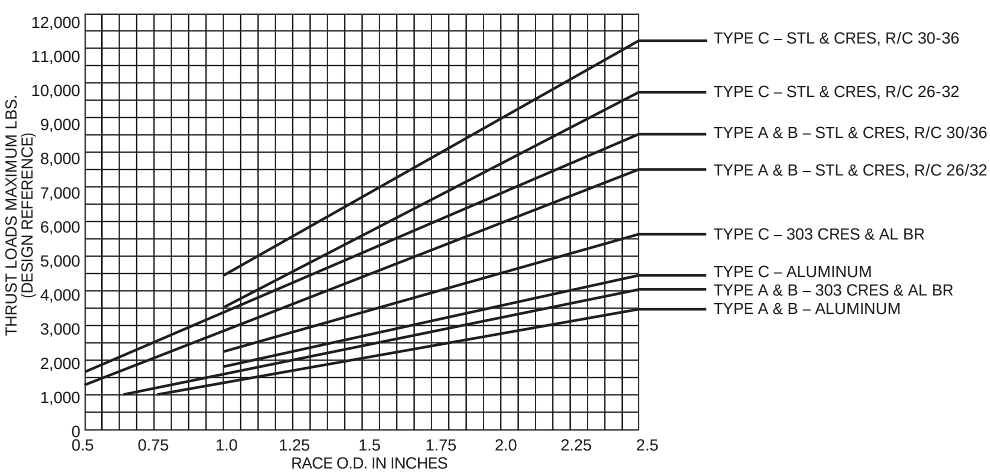
Groove Size*	Lbs.
A	7700
B	12000
C	17700
D	25800

*See 46 for groove sizes.

48 *Staked Bearing Proof Testing Method*



47 *Thrust Loads Based on 46 Groove Types and Materials Specified.*



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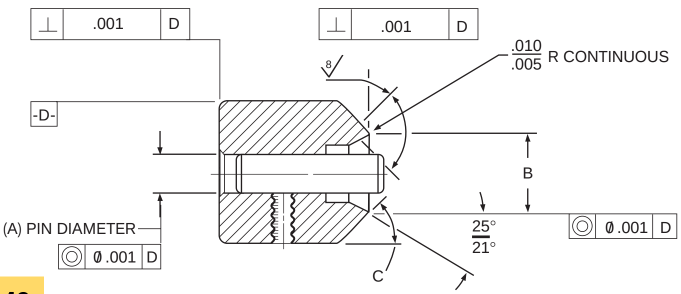
Bearing Installation and Retention

V-GROOVE STAKING TOOL

The staking tool and staking anvil depicted in 49 and 50 are made from tough, hardenable tool steel (for example, A-2) and heat treated to R_C55 to 60. The critical dimension of the tools are as listed. As a final check on the staking tool and anvil, a final layout drawing should be made to check fit-up. NHBB manufactures staking tools to meet many customers' needs. To obtain staking tools specially manufactured by NHBB, please refer to ordering information on page 77.

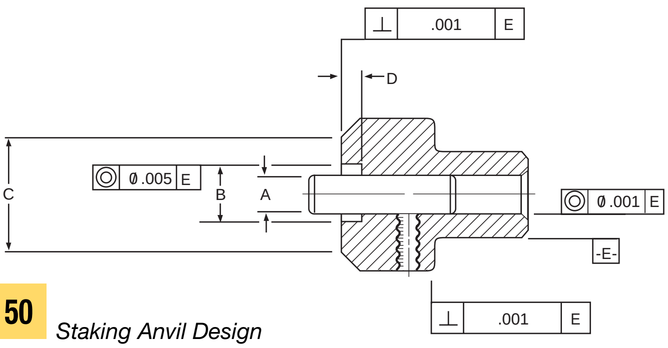


49 *Staking tool design*

A = Ball bore min. - .001
(Tolerance + .000/ - .001)

B = Bearing O.D. - 2 X Min. lip thickness - Min. groove width
(Tolerance + .005/ - .000. See 46 for lip thickness (page 75) "S" and groove width "X".)

C = Adequate stakes for most applications are obtained with staking tools having 45° to 50° outside angles. When required, secondary staking tools having an outside angle of 60° to 70° can be used to obtain maximum retention and to reduce the amount of gap between the housing chamfer and the lip of the outer race.



50 *Staking Anvil Design*

A = Ball bore min. - .001
(Tolerance + .000/ - .001)

B = $\sqrt{\text{Ball spherical dia.}^2 - \text{Race width}^2 + .030}$
(Tolerance ± .010)

C = $\sqrt{\text{Body head dia.}^2 - \text{Body width}^2}$
(Tolerance ± .010)

D = $\dfrac{\text{Ball width max.} - \text{Race width min.}}{2} + .015$
(Tolerance ± .010)

Staking Tool Sets – Ordering Information

Hydraulic (Anvil) staking tools are available for all NHBB standard and special spherical bearings with staking grooves. Each set consists of one staking (flaring) tool and one staking anvil, both with guide pins installed. For spherical bearings in this catalog, order staking tool sets by the part numbers below.

For special (non-catalog) bearings or larger sizes, consult NHBB.

NHBB Part Number	Bore	Staking Tool Part Number
ADB( )V	3	STN 0003
ADB( )V(L)	4	STN 0004
HT( )V(L1)	5	STN 0005
AG( )V	6	STN 0006
AG( )V300	7	STN 0007
HSBG( )V	8	STN 0008
AHT( )V	9	STN 0009
AHET( )V	10	STN 0010
ABG( )V(L)	12	STN 0012
ABG( )V-501(L)	14	STN 0014
ADBL( )V		
HTL( )V(L1)		
ADW( )V	3	STW 0003
AW( )V	4	STW 0004
ADW( )V(L)	5	STW 0005
WHT( )V(L1)	6	STW 0006
ADWL( )V	7	STW 0007
ADWL( )V(L)	8	STW 0008
WHTL( )V(L1)	9	STW 0009
	10	STW 0010
	12	STW 0012
	14	STW 0014
	16	STW 0016
ADBY( )V	3	STY 0003
ASBY( )V	4	STY 0004
ADBY( )V(L)	5	STY 0005
	6	STY 0006
	7	STY 0007
	8	STY 0008
	9	STY 0009
	10	STY 0010
	12	STY 0012
	14	STY 0014
	16	STY 0016
	20	STY 0020
	24	STY 0024

EXAMPLES: NHBB P/N	STAKING TOOL
1. ADB10V	STN 0010
2. ABG8V (L)	STN 0008
3. ADW5V	STW 0005
4. ADBY6V	STY 0006

Load Ratings and Misalignment Capabilities

DEFINITIONS FOR ROD END AND SPHERICAL BEARING TERMINOLOGY

Radial Load
A load applied normal to the bearing bore axis (see 51A).

Axial Load
A load applied along the bearing bore axis (see 51B).

Static Load
The load to be supported while the bearing is stationary.

Dynamic Load
The load to be supported while the bearing is moving 52.

Static Radial Limit Load
That static load required to produce a specified permanent set in the bearing. It will vary for a given size as a function of configuration. It may also be pin limited, or may be limited as a function of body restraints as in the case of a rod end bearing. Structurally, it is the maximum load which the bearing can see once in its application without impairing its performance.

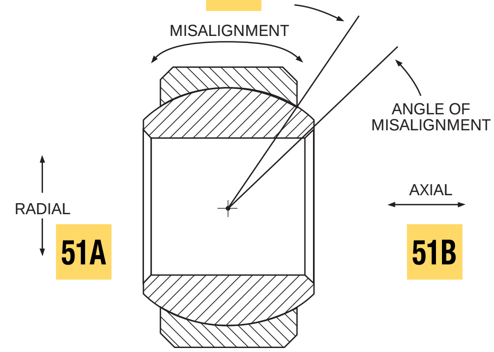
Static Radial Ultimate Load
That load which can be applied to a bearing without fracturing the ball, race or rod end eye. The ultimate load rating is usually, but not always, 1.5 times the limit load. Plastic deformation may occur.

Static Axial Limit Load
That load which can be applied to a bearing to produce a specified permanent set in the bearing structure. Structurally, it is the maximum load which the bearing can see once in its application without impairing its performance.

Static Axial Ultimate Load
That load which can be applied to a bearing without separating the ball from the race. The ultimate load rating is usually, but not always, 1.5 times the limit load.

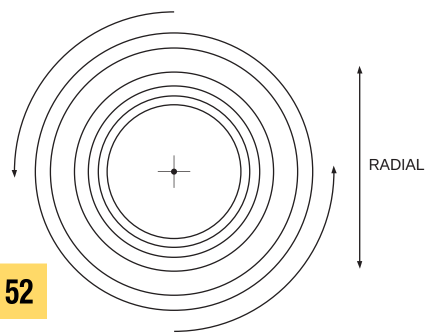
Axial Proof Load
That axial load which can be applied to a mounted spherical bearing without impairing the integrity of the bearing mounting or bearing performance. It is always less than the static axial limit load. Bearing movement after proof load is usually .003 or less. See the Bearing Installation and Retention section for further information beginning on page 75.

51C

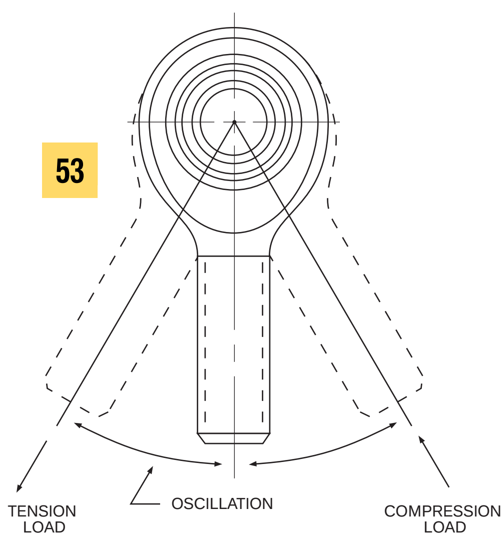


51A

51B



52



53

Rotation
Is the relative angular displacement between the ball and race that occurs within the plane perpendicular to the axis of the ball bore (see 53). The direction of rotation is about the axis of the ball bore.

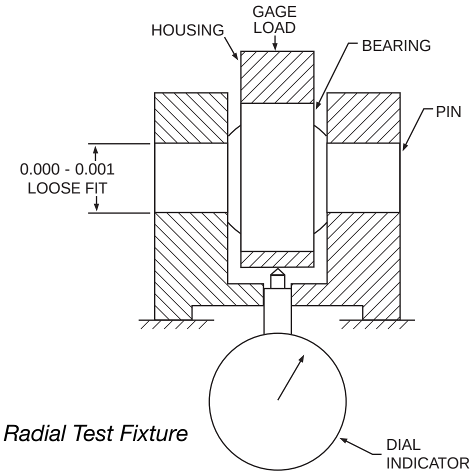
Misalignment
Is the relative angular displacement between the ball and race that occurs within any plane that coincides with the axis of the ball bore (see 51C). The direction of misalignment is about any axis perpendicular to the ball bore.

Oscillating Radial Load or Dynamic Load
The uni-directional load produces a specified maximum amount of wear when the bearing is oscillated at a specified frequency and amplitude. This rating is usually applied to self-lubricating bearings only. The dynamic capability of metal-to-metal bearings depends upon the degree and frequency of grease lubrication, and that of dry film lubricated bearings upon the characteristics of the specific dry film lubricant applied.

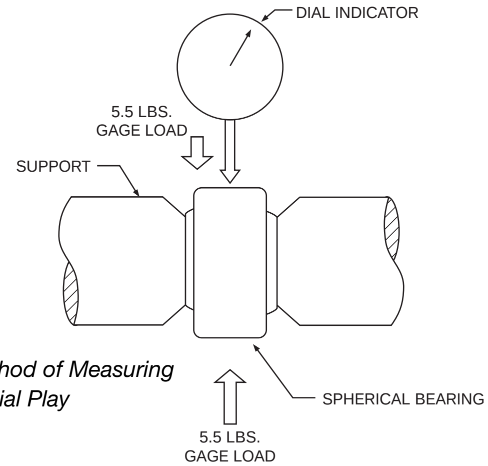
Radial Play
Radial play (or radial clearance) is the total movement between the ball and the race in both radial directions less shaft clearance (when applicable). Industry specifications have established the gaging load at ±5.5 lbs., and this is now considered as the industry standard (see 54 and 55). Unless otherwise specified, the industry wide standard for metal-to-metal spherical bearing and rod end radial clearance is “free-running to .002 max.” Radial play is sometimes referred to as “Diametral clearance.” The two terms are synonymous.

Axial Play
Axial play (or axial clearance) is the total movement between the ball and the race in both axial directions (see 56). The gaging load is again ±5.5 lbs. Axial play is a resultant, being a function of radial play, of ball diameter and race width. The ratio between radial and axial play varies with bearing geometry.

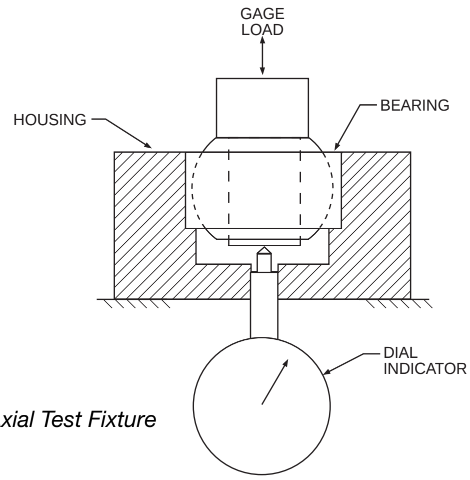
Fatigue Load of Rod Ends
Aerospace Standard series rod end bearings AS81935 must be capable of withstanding a minimum of 50,000 cycles of loading when tested as follows: The loading must be tension-tension with the maximum load equal to the fatigue loads listed on the NHBB drawing of the ADNE and ADN series rod end bearings. The minimum load must be equal to 10% of the fatigue loads.



54 *Radial Test Fixture*



55 *Method of Measuring Radial Play*



56 *Axial Test Fixture*

Load Ratings and Misalignment Capabilities

LOAD RATINGS

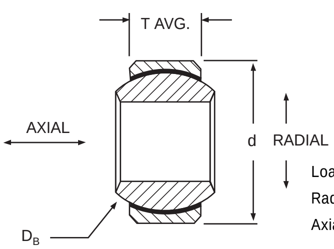
The load rating of a bearing is determined by the dimensions and strength of its weakest component. External factors, such as mounting components, pins, bolts, and housings are not considered part of a bearing when load ratings are investigated but should be considered separately.

SPHERICAL BEARING LOAD RATINGS

The weakest part, or load-limiting area, of a spherical bearing is its race. For this reason, formulas have been developed that use the race to calculate static load ratings based on size and material strength. The static load rating formulas for self-lubricating and metal-to-metal spherical bearings are shown in 57 and 58. These formulas will yield approximate ratings, which should be used as ballpark numbers for bearing design.

The allowable radial stress values given in the tables were determined from the ultimate tensile strength specifications for various race materials. Allowable axial stress values were derived from material yield strengths.

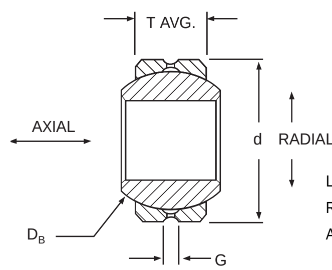
Allowable Stress - TEFLON®-Lined Bearings



Load = Projected Area x Allowable Stress
Radial Projected Area = $(.91T)(D_B)$
Axial Projected Area = $.636T^2 - .05D_B$

57 *Static Load Rating Formulas for Self-Lubricating Spherical Bearings*

Allowable Stress - Metal-to-Metal Bearings



Load = Projected Area x Allowable Stress
Radial Projected Area = $(.83T - .92G)(D_B)$
Axial Projected Area = $.636T^2$

58 *Static Load Rating Formulas for Metal-to-Metal Spherical Bearings*

Allowable Stress TEFLON® Lined Bearings (psi)

Race Material	Radial Ultimate	Radial Limit	Axial Ultimate	Axial Limit
17-4PH, R_C28 MIN	112500	75000	67500	45000
ALUM 2024-T351	60000	40000	36000	24000

Standard Groove Sizes

Bearing Size Bore Code	G Width
3 & 4	.062
5 - 10	.078
12 - 16	.094
20 & above	.109

Allowable Stress Metal-to-Metal Bearings (psi)

Race Material	Radial Ultimate	Radial Limit	Axial Ultimate	Axial Limit
17-4PH, R_C32-36	150000	100000	125000	83000
4130 R_C32-36	150000	100000	125000	83000
A286 (AMS 5737)	140000	93000	95000	63000
AMPCO® 15 Bronze	75000	50000	45000	30000

AMPCO® is a registered trademark of AMPCO Metal Inc.

TEFLON® is a Du Pont registered trademark

ROD END BEARING LOAD RATING

Rod end bearing load ratings can be generated only after carefully determining the load restrictions that each element of the rod end bearing imposes on the entire unit. In order to generate a frame of reference, consider the rod end bearing as a clock face, with the shank pointing down to the 6 o'clock position. The limiting factors in rating a rod end bearing are as follows:

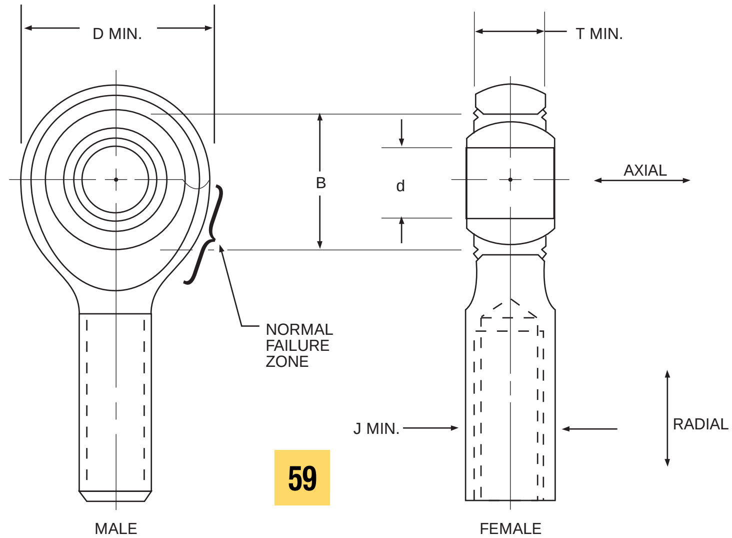
1. The double shear capability of the bolt passing through the ball bore.
2. The bearing capability, a function of race material or self-lubricating liner system.
3. The rod end eye or hoop tension stress in the 3 o'clock-9 o'clock position.
4. The shank stress area, as a function of male or female rod end configuration.
5. The stress in the transition area between the threaded shank transition diameter and the rod end eye or hoop.

Most rod ends will fail under tension loading in about the 4 o'clock-8 o'clock portion of the eye or hoop. The Net Tension Area (NTA) can be found as follows:

$$\text{NTA} = .008726 \times D^2 \times \text{Sin}^{-1}\left(\frac{T}{D}\right) + \frac{T}{2}\sqrt{D^2 - T^2} - B\times T$$

Solve the $\text{Sin}^{-1}\left(\frac{T}{D}\right)$ in units of degrees, not radians.

This simple rod end load rating formula does not take into consideration such variables as special body shapes, thin race sections, hardness variation, lubrication holes, grooves, and hoop tension, which could significantly affect the load rating. Contact NHBB Applications Engineering for assistance in determining the load rating for specially designed Rod Ends and Sphericals.



The shank stress area (SSA) is a function of being either male or female, as follows:

For the male:

$$\text{SSA} = (\text{minor thread diameter})^2 \frac{\pi}{4}$$

For the female:

$$\text{SSA} = [J^2 - (\text{major thread diameter})^2] \frac{\pi}{4}$$

Pin shear stress (PSS) for load "F" is as follows:

$$\text{PSS} = \frac{2F}{\pi d^2}$$

The axial load capability of a rod end is a function of the following:

1. The retention method used to mount the bearing in the rod end eye. See the Bearing Installation and Retention section for further information beginning on page 71.
2. The axial load capability of the bearing element.
3. The bending moment, if any, placed on the rod end.

Load Ratings and Misalignment Capabilities

PV Factor

While not a type of loading, the PV factor is very useful in comparing and predicting test results on high speed-low load applications such as helicopter conditions.

PV is the product of the stress (psi) and the velocity (fpm) applied to a bearing. Caution must be advised when considering extreme values of psi and fpm. The extreme must be considered individually, as well as together.

Because the PV factor is derived from the geometry and operating conditions of a bearing, it serves as a common denominator in comparing or predicting test results. For this reason PV values are included in the wear curves of 22 and 23 (page 61) in the Self-Lubricating TEFLON® Liner Systems section, page 60.

The formula for determining the PV value for a spherical bearing is as follows:
PV = (∞) (cpm) (D_B) (psi) (.00073)

Where:
∞ = total angular travel in degrees per cycle
(ie. ± 25°=100° total travel)

cpm = cycles per minute (oscillation rate)
D_B = ball diameter
psi = bearing stress

Dynamic Oscillating Radial Load

The dynamic oscillating radial load ratings given in this catalog for ADB, ADW, ADBY, ADB-N, ADW-N, ADBL and ADWL series self-lubricating spherical bearings are based on testing in accordance with AS81820. For conditions other than those specified by AS81820 contact NHBB Applications Engineering.

NHBB TESTING CAPABILITIES

Mechanical Test Equipment

NHBB has a variety of equipment to test spherical and rod end bearings under diverse conditions. NHBB performance data exceeds military and individual manufacturers' design requirements. Maximum capabilities of NHBB testing machines are shown in table 9.

Polymer Test Equipment

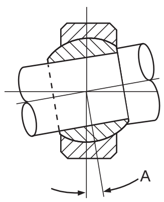
NHBB has the following thermal analysis (TA) equipment to support and control the quality of composites/polymers through analytical techniques that measure the physical and mechanical properties as a function of temperature and time:

1. Differential Scanning Calorimeter (DSC)
2. Thermogravimetric Analyzer (TGA)
3. Dynamic Mechanical Analyzer (DMA)
4. Thermomechanical Analyzer (TMA)
5. Thermo-Oxidative Stability Test (TOS)
6. Acid Digestion System
7. Fourier Transform Infrared Spectroscopy (FTIR)

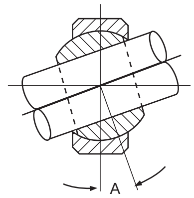
TABLE 9: NHBB Testing Capabilities

	Force
Material Testing (Universal Testing Machine)	110,000 Lbs.
Static Compression/Tension	200,000 Lbs.
Low Speed Oscillation (up to 50 cpm)	
Uni-directional Loading	
(1 machine, 2 station) (700°F)	20,000 Lbs.
(1 machine, 2 station) (700°F)	70,000 Lbs.
Moderate To High Speed Oscillation	
Uni-directional Load (room temp.)	
(1 machine, 2 station) (1000 cpm)	1,000 Lbs.
(1 machine, 2 station) (1500 cpm)	1,000 Lbs.
(1 machine, 6 station) (200-600 cpm)	8,000 Lbs.
Low Speed Oscillation	
Reversing or Alternating Load (room temp.)	
(1 machine, 2 station) (up to 50 cpm)	40,000 Lbs.
High Speed, Oscillation	
Reversing and Alternating Load (room temp.)	
(2 machines, 1 station each) (400 cpm)	2,500 Lbs.
Airframe Track Roller	
Testing Machine (roller against flat plate)	60,000 Lbs.

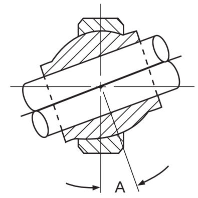
FORMULA FOR DETERMINING MISALIGNMENT OF ROD END & SPHERICAL BEARINGS



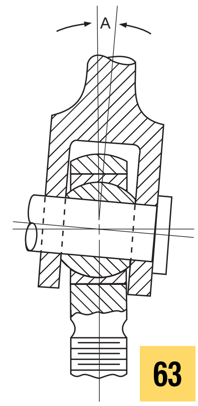
60 $A = \sin^{-1}\frac{W}{E} - \sin^{-1}\frac{T}{E}$



61 $A = \cos^{-1}\frac{B}{E} - \sin^{-1}\frac{T}{E}$



62 $A = \cos^{-1}\frac{S}{E} - \sin^{-1}\frac{T}{E}$



63 $A = \sin^{-1}\frac{W}{D} - \sin^{-1}\frac{T}{D}$

60 Standard Method
Most standard rod end and spherical bearing misalignment angles specified in NHBB catalogs are based on this method.

61 Design Reference
This method may be used as design reference for installation purposes, but should not be used as a functioning misalignment under load.

62 High Misalignment Series Method
(Neck balls only)

63 Rod End Clevis Misalignment

HOW NHBB SPECIFIES CATALOG BEARING AND ROD END MISALIGNMENT

The misalignment angle of a rod end or spherical bearing refers to the angle between the ball centerline and the outer member centerline when the ball is misaligned to the extreme position allowed by the clevis or shaft design, as applicable.

NOTE: Since angle "A" applies equally on both sides of the centerline, it follows that total misalignment of the bearing is double the value obtained for "A".

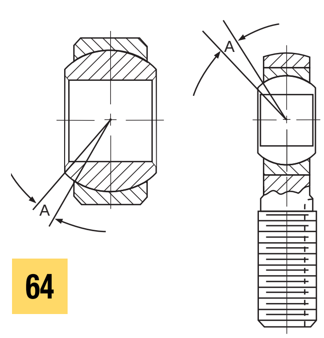
60 through **63** illustrate varying types of bearing misalignment and a formula for calculating each

Where:

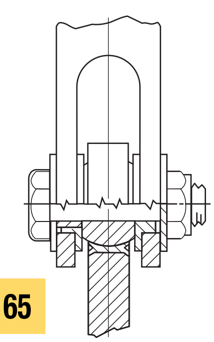
- A = angle of misalignment
- D = head diameter (rod end)
- S = shoulder diameter (neck ball)
- W = width of ball
- B = bore of ball
- E = ball spherical diameter
- T = housing (race) width

64 illustrates how misalignment angles for standard ball spherical bearings and rod ends are represented in NHBB catalogs. The misalignment angle is calculated per **60** formula. Neck ball (high misalignment) bearings and rod ends are represented in the same manner, but are calculated per **62** formula.

NHBB prefers not to use rod end clevis misalignment for the following reason. The rod end clevis misalignment formula presupposes a clevis configuration as shown in **63** in which the clevis slot and ball faces are of equal width and in direct contact. In aircraft applications the configuration shown in **65** is more typical than that of **63**. As pictured in **65**, the clevis slot is wider than the ball to permit installation of flanged bushings and/or spacers. This results in a higher but more variable misalignment capability, and the angle of misalignment becomes a function of the user's bushing flange or spacer diameter instead of the fixed rod end head diameter.



64



65

Typical Rod End/Clevis Installation

Bearing Selection Factors

ROLLING ELEMENT BEARINGS

1. Low load – high speed bearings should usually be antifriction rolling element bearings, except for lubricated sleeve bearings under very low load and constant rotation rather than oscillatory.

METAL-TO-METAL SPHERICALS AND ROD ENDS

1. These are recommended for most joints which are primarily static, need only periodic lubrication and require a minimum of permanent set under high loads.
2. They are also recommended for some moving applications such as landing gears, where most of the motion occurs under low loading, but where the bearing is nearly static under the high impact loads when the gear is locked.
3. Hardened 52100 or 440C balls with heat-treated outer races of either chrome-moly, alloy steel, or precipitation hardened stainless steel are recommended when loads are very high in relation to the available envelope.
4. Aluminum bronze races are less apt to seize or gall under vibratory conditions or if lubrication conditions are minimal, providing the required maximum load capacity is not too great (the load capacity is usually about 1/2 that of the heat treated steel race bearings). In general, materials containing an appreciable amount of copper are good bearing materials.
5. A beryllium-copper ball operating against a heat treated stainless steel race is an excellent combination for dynamic oscillating conditions under very high loads, providing adequate lubrication is present. This requires either an automatic lube system or frequent maintenance provisions.
6. Metal-to-metal spherical bearings and rod ends are often fitted with aluminum-nickel-bronze sleeves in the ball bore, with lubrication provisions, so that the relative motion and resulting wear take place between the shaft and the sleeve, with only misalignment taking place at the ball spherical surface. This allows replacement of the sleeves without replacement of the expensive portion of the bearing.
7. For extremely high load carrying capacity in a limited envelope, spherical bearings with both ball and swaged outer race made of heat-treated maraging steel of 300ksi tensile strength are sometimes used, and can be formed by a special processing procedure.
8. Special types of metal-to-metal sphericals such as loader slot bearings, fractured outer race bearings, or snap-assembled bearings (page 54 and 55) are used for some applications where very hard inner and outer races are desirable for wear and strength reasons, but require special geometry (a relatively narrow ball).
9. Spherical and rod end bearings for both high temperature and cryogenic applications are available using special materials such as the Inconels®, Stellite® and other cobalt alloys, A-286, Rene 41® and others. Special dry film lubricants or silverplating in the race I.D. are sometimes used in these bearings.
10. Two-piece swage-coined rod ends (page 56 11) should be used primarily for applications which require high load carrying capacity in a basically static condition with some misalignment capability, since the rod end body cross-sectional area available to carry tension is greater than with a 3-piece rod end, the insert outer race area having been replaced by body area. However, ball-to-race conformity is usually poor, hence rapid wear and/or fretting and galling can occur under dynamic or oscillating loading.
11. Two-piece Mohawk rod ends (page 56 12) for commercial use or non-critical applications are available. The Mohawk design has better ball-to-race conformity than the 2-piece swage-coined design and can be used in dynamic applications but only at relatively low loads.
12. Most metal-to-metal bearings are designed with a small radial clearance to facilitate assembly with the mating part and assure that the bearing does not bind up if assembled into its housing with an interference fit. However, they may be made with a preload, providing there is a fairly large tolerance on this preload, for applications where absolutely no play can be tolerated.

SELF-LUBRICATING TEFLON® TYPE LINED SLEEVES, SPHERICALS AND ROD END BEARINGS

1. These consist of a relatively thin composite liner containing TEFLON® (polytetrafluoroethylene) as a lubricant and bonded to a metallic backing material.
2. They are recommended for applications requiring considerable oscillation and misalignment under very heavy loads and where frequent lubrication is undesirable or impossible. To gain full life from these bearings, a wear of about .005 from the liner surface must be tolerable.
3. This type is especially suited for hydraulic actuators, many aircraft landing gear door applications, vibration damping devices, hinge and actuation link bearings for control surfaces, sliding guide bearings for flaps and leading edge slats, and power control system drive linkage bearings, along with many others not mentioned.

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CHECK LIST OF FACTORS TO BE CONSIDERED BY THE APPLICATIONS ENGINEER IN SELECTION OR DESIGN OF SPHERICAL BEARINGS

1. Bearing envelope requirements and/or restrictions
2. Weight limitations
3. Whether used in a static or dynamic application
4. For sleeve bearings, whether the shaft is oscillating or rotating continuously in one direction or both directions
5. Loading:
   (A) Maximum static radial or axial
   (B) Maximum and normal dynamic
   (C) Reversing or uni-directional
   (D) Shock or vibratory conditions
6. Relative movement
   (A) Angle of oscillation
   (B) Velocity in terms of rpm or cycles per minute
   (C) Required angle of misalignment
   (D) Load-velocity phase relationship
7. Allowable wear
8. Life requirement, preferably in number of cycles
9. Operating temperature range
10. Preload or clearance requirements
11. Lubrication methods, accessibility, and frequency of maintenance available
12. Environmental conditions including exposure to dirt, moisture and other contaminants
13. Installation requirements, including staking methods, housing and shaft fits, etc.

For additional considerations, please consult NHBB Applications Engineering staff.

Specifications Compliance

NHBB complies with many government specifications in the manufacture of its products. The most common of these specifications are listed in table 10.

NHBB also complies with most of the major aerospace manufacturers specifications regarding procedures such as plating, testing, and heat treating.

TABLE 10: Specifications Compliance

Plating, Coating and Surface Treatment	
Alodine	* SAE AMS-C-5541
Anodize (Chromic)	SAE AMS-A-8625 Type I Class 1
Anodize (Sulphuric)	* SAE AMS-A-8625 Type II Class 1
Anodize (Hard)	* SAE AMS-A-8625 Type III Class 1
Cadmium	* SAE AMS-QQ-P-416 Type I Class 3 (Races)
Cadmium (Supplementary Chromate Treatment)	* SAE AMS-QQ-P-416 Type II Class 2 (Bodies)
Cadmium (Vacuum Deposited)	SAE AMS-C-8837
Chromium	* SAE AMS-QQ-C-320 Class 2 (.0002" to .0005" thickness)
Chromium	AMS 2406
Nickel (Electroless)	SAE AMS-C-26074
Nickel (Electrodeposited)	SAE AMS-QQ-N-290
Passivate	AMS QQ-P-35 or ASTM-A 967
Silver	AMS 2410
Zinc (Chromate Primer)	TT-P-1757
Heat Treatment	
Steel, Alloy and Stainless	SAE-AMS-H-6875
Aluminum	SAE-AMS-H-6088
Beryllium Copper	SAE-AMS-H-7199
Titanium	AS-H-81200
Non-Destructive Testing	
Fluorescent Penetrant	ASTM-E-1417
Magnetic Particle	ASTM-E-1444
Ultrasonic	SAE AMS STD 2154
Quality Control	
Quality Systems	ISO 9001
Aerospace Quality Systems	AS 9000
Sampling Procedures and Tables for Inspection by Attributes	ANSI/ASQE Z 1.4
Machining	
Threads, Rolled or Turned	AS 8879 and MIL-S-7742
Marking and Packaging	
Military Packaging	MIL-STD-129
Marking	MIL-STD-130
Preservation	MIL-DTL-197

*NHBB Standards

Inch/Metric Conversion Table

TABLE 11: Inch/Metric Conversion Table

Fraction	Inch Decimal	mm
	0.00004	0.001
	0.00039	0.01
	0.0010	0.025
	0.0020	0.051
	0.0030	0.0762
	0.00394	0.1
	0.0050	0.1270
	0.00984	0.25
	0.0100	0.254
1/64	0.0156	0.396
1/32	0.0312	0.793
	0.03937	1.
3/64	0.0469	1.191
	0.0591	1.5
1/16	0.0625	1.5875
5/64	0.0781	1.984
	0.0787	2.
3/32	0.0937	2.381
	0.0984	2.5
	0.1000	2.54
7/64	0.1094	2.778
	0.1181	3.
1/8	0.1250	3.175
	0.1378	3.5
9/64	0.1406	3.571
5/32	0.1562	3.968
	0.1575	4.
11/64	0.1719	4.366
	0.1772	4.5
3/16	0.1875	4.7625
	0.1969	5.
13/64	0.2031	5.159
7/32	0.2187	5.556
15/64	0.2344	5.953
	0.2362	6.
1/4	0.2500	6.35

Fraction	Inch Decimal	mm
17/64	0.2656	6.746
	0.2756	7.
9/32	0.2812	7.1437
19/64	0.2969	7.5406
5/16	0.3125	7.9375
	0.3150	8.
21/64	0.3281	8.334
11/32	0.3437	8.731
	0.3543	9.
23/64	0.3594	9.1281
3/8	0.3750	9.525
25/64	0.3906	9.9219
	0.3937	10.
13/32	0.4062	10.318
27/64	0.4219	10.716
	0.4331	11.
7/16	0.4375	11.1125
29/64	0.4531	11.509
15/32	0.4687	11.906
	0.4724	12.
31/64	0.4844	12.303
1/2	0.5000	12.7
	0.5118	13.
33/64	0.5156	13.096
17/32	0.5312	13.493
35/64	0.5469	13.891
	0.5512	14.
9/16	0.5625	14.2875
37/64	0.5781	14.684
	0.5906	15.
19/32	0.5937	15.081
39/64	0.6094	15.478
5/8	0.6250	15.875
	0.6299	16.
41/64	0.6406	16.271
21/32	0.6562	16.668

Fraction	Inch Decimal	mm
	0.6693	17.
43/64	0.6719	17.066
11/16	0.6875	17.4625
45/64	0.7031	17.859
	0.7086	18.
23/32	0.7187	18.256
47/64	0.7344	18.653
	0.7480	19.
3/4	0.7500	19.05
49/64	0.7656	19.446
25/32	0.7812	19.843
	0.7874	20.
51/64	0.7969	20.240
13/16	0.8125	20.6375
	0.8268	21.
53/64	0.8281	21.034
27/32	0.8437	21.431
55/64	0.8594	21.828
	0.8661	22.
7/8	0.8750	22.225
57/64	0.8906	22.621
	0.9055	23.
29/32	0.9062	23.018
59/64	0.9219	23.416
15/16	0.9375	23.8125
	0.9449	24.
61/64	0.9531	24.209
31/32	0.9687	24.606
	0.9843	25.
63/64	0.9844	25.003
1	1.0000	25.4
	1.0630	27.
	1.1024	28.
	1.1811	30.
1 1/4	1.2500	31.75
	1.2992	33.

Fraction	Inch Decimal	mm
	1.3780	35.
	1.4173	36.
1 1/2	1.5000	38.1
	1.5354	39.
	1.5748	40.
	1.6535	42.
1 3/4	1.7500	44.45
	1.7717	45.
	1.8898	48.
	1.9685	50.
2	2.000	50.8
	2.0472	52.
	2.1654	55.
	2.2047	56.
2 1/4	2.2500	57.15
	2.3622	60.
2 1/2	2.5000	63.5
	2.5197	64.
2 3/4	2.7500	69.85
	2.8346	72.
	2.9528	75.
3	3.0000	76.2
	3.1496	80.
3 1/4	3.2500	82.55
3 1/2	3.5000	88.9
	3.5433	90.
3 3/4	3.7500	95.25
	3.9370	100.
4	4.0000	101.6
4 1/4	4.2500	107.95
	4.3307	110.
4 1/2	4.5000	114.3
	4.7244	120.
4 3/4	4.7500	120.65
5	5.0000	127.
5 1/2	5.5000	139.7

TABLE 12: Conversion Factors for The U.S. Customary System (USCS) and The International System of Units (SI)

	USCS to SI		SI to USCS	
Length	1 in	= 25.4 mm	1 mm	= 0.0393701 in
Surface Texture	1 µ in	= 0.0254 um	1 µm	= 39.3701 µ in
Area	1 in^2	= 645.16 mm^2	1 mm^2	= 0.00155 in^2
Volume	1 in^3	= 16.3871 cm^3	1 cm^3	= 0.0610237 in^3
Mass	1 lb	= 0.45359 kg	1 kg	= 2.20462 lb
	1 oz	= 28.3495 g	1 g	= 0.035274 oz
Density	1 lb/in^3	= 27.6799 g/cm^3	1 g/cm^3	= 0.036 lb/in^3
Force	1 lbf	= 4.44822 N	1 N	= 0.224809 lbf
Moment of Force (Torque)	1 lbf in	= 0.112985 Nm	1 Nm	= 8.85 lbf in
Stress	1 lbf/in^2	= 0.00689 N/mm^2	1 N/mm^2	= 145.038 lbf/in^2

Fahrenheit/Celsius Conversion Table

The numbers in center column refer to the temperatures either in Celsius or Fahrenheit which need conversion to the other scale. When converting from Fahrenheit to Celsius, the equivalent temperature will be found to the left of the center column. If converting from Celsius to Fahrenheit, the answer will be found to the right.

TABLE 13: Fahrenheit/Celsius Conversion Table

°C	°C/°F	°F
-79	-110	-166
-73	-100	-148
-68	-90	-130
-62	-80	-112
-57	-70	-94
-51	-60	-76
-45	-50	-58
-40	-40	-40
-34	-30	-22
-29	-20	-4
-23	-10	14
-17.7	0	32
-17.2	1	33.8
-16.6	2	35.6
-16.1	3	37.4
-15.5	4	39.2
-15.0	5	41.0
-14.4	6	42.8
-13.9	7	44.6
-13.3	8	46.4
-12.7	9	48.2
-12.2	10	50.0
-6.6	20	68.0
-1.1	30	86.0
4.4	40	104.0
9.9	50	122.0
15.6	60	140.0
21.0	70	158.0
26.8	80	176.0
32.1	90	194.0
37.7	100	212
43	110	230
49	120	248
54	130	266
60	140	284
65	150	302
71	160	320
76	170	338
83	180	356
88	190	374
93	200	392
99	210	410
104	220	428
110	230	446
115	240	464
121	250	482
127	260	500
132	270	518
138	280	536
143	290	554
149	300	572
154	310	590
160	320	608
165	330	626
171	340	644
177	350	662
182	360	680
188	370	698
193	380	716
199	390	734
204	400	752
210	410	770
215	420	788
221	430	806
226	440	824
232	450	842
238	460	860
243	470	878
249	480	896
254	490	914
260	500	932
265	510	950
271	520	968
276	530	986
282	540	1004
288	550	1022
293	560	1040
299	570	1058
304	580	1076
310	590	1094
315	600	1112
321	610	1130
326	620	1148
332	630	1166
338	640	1184
343	650	1202
349	660	1220
354	670	1238
360	680	1256
365	690	1274
371	700	1292
376	710	1310
382	720	1328
387	730	1346
393	740	1364
565	1050	1922
571	1060	1940
576	1070	1958
582	1080	1976
587	1090	1994
593	1100	2012
598	1110	2030
604	1120	2048
609	1130	2066
615	1140	2084
620	1150	2102
626	1160	2120
631	1170	2138
637	1180	2156
642	1190	2174
648	1200	2192
653	1210	2210
659	1220	2228
664	1230	2246
670	1240	2264
675	1250	2282
681	1260	2300
686	1270	2318
692	1280	2336
697	1290	2354