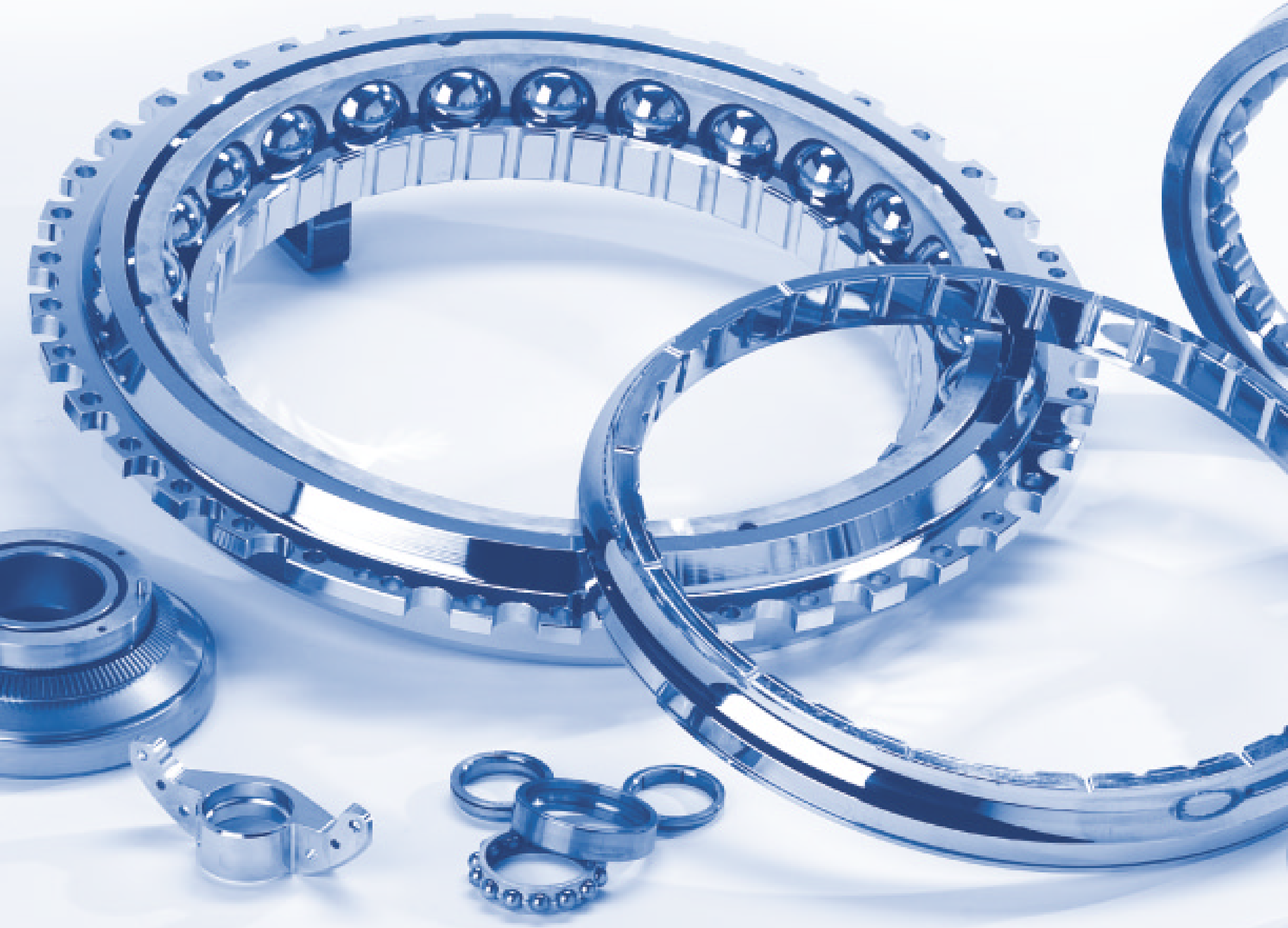
TIMKEN

aerospace

Design Guide

for Precision Metric Ball and Cylindrical Roller Bearings



A TIMKEN COMPANY SUBSIDIARY

precision

innovative design enhances performance

The Timken Company has the largest aerospace product offering in the world. Our success is built upon the foundations of research, design and manufacturing excellence. Aerospace customers around the world rely on Timken for precision, performance and technical services that keep aircraft running smoothly.

At Timken research facilities in the United States, Europe and Asia, engineers develop and test aerospace bearings and components in the conditions in which they will operate. Our approach to product development governs our manufacturing direction and ensures that Timken products will operate consistently and accurately in a host of aerospace applications.

One of The Timken Company's competitive advantages is its knowledge and experience in steel making. As the only aerospace bearing manufacturer that develops and produces remelted aerospace steel, Timken understands how slight variations in metallurgy can affect overall performance.

Timken is the world's largest producer of bearing steel.

design

customer-driven solutions

Our products – used in aircraft propulsion engines and APU's, gear boxes, helicopter transmissions, accessory subsystems, airframes, landing wheels and instrumentation – continue to evolve to meet today's high-performance requirements. Timken engineers experiment with advanced materials, engineered surfaces and modified internal geometry to identify the most effective options for customers.

Collaboration has led to the development of enhanced products that are helping customers produce new models and better maintain existing aircraft. Timken regularly consults, designs prototypes and manufactures ball bearings and cylindrical, spherical, needle and tapered roller bearings. While most production quantities are made to order, many prototypes are available with short lead times and are made from the newest materials to meet customer demands.

Our engineers also offer advanced technical services to identify and solve performance issues within aerospace operations, including:

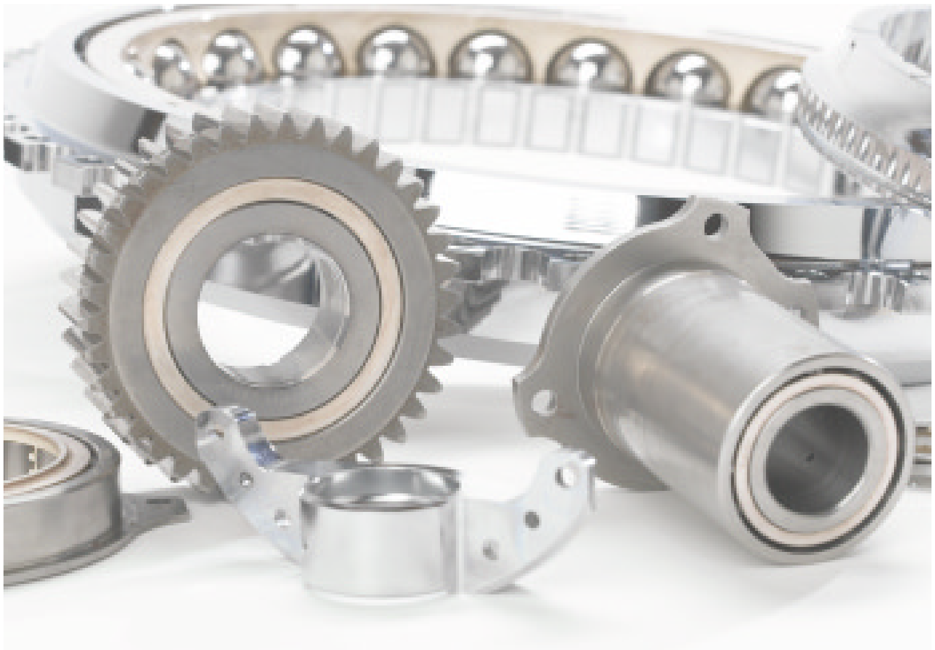
- Application testing
- Material development and testing
- Metrology and measurement
- Advanced modeling and simulation
- Tribology and lubrication analysis
- Metallurgical services.

technology

your value-added resource

Throughout our global operations, which include 90 manufacturing facilities and 10 technical centers, Timken maintains quality standards that exceed industry norms. Our aerospace facilities have led the organization in the implementation of Lean Manufacturing and Six Sigma techniques that heighten quality and streamline production. Associates embrace continuous improvement initiatives and regularly offer suggestions that enhance quality, reduce waste and speed products to customers.

Our goal is to enhance our already strong reputation as an innovative aerospace leader and a responsive resource for customers around the world. We look forward to helping your company enhance its performance with Timken products and services.



advanced products and services

The Timken Company offers an array of products and services to the aerospace industry. You can learn more by requesting information from your Timken representative. Below are examples of literature available to you:

AEROSPACE CAPABILITIES

Aerospace Capabilities Brochure
Timken has the largest aerospace product offering in the world. We offer in-depth research and technologically advanced products to customers around the world. The capabilities brochure is available in English, French, German, Italian and Chinese (Order #5910).

Aerospace Services
Timken offers comprehensive services for bearings used in aircraft engine mainshafts, gearboxes and accessories. Timken aerospace services can restore bearings to like-new condition through cost-effective remanufacturing processes. To learn more, request the Aerospace Services sheet (Order #5572) in English, French, German or Italian.

Innovation in Aerospace
As a technology leader in the aerospace industry, Timken collaborates with customers to engineer value-added solutions to meet application requirements. The company maintains global research, development and testing facilities for this purpose. This brochure is available in English, French, German, Italian and Chinese (Order #5952).

Aerospace Products
Timken offers a broad range of ball bearings and cylindrical, spherical, needle and tapered roller bearings specifically for aerospace applications. This sell sheet offers descriptions on all of the bearing products and services available. This brochure is available in English, French, German, Italian and Chinese (Order #5951).

Aerospace Landing Wheel Bearings
Aerospace landing wheel bearings offer reliability and performance – at a cost-effective price. Timken's range includes Code 629 bearings, made specifically for landing wheels, and bearings with engineered surfaces to decrease rib/roller end scuffing. (Order #5953)

TECHNICAL SERVICES

Timken Technical Services
Timken offers a wide range of technical services to help customers solve issues including gauging, metrology and lubrication. Timken offers its expertise and experience in technical areas to customers around the world. Technical Services (Order #1403) highlights how Timken can help your company.

Tribology & Lubrication Analysis
The tribology and lubrication sell sheet (Order #1411) describes Timken's service offerings in analyzing friction. Timken can evaluate your lubricant properties as well as perform rolling-contact fatigue tests and rolling-element performance evaluations.

Metrology & Measurement Services
Information regarding metrology and measurement services offered by Timken is included in this sell sheet (Order #1408), which highlights the company's array of measurement capabilities. Measurement services are tailored to meet your specific metrology requirements.

Automated Bearing Setting & Gauging
Timken Technical Services can help your company obtain bearing lateral settings for your applications to achieve optimal system performance. The Automated Bearing Setting and Gauging (Order #1405) sell sheet provides more information.

Application Testing
With a broad range of testing capabilities, Timken is able to develop specific parameters to measure performance in a variety of conditions. We can evaluate your bearing systems, seal performance, driveline systems, driveline components and much more. Timken's Application Testing (Order #1404) shares our experience in this field.

Metallurgical Services
As a bearing and steel manufacturer, Timken has the ability to provide value-added metallurgical services, including supplying of experimental materials, conducting mechanical testing, analyzing material and failures and consulting regarding heat treating materials and thermal treatment processes. The Metallurgical Services sell sheet (Order #1435) provides details.

TECHNICAL CAPABILITIES

Engineered Surfaces
Work with Timken engineers to find out how engineered surfaces can improve bearing and component performance and life. Engineered surfaces improve the wear, fatigue and frictional performance on precision components. Learn more through this sales sheet. (Order #5673)

Tapered Roller Bearing Selection Guide
The interactive Tapered Roller Bearing Selection Guide will help you locate the most appropriate Timken® bearing for your application. Users can vary size and performance data to predict bearing life and save application data for future reference. Translations are available on the CD in French, German, English, Italian, Spanish and Swedish (Order #5667).

Timken Aerospace Precision Metric Ball and Cylindrical Roller Bearings

This is a design guide for aircraft gas turbine, transmission and accessory bearing applications, as well as other applications requiring the highest precision and quality.

- 10 mm bore to 300 mm outside diameter (O.D.)
- 000,100,200,300,400 Series
- ABEC/RBEC Classes 1,3,5,7,9
- Standard and custom designs

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Bearing Design

From applications to specification – a logical approach.

This design guide is prepared to help you choose the optimum bearing for your specific application. Too often bearings are selected in a haphazard manner resulting in poor performance, unexpected problems and early failures. To help you avoid these and other issues, Timken has developed a four-step procedure that summarizes all key concepts that should be considered when developing a specification. The interrelationship of these concepts covers the entire field of bearing engineering.

Many answers are provided in this design guide but many others require the assistance of an experienced bearing engineer. In unusual or state-of-the-art applications, the solution is a carefully monitored test program. Bearing chassis sizes and capabilities listed in this guide can be modified and optimized to meet specific requirements including special features.

■ STEP 1 – Determine Performance Requirements

Simply stated, there are two basic performance requirements, which if adequately defined, control everything that a bearing must do within an application. Every bearing must:

1) Provide a defined level of rotational freedom.
2) Provide a defined level of position control (from basic free movement to high-frequency movement or noise).

It is important to determine the actual limits of these requirements since bearing life is nothing more than how long the bearing is statistically expected to operate within these limits. Of course, limits vary significantly from one type of application to another, so thorough definitions must be established.

■ STEP 2 – Determine Application Parameters

Performance is governed by a number of application parameters. Although only a portion may be significant in any given application, meticulous review of each will ensure that nothing important has been overlooked.

Performance application parameters can be categorized four ways:

1) Physical Parameters
2) Operational Parameters
3) Environmental Parameters
4) Economic Parameters

In any given application, many of these are fixed while others are variable and can be modified or controlled when necessary. Final selection is always a series of compromises.

Physical Parameters

These include:

1) Space available for the bearing or bearing systems.
2) Allowable weight for the bearing or bearing systems.
3) The shape, material and tolerance control of the housing and shaft.
4) Combining features onto the bearing to simplify mounting structures.
5) Operational temperature.

The more space and weight that can be allowed to the bearing system, the more sophisticated and reliable it will be. However, added weight may be an expensive luxury unless absolutely necessary, as would be true of supplementary lubrication systems for high-speed turbine and accessory bearings. The housing and shaft design has a significant impact in ultimate bearing performance. Ideally, the shaft will be a solid, perfectly round cylinder made from material absolutely compatible with the thermal coefficient of expansion of the bearing. The housing cross section should be uniform, giving full hoop support for the bearing. Both housing and shaft should have precision-machined shoulders or seats to ensure the bearing races are perfectly aligned.

But many compromises occur in actual applications. Timken's extensive bearing design experience can prove a valuable aid to a designer facing critical physical restrictions.

Operational Parameters

1) **Speed** governs the number of load cycles the bearing experiences and is therefore related to life. Speed in terms of a relative guide parameter, called "dn" (inner ring bore in mm x RPM) also influences many other aspects of bearing operations. Included are lubricant flow patterns and film thickness, centrifugal rolling-element loads, skidding and excessive heat generation and removal method.
2) **Loads** can be broken down in three directions: radial, axial and moment. These in turn can be applied as constant, variable, vibratory or impact loading. The combination must be carefully considered for optimum life and performance.

Environmental Parameters

The environment is a fixed condition of the end product. However, the decision to protect or expose the bearing to the environment is a design option. Temperature, either ambient or internally generated, is a major consideration. The nature of the surrounding media, liquid or gas (for both materials and lubrication), may establish the need for seals, special corrosion protection or supplemental lubrication. Any special environments such as magnetic fields or radiation also should be considered for their design impact.

Economic Parameters

Total system cost should be carefully weighed, not just the cost of the bearing, but the total cost of bearing, mounting and replacement if the bearing does not operate satisfactorily. Special designs, while more expensive initially, may be most cost effective, since normally they would result in simplified mounting structures.

■ STEP 3 – Evaluate Potential Failure Modes

Failure in a particular application occurs when there is sufficient performance degradation so that the bearing no longer meets the original requirements. There are nine commonly identified primary failure modes:

1) Classic fatigue
2) True load brinell
3) False brinell (fretting corrosion)
4) Skidding
5) Race or rolling element fracture
6) Separator fracture
7) Temper smearing
8) Rotational interference
9) Wear

A complete discussion of these failure modes is beyond the scope of this design guide. It is important to note that only classic fatigue and true load brinell have specific formulas that permit a believable theoretical calculation of life or numerical limit. All of the others are experience factors that are a function of the specific application, where temperatures, lubrication, overload or contamination are contributors to decreased life.

■ STEP 4 – Determine Bearing Design

Only after careful consideration of the foregoing should a specific bearing selection be made. In many cases, it is possible to select a size and type from this guide without defining restrictions on other characteristics. In more critical applications, specific decision and/or controls can be developed on:

1) Lubrication type, method and/or quantity
2) Use of shields and/or seals
3) Separator configuration material and clearances
4) Basic tolerance and modifications
5) Radial play or contact angle
6) Preload
7) Material variation
8) Contact area geometry modifications (curvature, crowning, etc.)
9) Special ball or roller complements
10) Complete special and/or integral designs

If the analysis has been completed properly, the final design will function as intended. Reliability and life expectancy will be optimized with minimum chance of premature failures or unanticipated problems. Timken aerospace product design engineers are ready to provide whatever assistance is necessary toward achieving this goal.

Construction Selection

Evaluation of the design criteria contained in the following chart will help you choose the optimum design construction. While no individual construction can satisfy all possible service functions, proper selections makes it possible to meet the most critical functions or conditions in each application. The chart rates each construction on a relative basis.

Construction Selector Chart

BEARING TYPES

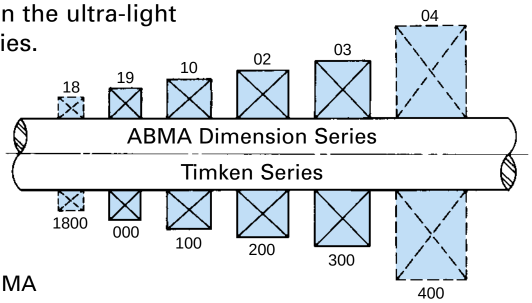
DESIGN FUNCTION	Conrad HK	Angular Contact HA	Fractured Outer HD	Two-Piece Inner HT	Roller Radial
Radial load	S	M	E	S	E
Thrust – unidirectional	S	E	S*	E	M
Thrust – reversing	S	N/A	S*	E	N/A
Radial and unidirectional thrust	S	E	E	S	M
Radial and reverse thrust	S	N/A	E	S	N/A
Moment (cocking load)	S	N/A	M*	S	N/A
High speed	S	E	S*	E	E
Optimum design, one-piece retainer	N/A	E	E	E	E
Ability to resist mishandling	E	S	S	S	S
Ease of mounting	E	S	E	S	S
Ability to resist housing distortion	E	S	M	E	S
Continuity (life) after failure	M	E	E	E	E
Ability to meet life with misalignment	E	M	E	S	M
Ability to absorb axial expansion with fixed races	M	M	M	M	E

CODES: E = excellent S = satisfactory M = marginal N/A = not adequate or not available

**May be used with closely restraining housing fits and face clamping*

Size and Chassis Selection

Timken aerospace ball and roller bearings are offered in five basic ABMA boundary dimension series (000,100,200,300 & 400). These series, presented in the specification tables, include bearings ranging in size from 10mm bore to 300mm O.D. The 000 (ABMA 1900) series has become increasingly popular with the aircraft industry due to its very thin cross section and reduced weight. Should the need exist, Timken can also supply bearings in the ultra-light (1800) series.

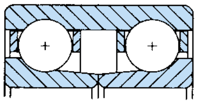


Source: ABMA

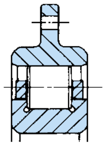
Special Designs

Many special designs can be made to simplify mounting and improve performance in complex engine assemblies.

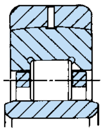
A typical design would include bearings with puller grooves, self-aligning seats, flange mounts or double-row duplex assemblies. To speed delivery and reduce cost, all specialized bearings should be designed around standard bore, O.D. width or ball/roller complements as listed in the bearing specification tables as a starting point.



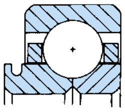
Double-row duplex assembly



Roller bearing with integral flange mount



Roller bearing with self-aligning seat



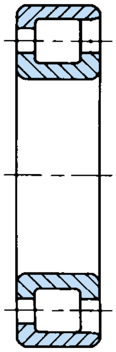
Split-inner-race bearing with puller groove

Cylindrical Roller Bearings

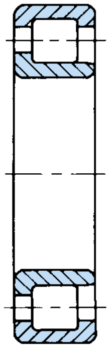
Basic Construction Types

Aerospace roller bearings are designed to meet the need for improved quality bearings used in high-speed operations. Attention to detail – including roller configuration, separator design, guide flange finish and contour and material stability – significantly reduces end wear and improves life at high speeds.

Conventionally designed roller bearings in standard 52100 or VIM-VAR M-50 are normally manufactured in RBEC 5 tolerance with high-strength machined cages. Any of at least seven race configurations may be selected depending on the application. All types (except RAA) provide precision control of the roller for operation over a wide speed range with precision-ground, double-ribbed guide flanges on one ring. Generally, the outside surfaces are also ground to close tolerances to offer a riding surface for the retainer to land clearance control.

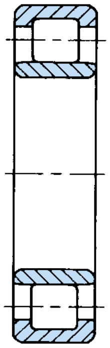


RF

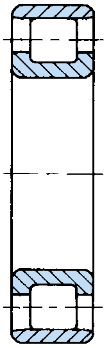


RJ

For applications requiring axial position control or limited thrust capabilities in one direction, type RF is most frequently used. Under light loads, type RF is less prone to skidding. Under higher loads at higher speeds, type RJ is easier to lubricate with an oil jet onto the inner race.

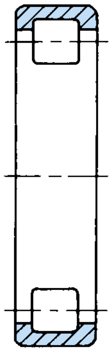


RU

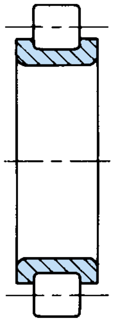


RN

These full-floating configurations allow limited axial motion during operation. Type RU is easier to lubricate under heavy loads. Type RN is less prone to slip or skid under lighter or varying loads at high speeds.

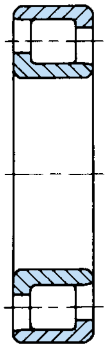


RUS



RNH

These configurations are used in integral designs where the rollers run directly on a hardened and ground shaft or housing. Nominal matching shaft and housing diameters are shown in the tabulations. Performance characteristics are similar to types RU and RN.



RAA

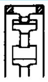
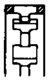
Single-ribbed inner and outer rings are a lower-cost version of type RF for use at low speeds or under oscillating conditions. This design generally has high guide flanges to accept some thrust in one direction (with well-lubricated guide flanges).

Rollers

Rollers in all sizes over 3.5mm are contoured by crown blending for uniform stress distribution under load. The length is closely matched for uniform minimum clearance within the guide flanges to ensure optimum tracking at all speeds. All rollers listed in the specification table have the preferred equal length to diameter ratio. These "square" rollers have superior ability to accept thrust and misalignment. Where theoretical capacity is critical, when load conditions and O.D. restrictions dictate, rollers of diameter to length ratio less than 1 can be supplied.

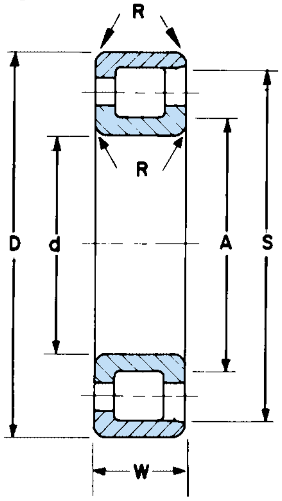
Separator Options

Separators are machined from high-strength, bearing-quality bronze with precision broached pockets. The rollers are retained through a Timken proprietary formed tab design. The floating ring can be removed to facilitate inspection or assembly. Silicon-iron-bronze or silver plated 4340 steel may be specified for higher temperature or speed conditions.

Separator Code	Material & Type	Design	Temp. Limit	Speed Limit dn 10^6	Description
B	Machined bronze		375°F 190°C	1.0	Use in heavily loaded transmission, machine tool and accessory applications. Operates in oil lubrication. Excellent strength and wear performance. Most readily available separator on most sizes.
Z	AMS 4616 silicon-iron-bronze		500°F 260°C	1.5	Similar to standard bronze with better strength and wear resistance. Frequently used in combination with VIM-VAR M-50 rings where temperatures exceed the 375° limit for 52100 steel.
H	Machined and hardened AMS 6415 alloy steel silver plated		900°F 480°C	3.0	Silver plated to enhance run-in, wear life and to provide maximum continuity after lubricant loss. VIM-VAR M-50 bearings with silver-plated steel cages are the first choice of the turbine industry for critical performance mainshaft and power train bearings.
F	Full roller complement, no separator		Same as bearing material	0.3	Use primarily at low speeds under high radial loads. Provides the maximum possible static load capacity. Also use to reduce cost where a separator is not required.

Part Numbers, Dimension and Capability Table

Cylindrical Roller Bearing Specifications



AVAILABILITY:
Most production quantities are made to order. Prototypes may be available. Check with Timken for latest availability.

To Develop a Complete Bearing Part Number:

1) Select MATERIAL prefix (see page 17).

2) Select CONSTRUCTION TYPE and SEPARATOR prefixes.

		CONSTRUCTION TYPES						
Separators		**RF**	**RJ**	**RU**	**RN**	**RUS**	**RNH**	**RAA**
Machined Bronze	B	RFB	RJB	RUB	RNB	RUSB	RNHB	RAAB
Machined Si-Fe Bronze	Z	RFZ	RJZ	RUZ	RNZ	RUSZ	RNHZ	RAAZ
Machined Steel Silver plated	H	RFH	RJH	RUH	RNH	RUSH	RNHH	RAAH
Full roller complement	F	RFF	RJF	RUF	RNF	RUSF	RNHF	RAAF

3) Select basic bearing SIZE code (tabulation below)

4) Add suffixes for TOLERANCE code (see pages 12-15), RADIAL PLAY code (see page 17) and LUBRICATION code (see page 26). If any codes are omitted, standard values will be applied. For complex assemblies, Timken will substitute a dash number (in lieu of suffixes) to cover all special features.

	EXAMPLES	
	RFZ201 P7(3) LY 240	**5 RNF 109-28**
Material	– 52100 steel	5 = VIM-VAR M-50 steel
Construction	RF = RF type	RN = RN type
Separator	Z = machined Si-Fe bronze	F = full roller complement
Size	201 = size 201	109 = size 109
Tolerance	P7 = ABEC 7	-28 = { special features detailed under "dash" 28 code
Radial Play	(3) = Range 3 clearance	
Lubrication	LY240 = Shell Darina EP2	

Part Numbers, Dimension and Capability Table continued

Cylindrical Roller Bearing Specifications

	BOUNDARY DIMENSIONS													LOAD RATINGS	
	Bore d		Outside Diameter D		Width W		Mounting Shoulder Diameter		Radius	Nominal Roller Path Diameter		Roller		Dynamic Radial Capacity Cr (lbs.)	Static Radial Capacity Cor (lbs.)
Basic Size Code	mm	Inch	mm	Inch	mm	Inch	Min. Shaft A	Max. Housing S	R	Inner	Outer	No.	Diameter x Length mm		
000	10	0.3937	22	0.8661	6	0.2362	0.473	0.786	0.012	0.4921	0.7677	10	3.5 x 3.5	1,032	746
100	10	0.3937	26	1.0236	8	0.3150	0.489	0.928	0.012	0.5118	0.9055	8	5 x 5	1,740	1,221
200	10	0.3937	30	1.1811	9	0.3543	0.552	1.023	0.024	0.5905	0.9842	8	5 x 5	1,772	1,268
300	10	0.3937	35	1.3780	11	0.4331	0.569	1.203	0.024	0.6692	1.1810	8	6.5 x 6.5	2,892	2,449
001	12	0.4724	24	0.9449	6	0.2362	0.552	0.866	0.012	0.5778	0.8533	10	3.5 x 3.5	1,038	771
101	12	0.4724	28	1.1024	8	0.3150	0.564	1.011	0.012	0.5905	0.9842	8	5 x 5	1,772	1,268
201	12	0.4724	32	1.2598	10	0.3937	0.618	1.114	0.024	0.6299	1.1024	8	6 x 6	2,460	2,059
301	12	0.4724	37	1.4567	12	0.4724	0.671	1.261	0.039	0.7100	1.2612	8	7 x 7	3,261	2,406
002	15	0.5906	28	1.1024	7	0.2756	0.671	1.022	0.012	0.7087	0.9843	14	3.5 x 3.5	1,333	1,120
102	15	0.5906	32	1.2598	9	0.3543	0.686	1.165	0.012	0.7382	1.1319	10	5 x 5	2,133	1,668
202	15	0.5906	35	1.3780	11	0.4331	0.730	1.239	0.024	0.7480	1.2205	10	6 x 6	2,906	2,261
302	15	0.5906	42	1.6535	13	0.5118	0.796	1.453	0.039	0.8228	1.4528	8	8 x 8	4,253	3,222
003	17	0.6693	30	1.1811	7	0.2756	0.749	1.102	0.012	0.7874	1.0630	14	3.5 x 3.5	1,327	1,138
103	17	0.6693	35	1.3780	10	0.3937	0.763	1.284	0.012	0.8366	1.2303	12	5 x 5	2,455	2,053
203	17	0.6693	40	1.5748	12	0.4724	0.815	1.429	0.024	0.8789	1.3907	10	6 x 6	3,434	2,751
303	17	0.6693	47	1.8504	14	0.5512	0.879	1.641	0.039	0.9232	1.6319	8	9 x 9	5,352	4,140
403	17	0.6693	62	2.4409	17	0.6693	0.946	2.164	0.039	1.1220	1.9882	8	11 x 11	7,582	5,997
004	20	0.7874	37	1.4567	9	0.3543	0.874	1.370	0.012	0.9350	1.3287	14	5 x 5	2,753	2,444
104	20	0.7874	42	1.6535	12	0.4724	0.927	1.514	0.024	0.9449	1.4961	10	7 x 7	4,006	3,313
204	20	0.7874	47	1.8504	14	0.5512	0.972	1.665	0.039	1.0197	1.6496	10	8 x 8	5,189	4,332
304	20	0.7874	52	2.0472	15	0.5906	0.992	1.843	0.039	1.0236	1.8110	8	10 x 10	6,569	5,173
404	20	0.7874	72	2.8346	19	0.7480	1.064	2.558	0.039	1.3386	2.2834	8	12 x 12	9,147	7,478
005	25	0.9843	42	1.6535	9	0.3543	1.070	1.568	0.012	1.1424	1.5361	16	5 x 5	3,020	2,884
105	25	0.9843	47	1.8504	12	0.4724	1.128	1.706	0.024	1.1417	1.6929	12	7 x 7	4,603	4,036
205	25	0.9843	52	2.0472	15	0.5906	1.166	1.866	0.039	1.2000	1.8300	12	8 x 8	5,978	5,294
305	25	0.9843	62	2.4409	17	0.6693	1.205	2.220	0.039	1.3214	2.1876	10	11 x 11	9,341	8,033
405	25	0.9843	80	3.1496	21	0.8268	1.303	2.831	0.059	1.5558	2.5781	10	13 x 13	12,683	11,167
006	30	1.1811	47	1.8504	9	0.3543	1.268	1.764	0.012	1.3287	1.7224	18	5 x 5	3,261	3,313
106	30	1.1811	55	2.1654	13	0.5118	1.360	1.987	0.039	1.4114	1.9626	14	7 x 7	5,156	4,890
206	30	1.1811	62	2.4409	16	0.6299	1.374	2.248	0.039	1.4575	2.2449	12	10 x 10	9,225	8,460
306	30	1.1811	72	2.8346	19	0.7480	1.413	2.602	0.039	1.5217	2.5453	10	13 x 13	12,885	11,372
406	30	1.1811	90	3.5433	23	0.9055	1.500	3.225	0.059	1.9110	2.9134	10	14 x 14	14,554	13,075
007	35	1.3780	55	2.1654	10	0.3937	1.510	2.034	0.024	1.5472	2.0197	18	6 x 6	4,507	4,653
107	35	1.3780	62	2.4409	14	0.5512	0.156	2.259	0.039	1.6102	2.2402	14	8 x 8	6,713	6,522
207	35	1.3780	72	2.8346	17	0.6693	1.589	2.623	0.039	1.6949	2.5610	12	11 x 11	10,898	10,194
307	35	1.3780	80	3.1496	21	0.8268	1.683	2.844	0.059	1.7126	2.8150	10	14 x 14	14,951	13,438
407	35	1.3780	100	3.9370	25	0.9843	1.697	3.619	0.059	2.0669	3.2481	10	15 x 15	16,737	15,372
008	40	1.5748	62	2.4409	12	0.4724	1.707	2.309	0.024	1.7323	2.2835	18	7 x 7	6,153	6,484
108	40	1.5748	68	2.6772	15	0.5906	1.755	2.497	0.039	1.7716	2.4803	14	9 x 9	8,456	8,354
208	40	1.5748	80	3.1496	18	0.7087	1.793	2.931	0.039	1.9134	2.8583	12	12 x 12	12,925	12,348
308	40	1.5748	90	3.5433	23	0.9055	1.895	3.223	0.059	1.9606	3.2205	10	16 x 16	19,334	17,776
408	40	1.5748	110	4.3307	27	1.0630	1.988	3.918	0.079	2.2835	2.6221	10	17 x 17	21,323	19,945
009	45	1.7717	68	2.6772	12	0.4724	1.913	2.536	0.024	1.9488	2.5000	20	7 x 7	6,593	7,316
109	45	1.7717	75	2.9528	16	0.6299	1.959	2.765	0.039	2.0256	2.7342	16	9 x 9	9,295	9,751
209	45	1.7717	85	3.3465	19	0.7480	1.985	3.133	0.039	2.0728	3.0965	12	13 x 13	15,098	14,626
309	45	1.7717	100	3.9370	25	0.9843	2.087	3.622	0.059	2.1850	3.5236	10	17 x 17	21,257	19,744
409	45	1.7717	120	4.7244	29	1.1417	2.185	4.311	0.079	2.5394	3.9568	12	18 x 18	27,417	27,306
010	50	1.9685	72	2.8346	12	0.4724	2.109	2.695	0.024	2.1260	2.6772	20	7 x 7	6,528	7,392
110	50	1.9685	80	3.1496	16	0.6299	2.157	2.961	0.039	2.2224	2.9311	18	9 x 9	10,085	11,116
210	50	1.9685	90	3.5433	20	0.7874	2.180	3.332	0.039	2.2697	3.2933	14	13 x 13	16,965	17,361
310	50	1.9685	110	4.3307	27	1.0630	2.351	3.948	0.079	2.4390	3.9350	10	19 x 19	26,364	24,956
410	50	1.9685	130	5.1181	31	1.2205	2.518	4.569	0.079	2.7953	4.2913	12	19 x 19	30,155	30,415
011	55	2.1654	80	3.1496	13	0.5118	2.365	2.950	0.039	2.3957	2.9468	24	7 x 7	7,374	8,986
111	55	2.1654	90	3.5433	18	0.7087	2.398	3.311	0.039	2.4429	3.3090	16	11 x 11	13,461	14,496
211	55	2.1654	100	3.9370	21	0.8268	2.446	3.657	0.059	2.5000	3.6024	14	14 x 14	19,580	20,377
311	55	2.1654	120	4.7244	29	1.1417	2.558	4.332	0.079	2.7342	4.2303	12	19 x 19	30,468	30,726
411	55	2.1654	140	5.5118	33	1.2992	2.715	4.962	0.079	3.0512	4.6260	12	20 x 20	33,366	34,163
012	60	2.3622	85	3.3465	13	0.5118	2.560	3.148	0.039	2.5875	3.1387	24	7 x 7	7,298	9,056
112	60	2.3622	95	3.7402	18	0.7087	2.592	3.510	0.039	2.6181	3.4842	18	11 x 11	14,634	16,474
212	60	2.3622	110	4.3307	22	0.8661	2.648	4.045	0.059	2.7480	4.0079	14	16 x 16	25,312	26,751
312	60	2.3622	130	5.1181	31	1.2205	2.765	4.716	0.079	2.9527	4.5275	12	20 x 20	33,689	34,410
412	60	2.3622	150	5.9055	35	1.3780	2.912	5.356	0.079	3.2678	5.0000	12	22 x 22	40,081	41,527
013	65	2.5591	90	3.5433	13	0.5118	2.755	3.347	0.039	2.7756	3.3268	26	7 x 7	7,673	9,875
113	65	2.5591	100	3.9370	18	0.7087	2.787	3.709	0.039	2.8150	3.6811	18	11 x 11	14,551	16,639
213	65	2.5591	120	4.7244	23	0.9055	2.858	4.426	0.059	3.0433	4.3031	14	16 x 16	25,286	27,244
313	65	2.5591	140	5.5118	33	1.2992	2.949	5.122	0.079	3.2126	4.9449	12	22 x 22	40,441	41,905
413	65	2.5591	160	6.2992	37	1.4587	3.109	5.750	0.079	3.5237	5.3347	12	23 x 23	43,295	45,236
014	70	2.7559	100	3.9370	16	0.6299	2.963	3.730	0.039	3.0098	3.7185	24	9 x 9	12,118	15,375
114	70	2.7559	110	4.3307	20	0.7874	2.994	4.092	0.039	3.0315	4.0551	18	13 x 13	20,279	20,404
214	70	2.7559	125	4.9213	24	0.9449	3.054	4.623	0.059	3.1693	4.5079	14	17 x 17	27,698	29,812
314	70	2.7559	150	5.9055	35	1.3780	3.195	5.466	0.079	3.4331	5.3228	12	24 x 24	47,732	50,018
414	70	2.7559	180	7.0866	42	1.6535	3.445	6.397	0.098	3.8977	5.9449	12	26 x 26	54,842	58,400

R = the maximum shaft or housing fillet radius that bearing corner will clear
C = the dynamic radial capacity at 33⅓ RPM for 500 hours minimum life
Co = the static non-brinell radial capacity.

Part Numbers, Dimension and Capability Table continued

Cylindrical Roller Bearing Specifications

Basic Size Code	BOUNDARY DIMENSIONS													LOAD RATINGS	
	Bore d		Outside Diameter D		Width W		Mounting Shoulder Diameter		Radius	Nominal Roller Path Diameter		Roller		Dynamic Radial Capacity Cr (lbs.)	Static Radial Capacity Cor (lbs.)
	mm	Inch	mm	Inch	mm	Inch	Min. Shaft A	Max. Housing S	R	Inner	Outer	No.	Diameter x Length mm		
015	75	2.9528	105	4.1339	16	0.6299	3.161	3.926	0.039	3.1890	3.8976	24	9 x 9	12,034	15,466
115	75	2.9528	115	4.5276	20	0.7874	3.190	4.290	0.039	3.2283	4.2520	18	13 x 13	20,184	23,612
215	75	2.9528	130	5.1181	25	0.9843	3.250	4.820	0.059	3.3268	4.7441	14	18 x 18	30,953	33,591
315	75	2.9528	160	6.2992	37	1.4567	3.403	5.849	0.079	3.6535	5.7008	12	26 x 26	55,567	58,836
415	75	2.9528	190	7.4803	45	1.7717	3.642	6.791	0.098	4.1142	6.3190	12	28 x 28	63,196	67,917
016	80	3.1496	110	4.3307	16	0.6299	3.356	4.124	0.039	3.3858	4.0945	26	9 x 9	12,667	16,855
116	80	3.1496	125	4.9213	22	0.8661	3.389	4.682	0.039	3.5236	4.5472	20	13 x 13	20,280	23,403
216	80	3.1496	140	5.5118	26	1.0236	3.519	5.142	0.079	3.6220	5.0394	16	18 x 18	34,173	38,749
316	80	3.1496	170	6.6929	39	1.5354	3.611	6.232	0.079	3.9121	6.1169	12	28 x 28	63,014	67,180
416	80	3.1496	200	7.8740	48	1.8898	3.839	7.185	0.098	4.3307	6.6929	12	30 x 30	72,064	78,128
017	85	3.3465	120	4.7244	18	0.7087	3.571	4.500	0.039	3.6240	4.4901	24	11 x 11	17,567	27,866
117	85	3.3465	130	5.1181	22	0.8661	3.593	4.872	0.039	3.6811	4.7835	20	14 x 14	25,097	30,900
217	85	3.3465	150	5.9055	28	1.1024	3.721	5.531	0.079	3.8779	5.4527	14	20 x 20	37,901	42,268
317	85	3.3465	180	7.0866	41	1.6142	3.876	6.557	0.098	4.1142	6.3189	12	28 x 28	63,192	67,913
417	85	3.3465	210	8.2677	52	2.0472	4.243	7.372	0.118	4.5473	7.0669	12	32 x 32	81,461	89,043
018	90	3.5433	125	4.9213	18	0.7087	3.767	4.698	0.039	3.8209	4.6870	24	11 x 11	17,454	22,992
118	90	3.5433	140	5.5118	24	0.9449	3.842	5.213	0.059	3.9665	5.1476	20	15 x 15	28,594	35,829
218	90	3.5433	160	6.2992	30	1.1811	3.971	5.872	0.079	4.1339	5.7087	16	20 x 20	41,809	48,817
318	90	3.5433	190	7.4803	43	1.6929	4.085	6.939	0.098	4.3898	6.7520	12	30 x 30	72,119	78,354
418	90	3.5433	225	8.8583	54	2.126	4.439	7.962	0.118	4.8622	7.5394	12	34 x 34	91,501	101,123
019	95	3.7402	130	5.1181	18	0.7087	3.965	4.893	0.039	4.0177	4.8839	26	11 x 11	18,408	25,033
119	95	3.7402	145	5.7087	24	0.9449	4.039	5.410	0.059	4.1260	5.3858	20	16 x 16	32,494	40,753
219	95	3.7402	170	6.6929	32	1.2598	4.181	6.252	0.079	4.3937	6.1260	16	22 x 22	50,273	59,256
319	95	3.7402	200	7.8740	45	1.7717	4.294	7.320	0.098	4.6102	7.1299	12	32 x 32	81,524	89,308
419	95	3.7402	240	9.4488	55	2.1654	4.636	8.553	0.118	5.2165	7.9720	12	35 x 35	98,068	110,013
020	100	3.9370	140	5.5118	20	0.7874	4.172	5.277	0.039	4.2520	5.1968	24	12 x 12	20,628	27,714
120	100	3.9370	150	5.9055	24	0.9449	4.230	5.612	0.059	4.3228	5.5827	20	16 x 16	32,635	41,000
220	100	3.9370	180	7.0866	34	1.3386	4.391	6.633	0.079	4.5275	6.4960	14	25 x 25	58,241	66,539
320	100	3.9370	215	8.4646	47	1.8504	4.566	7.835	0.098	4.8543	7.6890	10	36 x 36	88,623	93,625
420	100	3.9370	250	9.8424	58	2.2835	4.833	8.946	0.118	5.4724	8.3070	12	36 x 36	101,728	114,424
021	105	4.1339	145	5.7087	20	0.7874	4.368	5.474	0.039	4.4488	5.3937	24	12 x 12	20,491	27,837
121	105	4.1339	160	6.2992	26	1.0236	4.522	5.911	0.079	4.5807	5.9193	20	17 x 17	35,448	45,007
221	105	4.1339	190	7.4803	36	1.4173	4.601	7.013	0.079	4.8346	6.8819	14	26 x 26	62,742	72,519
321	105	4.1339	225	8.8583	49	1.9291	4.774	8.218	0.098	5.1496	7.9842	12	36 x 36	102,030	113,826
421	105	4.1339	260	10.2362	60	2.3622	5.030	9.340	0.118	5.7284	8.6418	12	37 x 37	107,270	121,575
022	110	4.3307	150	5.9055	20	0.7874	4.564	5.672	0.039	4.6457	5.5905	26	12 x 12	21,625	30,280
122	110	4.3307	170	6.6929	28	1.1024	4.728	6.296	0.079	4.7638	6.2598	18	19 x 19	40,869	50,731
222	110	4.3307	200	7.8740	38	1.4961	4.811	7.393	0.079	5.0000	7.2047	14	28 x 28	71,220	82,313
322	110	4.3307	240	9.4480	50	1.9685	5.004	8.775	0.098	5.4685	8.4606	12	38 x 38	113,129	127,444
422	110	4.3307	280	11.0236	65	2.5591	5.226	10.128	0.118	6.1024	9.2520	12	40 x 40	124,394	142,445
024	120	4.7244	165	6.4961	22	0.8661	4.967	6.254	0.039	5.0866	6.1890	26	14 x 14	29,422	41,670
124	120	4.7244	180	7.0866	28	1.1024	5.123	6.688	0.079	5.1949	6.6909	20	19 x 19	43,909	57,010
224	120	4.7244	215	8.4646	40	1.5748	5.201	7.988	0.079	5.4724	7.8346	14	30 x 30	81,273	95,415
324	120	4.7244	260	10.2362	55	2.1654	5.448	9.513	0.098	5.9094	9.2165	12	42 x 42	135,950	154,869
424	120	4.7244	310	12.2047	72	2.8346	6.100	10.829	0.157	6.8929	10.2363	12	45 x 45	155,479	180,696
026	130	5.1181	180	7.0866	24	0.9449	5.450	6.754	0.059	5.5118	6.6929	26	15 x 15	33,547	48,204
126	130	5.1181	200	7.8740	33	1.2992	5.534	7.458	0.079	5.7087	7.2835	20	20 x 20	48,298	63,838
226	130	5.1181	230	9.0551	40	1.5748	5.697	8.476	0.098	5.9646	8.3268	16	30 x 30	101,827	124,889
326	130	5.1181	280	11.0236	58	2.2835	5.937	10.204	0.118	6.3878	9.9311	12	45 x 45	155,082	178,904
426	130	5.1181	340	13.3858	78	3.0709	6.494	12.010	0.157	7.3229	11.1811	12	49 x 49	182,746	215,492
028	140	5.5118	190	7.4803	24	0.9449	5.844	7.148	0.059	5.9055	7.0866	28	15 x 15	35,118	52,249
128	140	5.5118	210	8.2677	33	1.2992	5.931	7.849	0.079	6.1024	7.6772	22	20 x 20	51,451	70,776
228	140	5.5118	250	9.8425	42	1.6535	6.139	9.215	0.098	6.4173	8.9370	16	32 x 32	101,406	126,236
328	140	5.5118	300	11.811	62	2.4409	6.353	10.970	0.118	6.7913	10.7283	10	50 x 50	164,649	183,357
428	140	5.5118	360	14.1732	82	3.2283	6.887	12.798	0.157	2.8346	11.8504	12	51 x 51	197,341	235,289
030	150	5.9055	210	8.2677	28	1.1024	6.297	7.876	0.079	6.4173	7.7559	28	17 x 17	43,786	65,396
130	150	5.9055	225	8.8583	35	1.3780	6.359	8.405	0.079	6.5750	8.3070	22	22 x 22	61,967	86,184
230	150	5.9055	270	10.6299	45	1.7717	6.561	9.974	0.098	6.8504	9.6850	14	36 x 36	115,040	140,314
430	150	5.9055	380	14.9606	85	3.3465	7.281	13.585	0.157	8.3465	12.5197	12	53 x 53	212,423	255,878
032	160	6.2992	220	8.6614	28	1.1024	6.688	8.273	0.079	6.7716	8.1890	28	18 x 18	48,949	73,774
132	160	6.2992	240	9.4488	38	1.4961	6.776	8.972	0.079	6.9291	8.8189	22	24 x 24	73,557	102,906
232	160	6.2992	290	11.4173	48	1.8898	6.987	10.730	0.098	7.4409	10.2756	16	36 x 36	126,945	162,531
034	170	6.6929	230	9.0551	28	1.1024	7.083	8.665	0.079	7.2008	8.6181	28	18 x 18	48,521	74,193
134	170	6.6929	260	10.2362	42	1.6535	7.192	9.737	0.079	7.4409	9.4882	22	26 x 26	85,784	121,387
036	180	7.0866	250	9.8425	33	1.2992	7.499	9.430	0.079	7.6771	9.2519	28	20 x 20	59,822	92,241
136	180	7.0866	280	11.0236	46	1.811	7.584	10.526	0.079	7.8740	10.2362	20	30 x 30	104,219	144,110
038	190	7.4803	260	10.2362	33	1.2992	7.890	9.826	0.079	8.0709	9.6456	28	20 x 20	59,383	92,661
138	190	7.4803	290	11.4173	46	1.8110	7.988	10.910	0.079	8.1890	10.7086	20	32 x 32	118,147	164,257
040	200	7.8740	280	11.0236	38	1.4961	8.342	10.555	0.079	8.5039	10.3937	26	24 x 24	81,257	124,380
042	210	8.2677	290	11.4173	38	1.4961	8.734	10.951	0.079	8.9823	10.7933	28	23 x 23	78,068	123,735
044	220	8.6614	300	11.811	38	1.4961	9.126	11.346	0.079	9.2913	11.1811	28	24 x 24	84,399	135,503

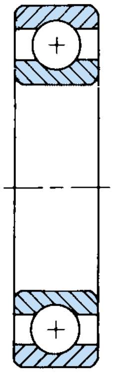
R = the maximum shaft or housing fillet radius that bearing corner will clear
C = the dynamic radial capacity at 33⅓ RPM for 500 hours minimum life
Co = the static non-brinell radial capacity.

Ball Bearings

Basic Construction Types

Any of four basic ball bearing constructions in size ranging from 10mm bore to 300mm O.D. can be manufactured to meet the most demanding performance requirements.

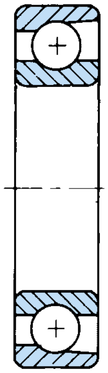
Selection of the construction best suited to the application must consider the relative importance of the various design functions (as listed on page 2). The following general description of each type will further assist in the proper selection.



HK SERIES

Conrad construction

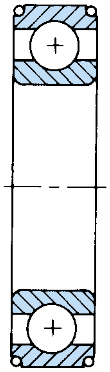
The conventional Conrad contact bearing's versatile load capability allows it to handle radial, thrust, moment, reversible thrust or combination loading conditions. Separators – either a two-piece (riveted or welded) design or a one-piece, open-face crown design – while not having the ultimate strength and speed capability of a one-piece solid design, perform well in most applications. Where speeds and loads are severe, Timken Aerospace has developed high-strength Conrad separator options. Seals and/or shields are readily adaptable to this series, particularly with high-strength, non-metallic molded crown separators.



HA SERIES

Angular contact

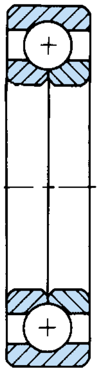
Conventional non-separable angular contact bearings with counter-bored outer rings and one-piece, high-strength separators are used in preloaded and/or thrust-type applications. For ultra-high speeds, bearings with deep-groove outer and relieved inner races can be supplied. Two contact angle ranges are normally specified: 15° nominal for lightly preloaded, radial applications; 25° nominal for heavy preloads and high external thrust loads. Angular contact bearings may be supplied as duplex, triplex, etc., sets, which are accurately preloaded to any specific level, with contact angles that can deviate from those normally specified.



HD SERIES

Deep groove fractured race

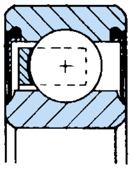
The fractured outer ring design allows a maximum ball complement in a radial- deep-groove bearing. This provides up to 56 percent greater dynamic load capacity and 280 percent longer service life over standard Conrad types. One-piece, high-strength separators allow for higher speeds and loads while reducing the chance of separator failure. While HD bearings are used primarily for radial loads, high-strength 17-4PH stainless holding bands pressed on ground shoulders retain the fracture under moderate thrust at all but the highest speeds. Normal mounting procedures are used except under severe thrust or misalignment. Several stacked holding bands can be used to increase the holding power for loose fit housings. In this case, special precaution should be observed to avoid displacement or opening of the fracture. Extensive experience has proven there is no advanced tendency to fatigue at the fracture under normal operation with a properly retained outer ring.



HT SERIES

Two-piece inner ring

High-performance, two-piece inner ring bearings are typically used on high-speed shafts with reversing thrust loads. Full deep groove outers, one-piece, high-strength separators and two extra-deep groove inner ring halves provide the maximum level of reliability with full thrust capacity in either direction. Simultaneous race grinding assures perfect matching between the two inner ring halves and a controlled offset may be specified to reduce end play. The HT series can be readily disassembled for inspection of the race and ball components. Ball retaining separators or a removable spring retaining clip designed to hold inner halves together during normal handling also are used. Operating contact angles are usually set between 25° and 35° but final selections of detailed characteristics should be developed with your Timken engineer.



Sealed Bearings

Conrad design bearings with molded ball riding crown separators (HKM) can be supplied with molded-lip Buna N rubber or Viton® contact seals, indicated in the part number as HKMZZ for double seals. These unique, long-lip, light contact seals are normally used for high-speed applications requiring adequate lubricant retention with minimum heat generation. Special seals with heavy-lip pressure can be manufactured for severe contamination environments under low-speed operation.

Ball Bearings

Separator Options

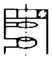
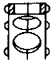
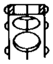
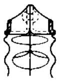
Following selection of the basic construction, selection of the proper separator and ball complement will result in the optimum bearing for the application. The ball bearing separator is critical to bearing performance. While its prime purpose is to separate the balls in the bearing assembly, it must be evaluated for each application as to:

- Performance at various speed levels.
- Compatibility with environmental conditions.
- Compatibility with lubricant systems.
- Cost and availability.

The tables below summarize separator options for metric ball bearings.

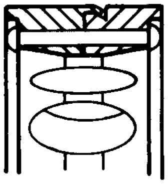
Conrad Bearing Separator Options

Conrad separators are two-piece or open-face crown designs.

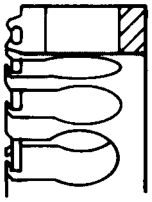
Separator Code	Material & Type	Design	Temp. Limit	Speed Limit $dn\ 10^6$	Description
M	High-strength, fiber-reinforced nylon; molded ball riding type		250°F 120°C	0.5	Provides extra-quiet operation with most types of grease lubrication. Tooling available for limited number of sizes.
R	Laminated cotton phenolic; one-piece crown snap in		275°F 135°C	0.4	Specify for use with oil impregnation or where a light-weight, land-riding separator is required.
B	Precision machined bronze; two-piece riveted		375°F 190°C	1.0	Use for high speeds in aircraft accessories and machine tools with forced lubrication.
H	Machined and hardened AMS 6415 alloy steel; silver-plated; two-piece riveted		900°F 480°C	2.0	Use for ultra-high speeds in aircraft accessories and machine tools with forced lubrication. Silver plating improves wear under marginal lubrication. Normally used with M-50 daces and balls.
U	Phosphor bronzes; stamped two-piece riveted; land piloted; with shaped pockets		375°F 190°C	1.0	Allows rapid acceleration with minimum inertia and maximum exposure to oil flow. Tooling available for limited number of sizes

Special Separator Options

Conrad design bearings utilizing precision machined cages can be provided with stepped interfaces and detents to provide reliability with Timken's unique "side wire" design to meet the needs of applications that experience extreme operating conditions.



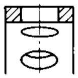
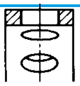
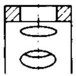
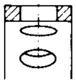
Anti-rotation detents



Side wires

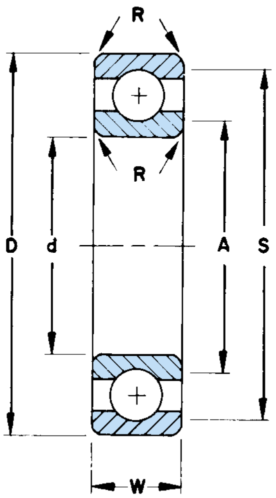
Maximum Capacity Bearing Separator Options

With the exception of the special full-ball complement or stamped-steel design, all separators for maximum capacity ball bearings are one-piece machined design for maximum strength and balance. They are normally designed to pilot on the outer land to optimize oil jet lubrication of the inner race. Outer-land piloting separators provide a self-balancing effect since any wear improves balance.

Separator Code	Material and Type	Design	Temp. Limit	Speed Limit $dn\ 10^6$	Description
B	Precision machined bronze; drilled; one piece		375°F 190°C	1.5	Use in heavily loaded transmission, machine tool and accessory applications. Operates in oil lubrication. Excellent strength and wear performance. Most readily available separator on most sizes.
R	Laminated cotton machined phenolic; one piece		275°F 135°C	1.0	Use on lightly loaded grease or oil mist lubricated spindles. May be vacuum impregnated to enhance life in "one shot" oiled or greased applications.
Z	AMS 4616 silicon-iron-bronze; machined; one piece		500°F 260°C	2.0	Similar to standard bronze with better strength and wear resistance. Frequently used in combination with VIM-VAR M-50 races where temperatures exceed the 375°F limit for 52100 steel.
H	Machined and hardened AMS 6415 alloy steel; silver-plated; one piece		900°F 480°C	3.0	VIM-VAR M-50 bearings with silver-plated steel cages are first choice of the turbine industry for critical performance mainshaft and power train bearings. Steel is silver-plated to enhance run-in, wear life and to provide maximum continuity after lubricant loss.
S	Stamped steel; outer-land piloted		500°F 260°C	1.0	Unique design developed by Timken provides a lightweight land riding separator. This design crosses the pitch diameter to avoid "roll under" failures common to other thin-walled, high-speed land riding separators. All surfaces are treated with a diffusion hardening process to enhance wear and reduce friction. Tooling available for limited number of sizes.
F	Full ball complement		Same as bearing material	0.3	Use primarily at low speeds under high radial loads. Provides the maximum possible static and dynamic load capacity. Use also to reduce cost where a separator is not required. Should not be used under heavy combined or misaligned loads with continuous rotation since the differential ball speeds will cause ball-to-ball scrubbing and a substantial reduction in life.

Part Numbers, Dimension and Capability Table

Ball Bearing Specifications



AVAILABILITY:
Most production quantities are made to order. Prototypes may be available. Check with Timken for latest availability.

To Develop a Complete Bearing Part Number:

1) Select MATERIAL prefix (see page 16).
2) Select CONSTRUCTION TYPE, SEPARATOR and SEAL prefixes.

		CONSTRUCTION TYPES			
Separators and Seals		**Conrad HK**	**Angular Contact HA**	**Fractured Race HD**	**Two-Piece Inner Ring HT**
Molded Crown Open	M	HKM			
Molded Crown Single Seal	MZ	HKMZ			
Molded Crown Double Seal	MZZ	HKMZZ			
Machined Phenolic	R	HKR	HAR	HDR	HTD
Machined Bronze	B	HKB	HAB	HDB	HTB
Stamped Bronze	U	HKU			
Si-Fe Bronze	Z		HAZ	HDZ	HTZ
Silver-Plated Steel	H	HKH	HAH	HDH	HTH
Stamped Steel	S		HAS	HDS	HTS
Full Ball Complement	F		HAF	HDF	HTF

3) Select basic bearing SIZE code (tabulation below).
4) Add suffixes for TOLERANCE code (see pages 12-15), RADIAL PLAY code (see page 17), PRELOAD code (see page 19) and LUBRICATION code (see page 26). If any codes are omitted, standard values will be applied. For complex assemblies, Timken will substitute a dash number (in lieu of suffixes) to cover all special features.

EXAMPLES		
	3HAH 104 P5(4)DB 10/20	**HDB 306-91**
Material	3 = 440C stainless steel	— 52100 steel
Construction	HA = Angular contact type	HD = Fractured-race type
Separator/seal	H = Silver-plated steel	B = Machined bronze
Size	104 = Size 104	306 = Size 306
Tolerance	P5 = ABEC 5	
Radial Play	(4) Range 4 clearance	
Preload	DB 10/20 = DB 10 lbs. min. to 20 lbs. max	-91 = Special features detailed under "dash" 91 code
Lubrication	Standard dip	

Basic Size Code	BOUNDARY DIMENSIONS										LOAD RATINGS					
	Bore d		Outside Diameter D		Width W		Mounting Shoulder Diameter		Radius	Ball Dia.	Maximum Capacity Types HA, HD, HT			CONRAD Type HK		
											Balls No.†	Capacity (lbs.)		Balls No.	Capacity (lbs.)	
	mm	Inch	mm	Inch	mm	Inch	Min. Shaft A	Max. Housing S	R	Inch		Cr	Cor		Cr	Cor
000	10	0.3937	22	0.8661	6	0.2362	0.473	0.786	0.012	9/64	11	800	398	8	688	307
100	10	0.3937	26	1.0236	8	0.3150	0.489	0.928*	0.012	3/16	10	1,241	601	7	1,030	443
200	10	0.3937	30	1.1811	9	0.3543	0.552	1.023	0.024	¼	9	1,866	877	6	1,473	612
300	10	0.3937	35	1.3780	11	0.4331	0.569	1.203	0.024	9/32	9	2,307	1,110	6	1,821	774
001	12	0.4724	24	0.9449	6	0.2362	0.552	0.866	0.012	9/64	13	894	487	9	749	362
101	12	0.4724	28	1.1024	8	0.3150	0.564	1.011	0.012	3/16	11	1,342	710	8	1,156	549
201	12	0.4724	32	1.2598	10	0.3937	0.618	1.114	0.024	15/64	10	1,864	954	7	1,552	708
301	12	0.4724	37	1.4567	12	0.4724	0.671	1.261	0.039	5/16	8	2,562	1,204	6	2,183	941
002	15	0.5906	28	1.1024	7	0.2756	0.671	1.022	0.012	5/32	14	1,133	663	10	972	506
102	15	0.5906	32	1.2598	9	0.3543	0.686	1.165*	0.012	7/32	11	1,766	942	8	1,514	725
202	15	0.5906	35	1.3780	11	0.4331	0.730	1.239	0.024	15/64	11	1,999	1,079	8	1,713	830
302	15	0.5906	42	1.6535	13	0.5118	0.796	1.453	0.039	11/32	9	3,341	1,698	6	2,650	1,179
003	17	0.6693	30	1.1811	7	0.2756	0.749	1.102	0.012	5/32	15	1,179	727	11	1,033	573
103	17	0.6693	35	1.3780	10	0.3937	0.763	1.284**	0.012	7/32	12	1,888	1,065	8	1,530	756
203	17	0.6693	40	1.5748	12	0.4724	0.815	1.429	0.024	9/32	10	2,592	1,381	8	2,359	1,172
303	17	0.6693	47	1.8504	14	0.5512	0.879	1.641	0.039	⅜	9	3,941	2,047	6	3,131	1,425
403	17	0.6693	62	2.4409	17	0.6693	1.088	2.022	0.079	½	8	5,986	3,094	6	5,104	2,426

* Reduce by .025 for fractured race HD bearings ** Reduce by .050 for fractured race HD bearings

† Ball complement is normally one less than the number listed when non-metallic separators or separable HT and HA bearings with drop center separators for ball retention are specified.

R = the maximum shaft or housing fillet radius that bearing corner will clear
C = the dynamic radial capacity at 33⅓ RPM for 500 hours minimum life
Co = the static non-brinell radial capacity

Part Numbers, Dimension and Capability Table continued

Ball Bearing Specifications

	BOUNDARY DIMENSIONS										LOAD RATINGS					
	Bore d		Outside Diameter D		Width W		Mounting Shoulder Diameter		Radius	Ball Dia.	Maximum Capacity Types HA, HD, HT			CONRAD Type HK		
												Capacity (lbs.)			Capacity (lbs.)	
Basic Size Code	mm	Inch	mm	Inch	mm	Inch	Min. Shaft A	Max. Housing S	R	Inch	Balls No.†	Cr	Cor	Balls No.	Cr	Cor
004	20	0.7874	37	1.4567	9	0.3543	0.874	1.370*	0.012	3/16	16	1,708	1,120	11	1,434	827
104	20	0.7874	42	1.6535	12	0.4724	0.927	1.514*	0.024	1/4	13	2,521	1,525	9	2,109	1,130
204	20	0.7874	47	1.8504	14	0.5512	0.972	1.665	0.039	5/16	11	3,751	2,270	8	2,877	1,479
304	20	0.7874	52	2.0472	15	0.5906	0.992	1.843	0.039	3/8	10	4,322	2,403	7	3,585	1,771
404	20	0.7874	72	2.8346	19	0.7480	1.206	2.416	0.079	9/16	7	6,884	3,557	6	6,461	3,180
005	25	0.9843	42	1.6535	9	0.3543	1.070	1.568	0.012	3/16	19	1,875	1,372	13	1,580	1,017
105	25	0.9843	47	1.8504	12	0.4724	1.128	1.706*	0.024	9/32	14	3,271	2,096	9	2,612	1,448
205	25	0.9843	52	2.0472	15	0.5906	1.166	1.866	0.039	5/16	13	3,768	2,378	9	3,151	1,760
305	25	0.9843	62	2.4409	17	0.6693	1.205	2.220	0.039	7/16	11	6,104	3,644	7	4,765	2,454
405	25	0.9843	80	3.1496	21	0.8268	1.467	2.667	0.0981	21/32	8	9,802	5,373	6	8,370	4,214
006	30	1.1811	47	1.8504	9	0.3543	1.268	1.764**	0.012	3/16	21	1,959	1,558	14	1,628	1,126
106	30	1.1811	55	2.1654	13	0.5118	1.360	1.987	0.039	9/32	17	3,691	2,674	11	2,976	1,859
206	30	1.1811	62	2.4409	16	0.6299	1.374	2.248	0.039	3/8	13	5,233	3,420	9	4,374	2,530
306	30	1.1811	72	2.8346	19	0.7480	1.413	2.602	0.039	1/2	11	7,785	4,817	7	6,087	3,252
406	30	1.1811	90	3.5433	23	0.9055	1.663	3.061	0.0981	11/16	9	11,793	6,946	7	10,410	5,649
007	35	1.3780	55	2.1654	10	0.3937	1.510	2.034*	0.024	1/4	19	3,144	2,444	13	2,650	1,811
107	35	1.3780	62	2.4409	14	0.5512	1.560	2.259	0.039	5/16	17	4,450	3,324	11	3,592	2,308
207	35	1.3780	72	2.8346	17	0.6693	1.589	2.623	0.039	15/32	12	7,401	4,833	8	6,012	3,420
307	35	1.3780	80	3.1496	21	0.8268	1.683	2.844	0.059	9/16	11	9,626	6,103	7	7,527	4,119
407	35	1.3780	100	3.9370	25	0.9843	1.860	3.455	0.091	23/32	10	13,890	8,756	7	11,505	6,442
008	40	1.5748	62	2.4409	12	0.4724	1.707	2.309*	0.024	1/4	22	3,395	2,899	14	2,735	1,999
108	40	1.5748	68	2.6772	15	0.5906	1.755	2.497	0.039	5/16	19	4,725	3,788	12	3,773	2,592
208	40	1.5748	80	3.1496	18	0.7087	1.793	2.931	0.039	15/32	15	8,590	6,239	9	6,546	4,021
308	40	1.5748	90	3.5433	23	0.9055	1.895	3.223	0.059	5/8	12	12,354	8,291	7	10,789	6,581
408	40	1.5748	110	4.3307	27	1.0630	2.200	3.705	0.118	25/32	10	16,197	10,430	7	11,727	6,771
009	45	1.7717	68	2.6772	12	0.4724	1.913	2.536*	0.024	1/4	24	3,525	3,222	16	2,938	2,326
109	45	1.7717	75	2.9528	16	0.6299	1.959	2.765	0.039	11/32	20	5,797	4,833	12	4,473	3,142
209	45	1.7717	85	3.3465	19	0.7480	1.985	3.133	0.039	1/2	14	9,211	6,664	9	7,356	4,594
309	45	1.7717	100	3.9370	25	0.9843	2.087	3.622	0.059	11/16	11	13,857	9,247	8	11,867	7,116
409	45	1.7717	120	4.7244	29	1.1417	2.397	4.099	0.118	13/16	11	18,645	12,691	8	15,931	9,796
010	50	1.9685	72	2.8346	12	0.4724	2.109	2.695*	0.024	1/4	26	3,659	3,514	17	3,012	2,507
110	50	1.9685	80	3.1496	16	0.6299	2.157	2.961	0.039	3/8	19	6,558	5,458	12	5,236	3,734
210	50	1.9685	90	3.5433	20	0.7874	2.180	3.332	0.039	1/2	15	9,614	7,299	10	7,887	5,207
310	50	1.9685	110	4.3307	27	1.0630	2.351	3.948	0.079	3/4	11	16,220	11,045	8	13,901	8,504
410	50	1.9685	130	5.1181	31	1.2205	2.801	4.286	0.157	27/32	11	20,050	13,979	8	17,183	10,763
011	55	2.1654	80	3.1496	13	0.5118	2.365	2.950	0.039	5/16	24	5,317	4,991	15	4,240	3,386
111	55	2.1654	90	3.5433	18	0.7087	2.398	3.311	0.039	7/16	18	8,401	6,982	12	6,943	5,028
211	55	2.1654	100	3.9370	21	0.8268	2.446	3.657	0.059	9/16	15	11,896	9,205	10	9,754	6,561
311	55	2.1654	120	4.7244	29	1.1417	2.558	4.332	0.079	13/16	11	18,747	13,002	8	16,073	10,015
411	55	2.1654	140	5.5118	33	1.2992	2.998	4.680	0.157	7/8	12	22,743	16,665	8	18,441	11,774
012	60	2.3622	85	3.3465	13	0.5118	2.560	3.148	0.039	5/16	25	5,384	5,264	16	4,369	3,649
112	60	2.3622	95	3.7402	18	0.7087	2.592	3.510	0.039	7/16	19	8,630	7,456	12	6,892	5,104
212	60	2.3622	110	4.3307	22	0.8661	2.648	4.045	0.059	5/8	14	13,743	10,575	10	11,796	8,071
312	60	2.3622	130	5.1181	31	1.2205	2.765	4.716	0.079	7/8	11	21,434	15,118	8	18,385	11,649
412	60	2.3622	150	5.9055	35	1.3780	3.194	5.073	0.157	29/32	12	24,256	18,162	8	19,725	12,871
013	65	2.5591	90	3.5433	13	0.5118	2.755	3.347	0.039	5/16	26	5,450	5,496	17	4,486	3,928
113	65	2.5591	100	3.9370	18	0.7087	2.787	3.709	0.039	7/16	20	8,846	7,968	13	7,210	5,592
213	65	2.5591	120	4.7244	23	0.9055	2.858	4.426	0.059	11/16	14	16,343	12,564	10	13,996	9,631
313	65	2.5591	140	5.5118	33	1.2992	2.949	5.122	0.079	15/16	12	25,731	18,973	8	20,834	13,405
413	65	2.5591	160	6.2992	37	1.4587	3.391	5.467	0.157	15/16	13	27,223	21,207	8	22,724	15,630
014	70	2.7559	100	3.9370	16	0.6299	2.963	3.730	0.039	3/8	24	7,309	7,253	16	6,092	5,237
114	70	2.7559	110	4.3307	20	0.7874	2.994	4.092	0.039	1/2	19	10,947	9,777	13	9,227	7,243
214	70	2.7559	125	4.9213	24	0.9449	3.054	4.623	0.059	11/16	15	17,043	13,839	10	13,985	9,884
314	70	2.7559	150	5.9055	35	1.3780	3.195	5.466	0.079	1	12	28,910	21,639	8	23,417	15,285
414	70	2.7559	180	7.0866	42	1.6535	3.800	6.043	0.197	1 1/16	13	33,272	27,156	8	25,664	177,787
015	75	2.9528	105	4.1339	16	0.6299	3.161	3.926	0.039	3/8	26	7,618	7,900	17	6,271	5,622
115	75	2.9528	115	4.5276	20	0.7874	3.190	4.290	0.039	1/2	20	11,236	10,425	13	9,159	7,313
215	75	2.9528	130	5.1181	25	0.9843	3.250	4.820	0.059	1 1/16	16	17,730	14,975	10	13,965	10,063
315	75	2.9528	160	6.2992	37	1.4567	3.403	5.849	0.079	1 1/16	12	31,476	24,488	8	25,507	17,293
415	75	2.9528	190	7.4803	45	1.7717	3.997	6.436	0.197	1 1/8	13	36,045	30,454	9	300,075	22,431

* Reduce by .025 for fractured race HD bearings ** Reduce by .050 for fractured race HD bearings

† Ball complement is normally one less than the number listed when non-metallic separators or separable HT and HA bearings with drop center separators for ball retention are specified.

R = the maximum shaft or housing fillet radius that bearing corner will clear
C = the dynamic radial capacity at 33⅓ RPM for 500 hours minimum life
Co = the static non-brinell radial capacity

	BOUNDARY DIMENSIONS										LOAD RATINGS					
	Bore d		Outside Diameter D		Width W		Mounting Shoulder Diameter		Radius	Ball Dia.	Maximum Capacity Types HA, HD, HT			CONRAD Type HK		
							Min. Shaft A	Max. Housing S			Balls No.†	Capacity (lbs.)		Balls No.	Capacity (lbs.)	
Basic Size Code	mm	Inch	mm	Inch	mm	Inch			R	Inch		Cr	Cor		Cr	Cor
016	80	3.1496	110	4.3307	16	0.6299	3.356	4.124	0.039	3/8	27	7,727	8,229	17	6,202	5,679
116	80	3.1496	125	4.9213	22	0.8661	3.389	4.682	0.039	9/16	19	13,507	12,412	13	11,388	9,188
216	80	3.1496	140	5.5118	26	1.0236	3.519	5.142	0.079	3/4	16	20,762	17,731	10	16,340	11,907
316	80	3.1496	170	6.6929	39	1.5354	3.611	6.232	0.079	1 1/8	12	34,104	27,512	8	27,647	19,435
416	80	3.1496	200	7.8740	48	1.8898	4.194	6.830	0.197	13/16	13	38,880	33,940	9	32,443	25,000
017	85	3.3465	120	4.7244	18	0.7087	3.571	4.500	0.039	7/16	25	9,845	10,324	16	7,989	7,167
117	85	3.3465	130	5.1181	22	0.8661	3.593	4.872	0.039	9/16	20	13,878	13,211	13	11,313	9,265
217	85	3.3465	150	5.9055	28	1.1024	3.721	5.531	0.079	13/16	15	22,995	19,422	10	18,880	13,904
317	85	3.3465	180	7.0866	41	1.6142	3.876	6.567	0.098	1 1/8	13	36,045	30,454	8	27,805	19,939
417	85	3.3465	210	8.2677	52	2.0472	4.703	6.911	0.256	1 1/4	13	41,776	37,615	9	34,861	27,709
018	90	3.5433	125	4.9213	18	0.7087	3.767	5.213	0.039	7/16	26	10,006	10,767	17	8,237	7,686
118	90	3.5433	140	5.5118	24	0.9449	3.842	5.872	0.059	5/8	20	16,871	16,167	13	13,748	11,363
218	90	3.5433	160	6.2992	30	1.1811	3.971	6.939	0.079	7/8	15	26,297	22,453	10	21,583	16,053
318	90	3.5433	190	7.4803	43	1.6929	4.085	4.893	0.098	1 3/16	13	38,881	33,940	8	29,993	22,223
418	90	3.5433	225	8.8583	54	2.1260	4.900	7.502	0.256	1 3/8	12	45,214	41,654	8	36,738	29,483
019	95	3.7402	130	5.1181	18	0.7087	3.965	4.893	0.039	7/16	28	10,414	11,614	18	8,477	8,194
119	95	3.7402	145	5.7087	24	0.9449	4.039	5.410	0.059	5/8	21	17,319	17,143	13	13,667	11,447
219	95	3.7402	170	6.6929	32	1.2598	4.181	6.252	0.079	15/16	15	29,792	25,715	10	24,444	18,356
319	95	3.7402	200	7.8740	45	1.7717	4.294	7.320	0.098	1 1/4	13	41,776	32,615	8	32,228	24,631
419	95	3.7402	240	9.4488	55	2.1654	5.097	8.092	0.256	1 7/16	13	50,784	49,584	9	42,356	36,499
020	100	3.9370	140	5.5118	20	0.7874	4.172	5.277	0.039	1/2	26	12,786	14,044	17	10,525	9,994
120	100	3.9370	150	5.9055	24	0.9449	4.230	5.612	0.059	5/8	21	17,188	17,246	14	14,274	12,436
220	100	3.9370	180	7.0866	34	1.3386	4.391	6.633	0.079	1	15	33,479	29,197	10	27,463	20,826
320	100	3.9370	215	8.4646	47	1.8504	4.566	7.835	0.098	1 3/8	12	45,214	41,654	8	36,739	29,483
420	100	3.9370	250	9.8424	58	2.2835	5.294	8.486	0.256	1 1/2	13	53,904	54,006	9	44,960	39,757
021	105	4.1339	145	5.7087	20	0.7874	4.368	5.474	0.039	1/2	27	13,003	14,618	17	10,438	10,072
121	105	4.1339	160	6.2992	26	1.0236	4.522	5.911	0.079	11/16	21	20,545	20,754	13	16,217	13,860
221	105	4.1339	190	7.4803	36	1.4173	4.601	7.013	0.079	1 1/16	15	36,462	32,898	10	29,904	23,457
321	105	4.1339	225	8.8583	49	1.9291	4.774	8.218	0.098	1 7/16	12	48,121	45,567	8	39,106	32,257
421	105	4.1339	260	10.2362	60	2.3622	5.490	8.879	0.256	1 9/16	13	57,076	58,618	9	47,608	43,155
022	110	4.3307	150	5.9055	20	0.7874	4.564	5.672	0.039	1/2	28	13,208	15,152	18	10,755	10,710
122	110	4.3307	170	6.6929	28	1.1024	4.728	6.296	0.079	3/4	20	23,374	23,359	13	19,050	16,404
222	110	4.3307	200	7.8740	38	1.4961	4.811	7.393	0.079	1 1/8	15	39,517	36,820	10	32,403	26,244
322	110	4.3307	240	9.4480	50	1.9685	5.004	8.775	0.098	1 5/8	11	53,757	52,008	7	42,165	35,051
422	110	4.3307	280	11.0236	65	2.5591	5.688	9.667	0.256	1 11/16	13	63,547	68,180	9	52,983	50,162
024	120	4.7244	165	6.4961	22	0.8661	4.967	6.254	0.039	9/16	27	16,031	18,514	17	12,869	12,779
124	120	4.7244	180	7.0866	28	1.1024	5.123	6.688	0.079	3/4	22	24,617	26,017	14	19,819	17,908
224	120	4.7244	215	8.4646	40	1.5748	5.201	7.988	0.079	1 1/8	16	41,046	40,081	10	32,328	26,933
324	120	4.7244	260	10.2362	55	2.1654	5.448	9.513	0.098	1 3/4	12	63,233	65,968	7	46,821	40,770
424	120	4.7244	310	12.2047	72	2.8346	6.394	10.535	0.315	1 7/8	13	73,628	83,948	9	61,355	61,710
026	130	5.1181	180	7.0866	24	0.9449	5.450	6.754	0.059	5/8	27	19,462	22,830	17	15,622	15,714
126	130	5.1181	200	7.8740	33	1.2992	5.534	7.458	0.079	7/8	20	30,802	31,870	13	25,106	22,367
226	130	5.1181	230	9.0551	40	1.5748	5.697	8.476	0.098	1 3/16	17	46,037	47,709	11	37,122	33,157
326	130	5.1181	280	11.0236	58	2.2835	5.937	10.204	0.118	1 7/8	12	69,680	75,893	7	51,613	46,919
426	130	5.1181	340	13.3858	78	3.0709	6.788	11.716	0.315	2 1/16	13	84,120	101,298	10	75,163	82,704
028	140	5.5118	190	7.4803	24	0.9449	5.844	7.148	0.059	5/8	29	20,138	24,480	18	16,020	16,749
128	140	5.5118	210	8.2677	33	1.2992	5.931	7.849	0.079	7/8	22	32,489	35,412	14	26,156	24,375
228	140	5.5118	250	9.8425	42	1.6535	6.139	9.215	0.098	1 5/16	16	50,941	54,519	10	40,117	36,632
328	140	5.5118	300	11.811	62	2.4409	6.353	10.970	0.118	2	12	76,293	86,555	8	61,797	61,139
428	140	5.5118	360	14.1732	82	3.2283	7.181	12.504	0.315	2 3/16	13	91,352	114,099	11	87,000	102,490
030	150	5.9055	210	8.2677	28	1.1024	6.297	7.876	0.079	3/4	26	26,528	31,598	16	20,972	21,163
130	150	5.9055	225	8.8583	35	1.3780	6.359	8.405	0.079	7/8	23	33,030	37,436	15	27,094	26,512
230	150	5.9055	270	10.6299	45	1.7717	6.561	9.974	0.098	1 7/16	16	57,935	65,055	10	45,588	43,681
430	150	5.9055	380	14.9606	85	3.3465	7.575	13.291	0.315	2 5/16	13	98,752	127,660	11	94,066	114,691
032	160	6.2992	220	8.6614	28	1.1024	6.688	8.273	0.079	3/4	27	26,906	32,914	17	21,598	22,717
132	160	6.2992	240	9.4488	38	1.4961	6.776	8.972	0.079	1	22	41,316	46,252	14	33,263	31,836
232	160	6.2992	290	11.4173	48	1.8898	6.987	10.730	0.098	1 5/8	15	66,106	76,907	9	50,535	49,347
034	170	6.6929	230	9.0551	28	1.1024	7.083	8.665	0.079	3/4	29	27,879	35,214	18	22,196	24,133
134	170	6.6929	260	10.2362	42	1.6535	7.192	9.737	0.079	1 1/8	21	47,627	55,487	13	37,582	37,060
036	180	7.0866	250	9.8425	33	1.2992	7.499	9.430	0.079	7/8	27	35,730	44,724	17	28,681	30,745
136	180	7.0866	280	11.0236	46	1.8110	7.584	10.526	0.079	1 1/8	22	48,531	58,721	14	39,096	40,505
038	190	7.4803	260	10.2362	33	1.2992	7.890	9.826	0.079	7/8	28	36,264	46,457	17	28,415	30,957
138	190	7.4803	290	11.4173	46	1.8110	7.988	10.910	0.079	1 3/16	22	52,455	65,320	14	42,243	45,007
040	200	7.8740	280	11.0236	38	1.4961	8.342	10.555	0.079	1	26	44,524	56,175	16	35,199	37,624
042	210	8.2677	290	11.4173	38	1.4961	8.734	10.951	0.079	1	27	45,278	58,471	17	36,346	40,288
044	220	8.6614	300	11.8110	38	1.4961	9.126	11.346	0.079	1	28	45,992	60,606	18	37,451	42,840

* Reduce by .025 for fractured race HD bearings ** Reduce by .050 for fractured race HD bearings

† Ball complement is normally one less than the number listed when non-metallic separators or separable HT and HA bearings with drop center separators for ball retention are specified.

R = the maximum shaft or housing fillet radius that bearing corner will clear
C = the dynamic radial capacity at 33 1/3 RPM for 500 hours minimum life
Co = the static non-brinell radial capacity

INNER RING

	Bore Diameter		Mean Bore Diameter (+.0000 to minus value below) ABEC/RBEC Classes					Bore Diametral Taper, Max ABEC/RBEC Classes					Ring Width (+.0000 to minus value below)			
													Single Bearing ABEC/RBEC		Preloaded Single Bearing ABEC/RBEC	
	Over	Includ.	1	3	5	7	9	1	3	5	7	9	1,3	5,7,9	1,3	5,7,9
INCHES	0.0984	0.3937	3	3	2	1.5	1	2.5	2	1	1	0.5	47	16	98	98
	0.3937	0.7087	3	3	2	1.5	1	2.5	2	1	1	0.5	47	31	98	98
	0.7087	1.1811	4	3	2.5	2	1	3	2.5	1	1	0.5	47	47	98	98
	1.1811	1.9685	4.5	4	3	2.5	1	3.5	3	1.5	1	0.5	47	47	98	98
	1.9685	3.1496	6	4.5	3.5	3	1.5	4.5	3.5	2	1.5	1	59	59	150	98
	3.1496	4.7244	8	6	4	3	2	6	4.5	2	1.5	1	79	79	150	150
	4.7244	5.9055	10	7	5	4	3	7.5	5.5	3	2	1.5	98	98	197	150
	5.9055	7.0866	10	7	5	4	3	7.5	5.5	3	2	1.5	98	98	197	150
	7.0866	9.8425	12	8.5	6	4.5	3	9	6.5	3	2.5	1.5	118	118	197	197
	9.8425	12.4016	14	10	7	-	-	10	7.5	3.5	-	-	138	138	197	197
	12.4016	15.7480	16	12	9	-	-	12	9	4.5	-	-	157	157	248	248
	15.7480	19.6850	18	14	-	-	-	13	10	-	-	-	177	-	-	-
	19.6850	24.8031	20	16	-	-	-	15	12	-	-	-	197	-	-	-
	24.8031	31.4961	30	-	-	-	-	-	-	-	-	-	295	-	-	-
MILLIMETERS	2.5	10	8	7	5	4	2.5	6	5	3	2	1.5	120	40	250	250
	10	18	8	7	5	4	2.5	6	5	3	2	1.5	120	80	250	250
	18	30	10	8	6	5	2.5	8	6	3	2.5	1.5	120	120	250	250
	30	50	12	10	8	6	2.5	9	8	4	3	1.5	120	120	250	250
	50	80	15	12	9	7	4	11	9	5	3.5	2	150	150	380	250
	80	120	20	15	10	8	5	15	11	5	4	2.5	200	200	380	380
	120	150	25	18	13	10	7	19	14	7	5	3.5	250	250	500	380
	150	180	25	18	13	10	7	19	14	7	5	3.5	250	250	500	380
	180	250	30	22	15	12	8	23	17	8	6	4	300	300	500	500
	250	315	35	25	18	-	-	26	19	9	-	-	350	350	500	500
	315	400	40	30	23	-	-	30	23	12	-	-	400	400	630	630
	400	500	45	35	-	-	-	34	26	-	-	-	450	-	-	-
	500	630	50	40	-	-	-	38	30	-	-	-	500	-	-	-
	630	800	75	-	-	-	-	-	-	-	-	-	750	-	-	-

Inch tolerance in .0001 inches

Metric tolerance in micrometers

	Bore Diameter		Bore 2pt Diametral Roundness, Max 000 (1900) Diameter Series ABEC/RBEC Classes					Bore 2pt Diametral Roundness, Max 100 Diameter Series ABEC/RBEC Classes					Bore 2pt Diametral Roundness, Max 200, 300, 400 Diameter Series ABEC/RBEC Classes				
	Over	Includ.	1	3	5	7		1	3	5	7	9	1	3	5	7	9
INCHES	0.0984	0.3937	4	3.5	2	1.5		3	3	1.5	1	1	2.5	2	1.5	1	1
	0.3937	0.7087	4	3.5	2	1.5		3	3	1.5	1	1	2.5	2	1.5	1	1
	0.7087	1.1811	5	4	2.5	2		4	3	2	1.5	1	3	2.5	2	1.5	1
	1.1811	1.9685	6	5	3	2.5		4.5	4	2.5	2	1	3.5	3	2.5	2	1
	1.9685	3.1496	7.5	6	3.5	3		7.5	6	3	2	1.5	4.5	3.5	3	2	1.5
	3.1496	4.7244	10	7.5	4	3		10	7.5	3	2.5	2	6	4.5	3	2.5	2
	4.7244	5.9055	12	9	5	4		12	9	4	3	3	7.5	5.5	4	3	3
	5.9055	7.0866	12	9	5	4		12	9	4	3	3	7.5	5.5	4	3	3
	7.0866	9.8425	15	11	6	4.5		15	11	4.5	3.5	3	9	6.5	4.5	3.5	3
	9.8425	12.4016	17	12	7	-		17	12	5.5	-	-	10	7.5	5.5	-	-
	12.4016	15.7480	20	15	9	-		20	15	7	-	-	12	9	7	-	-
	15.7480	19.6850	22	17	-	-		22	17	-	-	-	13	10	-	-	-
	19.6850	24.8031	25	20	-	-		25	20	-	-	-	15	12	-	-	-
	24.8031	31.4961	-	-	-	-		-	-	-	-	-	-	-	-	-	-
MILLIMETERS	2.5	10	10	9	5	4		8	7	4	3	2.5	6	5	4	3	2.5
	10	18	10	9	5	4		8	7	4	3	2.5	6	5	4	3	2.5
	18	30	13	10	6	5		10	8	5	4	2.5	8	6	5	4	2.5
	30	50	15	13	8	6		12	10	6	5	2.5	9	8	6	5	2.5
	50	80	19	15	9	7		19	15	7	5	4	11	9	7	5	4
	80	120	25	19	10	8		25	19	8	6	5	15	11	8	6	5
	120	150	31	23	13	10		31	23	10	8	7	19	14	10	8	7
	150	180	31	23	13	10		31	23	10	8	7	19	14	10	8	7
	180	250	38	28	15	12		38	28	12	9	8	23	17	12	9	8
	250	315	44	31	18	-		44	31	14	-	-	26	19	14	-	-
	315	400	50	38	23	-		50	38	18	-	-	30	23	18	-	-
	400	500	56	44	-	-		56	44	-	-	-	34	26	-	-	-
	500	630	63	50	-	-		63	50	-	-	-	38	30	-	-	-
	630	800	-	-	-	-		-	-	-	-	-	-	-	-	-	-

Inch tolerance in .0001 inches

Metric tolerance in micrometers

All bearings described in this design guide can be manufactured to ABEC/RBEC 1,3,5,7 or 9 tolerances. Generally, ABEC/RBEC 5 is the preferred tolerance level for high-reliability aircraft systems. ABEC 7 and 9 are normally specified only on ball bearings where closer mounting tolerances and runout are essential for precise position control. Otherwise, performance is similar to ABEC/RBEC 5, which is available at a lower cost.

ABEC/RBEC 1 and 3 are generally used in industrial and less critical aircraft accessory applications. To facilitate selection, the tolerance charts below summarize mean bore, outside diameter, width tolerance and maximum radial runout of each ring for all classes. Please refer to ABMA Standard 20 for a complete table of all dimensions.

How to specify

ABEC/RBEC precision tolerance levels 1 through 9 are indicated in split ball bearing part numbers by the suffixes P1, P3, P5 or P9.

INNER RING

	Bore Diameter		Radial Runout, Max ABEC/RBEC Classes					Axial Runout, Max ABEC/RBEC Classes					
	Over	**Includ.**	**1**	**3**	**5**	**7**	**9**	**1**	**3**	**5**	**7**	**9**	
INCHES	0.0984	0.3937	4	2.5	1.5	1	0.5	8	6	3	1	0.5	Inch tolerance in .0001 inches
	0.3937	0.7087	4	3	1.5	1	0.5	8	8	3	1	0.5	
	0.7087	1.1811	5	3	1.5	1	1	10	8	3	1.5	1	
	1.1811	1.9685	6	4	2	1.5	1	12	8	3	1.5	1	
	1.9685	3.1496	8	4	2	1.5	1	12	10	3	2	1	
	3.1496	4.7244	10	5	2.5	2	1	14	10	3.5	2	1	
	4.7244	5.9055	12	7	3	2.5	1	16	12	4	3	1	
	5.9055	7.0866	12	7	3	2.5	2	16	12	4	3	2	
	7.0866	9.8425	16	8	4	3	2	18	14	5	3	2	
	9.8425	12.4016	20	10	5	-	-	22	16	6	-	-	
	12.4016	15.7480	24	12	6	-	-	26	18	8	-	-	
	15.7480	19.6850	26	14	-	-	-	30	20	-	-	-	
	19.6850	24.8031	28	16	-	-	-	35	22	-	-	-	
	24.8031	31.4961	31	-	-	-	-	39	-	-	-	-	
MILLIMETERS	2.5	10	10	6	4	2.5	1.5	20	15	7	3	1.5	Metric tolerance in micrometers
	10	18	10	7	4	2.5	1.5	20	20	7	3	1.5	
	18	30	13	8	4	3	2.5	25	20	8	4	2.5	
	30	50	15	10	5	4	2.5	30	20	8	4	2.5	
	50	80	20	10	5	4	2.5	30	25	8	5	2.5	
	80	120	25	13	6	5	2.5	35	25	9	5	2.5	
	120	150	30	18	8	6	2.5	40	30	10	7	2.5	
	150	180	30	18	8	6	5	40	30	10	7	5	
	180	250	40	20	10	8	5	45	35	13	8	5	
	250	315	50	25	13	-	-	55	40	15	-	-	
	315	400	60	30	15	-	-	65	45	20	-	-	
	400	500	65	35	-	-	-	75	50	-	-	-	
	500	630	70	40	-	-	-	90	55	-	-	-	
	630	800	80	-	-	-	-	100	-	-	-	-	

	Bore Diameter		Face to Bore Runout, Max ABEC/RBEC Classes					Face Parallelism, Max ABEC/RBEC Classes					
	Over	**Includ.**	**1**	**3**	**5**	**7**	**9**	**1**	**3**	**5**	**7**	**9**	
INCHES	0.0984	0.3937	NR	NR	3	1	0.5	6	6	2	1	0.5	Inch tolerance in .0001 inches
	0.3937	0.7087	NR	NR	3	1	0.5	8	8	2	1	0.5	
	0.7087	1.1811	NR	NR	3	1.5	0.5	8	8	2	1	0.5	
	1.1811	1.9685	NR	NR	3	1.5	0.5	8	8	2	1	0.5	
	1.9685	3.1496	NR	NR	3	2	0.5	10	10	2.5	1.5	0.5	
	3.1496	4.7244	NR	NR	3.5	2	1	10	10	3	1.5	1	
	4.7244	5.9055	NR	NR	4	2.5	1	12	12	3	2	1	
	5.9055	7.0866	NR	NR	4	2.5	1.5	12	12	3	2	1.5	
	7.0866	9.8425	NR	NR	4.5	3	2	12	12	4	2.5	2	
	9.8425	12.4016	NR	NR	5	-	-	14	14	5	-	-	
	12.4016	15.7480	NR	NR	6	-	-	16	16	6	-	-	
	15.7480	19.6850	-	-	-	-	-	20	18	-	-	-	
	19.6850	24.8031	-	-	-	-	-	24	20	-	-	-	
	24.8031	31.4961	-	-	-	-	-	28	-	-	-	-	
MILLIMETERS	2.5	10	NR	NR	7	3	1.5	15	15	5	2.5	1.5	Metric tolerance in micrometers
	10	18	NR	NR	7	3	1.5	20	20	5	2.5	1.5	
	18	30	NR	NR	8	4	1.5	20	20	5	2.5	1.5	
	30	50	NR	NR	8	4	1.5	20	20	5	3	1.5	
	50	80	NR	NR	8	5	1.5	25	25	6	4	1.5	
	80	120	NR	NR	9	5	2.5	25	25	7	4	2.5	
	120	150	NR	NR	10	6	2.5	30	30	8	5	2.5	
	150	180	NR	NR	10	6	4	30	30	8	5	4	
	180	250	NR	NR	11	7	5	30	30	10	6	5	
	250	315	NR	NR	13	-	-	35	35	13	-	-	
	315	400	NR	NR	15	-	-	40	40	15	-	-	
	400	500	-	-	-	-	-	50	45	-	-	-	
	500	630	-	-	-	-	-	60	50	-	-	-	
	630	800	-	-	-	-	-	70	-	-	-	-	

OUTER RING

	Outside Diameter (O.D.)		Mean O.D. Diameter (+.0000 to minus value below) ABEC/RBEC Classes					O.D. Diameteral Taper, Max ABEC/RBEC Classes					Ring Width (+.0000 to minus value below)			
													Single Bearing ABEC/RBEC		Preloaded Single Bearing ABEC/RBEC	
	Over	**Includ.**	**1**	**3**	**5**	**7**	**9**	**1**	**3**	**5**	**7**	**9**	**1,3**	**5,7,9**	**1,3**	**5,7,9**
INCHES	0.7087	1.1811	3.5	3	2.5	2	1.5	3	2.5	1	1	1	47	31	98	98
	1.1811	1.9685	4.5	3.5	3	2.5	1.5	3	3	1.5	1	1	47	47	98	98
	1.9685	3.1496	5	4.5	3.5	3	1.5	4	3	2	1.5	1	47	47	98	98
	3.1496	4.7244	6	5	4	3	2	4.5	4	2	1.5	1	59	59	150	98
	4.7244	5.9055	7	6	4.5	3.5	2	5.5	4.5	2.5	2	1	79	79	150	150
	5.9055	7.0866	10	7	5	4	3	7.5	5.5	3	2	1.5	98	98	197	150
	7.0866	9.8425	12	8	6	4.5	3	9	6	3	2.5	1.5	98	98	197	150
	9.8425	12.4016	14	10	7	5	3	10	7.5	3.5	3	1.5	118	118	197	197
	12.4016	15.7480	16	11	8	6	4	12	8.5	4	3	2	138	138	197	197
	15.7480	19.6850	18	13	9	-	-	13	10	4.5	-	-	157	157	248	248
	19.6850	24.8032	20	15	11	-	-	15	11	5.5	-	-	177	-	-	-
	24.8032	31.4961	30	18	14	-	-	22	13	7	-	-	197	-	-	-
	31.4961	39.3701	39	24	-	-	-	30	18	-	-	-	295	-	-	-
MILLIMETERS	18	30	9	8	6	5	4	7	6	3	2.5	2	120	80	250	250
	30	50	11	9	7	6	4	8	7	4	3	2	120	120	250	250
	50	80	13	11	9	7	4	10	8	5	3.5	2	120	120	250	250
	80	120	15	13	10	8	5	11	10	5	4	2.5	150	150	380	250
	120	150	18	15	11	9	5	14	11	6	5	2.5	200	200	380	380
	150	180	25	18	13	10	7	19	14	7	5	3.5	250	250	500	380
	180	250	30	20	15	11	8	23	15	8	6	4	250	250	500	380
	250	315	35	25	18	13	8	26	19	9	7	4	300	300	500	500
	315	400	40	28	20	15	10	30	21	10	8	5	350	350	500	500
	400	500	45	33	23	-	-	34	25	12	-	-	400	400	630	630
	500	630	50	38	28	-	-	38	29	14	-	-	450	-	-	-
	630	800	75	45	35	-	-	55	34	18	-	-	500	-	-	-
	800	1000	100	60	-	-	-	75	45	-	-	-	750	-	-	-

Inch tolerance in .0001 inches

Metric tolerance in micrometers

	Outside Diameter (O.D.)		O.D. 2pt Diametral Roundness, Max 000 (1900) Diameter Series ABEC/RBEC Classes					O.D. 2pt Diametral Roundness, Max 100 Diameter Series ABEC/RBEC Classes					O.D. 2pt Diametral Roundness, Max 200, 300, 400 Diameter Series ABEC/RBEC Classes				
	Over	**Includ.**	**1**	**3**	**5**	**7**		**1**	**3**	**5**	**7**	**9**	**1**	**3**	**5**	**7**	**9**
INCHES	0.7087	1.1811	4.5	4	2.5	2		3.5	3	2	1.5	1.5	3	2.5	2	1.5	1.5
	1.1811	1.9685	5.5	4.5	3	2.5		4.5	3.5	2	2	1.5	3	3	2	2	1.5
	1.9685	3.1496	6.5	5.5	3.5	3		5	4.5	3	2	1.5	4	3	3	2	1.5
	3.1496	4.7244	7.5	6.5	4	3		7.5	6.5	3	2.5	2	4.5	4	3	2.5	2
	4.7244	5.9055	9	7.5	4.5	3.5		9	7.5	3	3	2	5.5	4.5	3	3	2
	5.9055	7.0866	12	9	5	4		12	9	4	3	3	7.5	5.5	4	3	3
	7.0866	9.8425	15	10	6	4.5		15	10	4.5	3	3	9	6	4.5	3	3
	9.8425	12.4016	17	12	7	5		17	12	5.5	4	3	10	7.5	5.5	4	3
	12.4016	15.7480	20	14	8	6		20	14	6	4.5	4	12	8.5	6	4.5	4
	15.7480	19.6850	22	16	9	-		22	16	6.5	-	-	13	10	6.5	-	-
	19.6850	24.8032	25	19	11	-		25	19	8.5	-	-	15	11	8.5	-	-
	24.8032	31.4961	37	22	14	-		37	22	10	-	-	22	13	10	-	-
	31.4961	39.3701	49	30	-	-		49	30	-	-	-	30	18	-	-	-
MILLIMETERS	18	30	12	10	6	5		9	8	5	4	4	7	6	5	4	4
	30	50	14	11	7	6		11	9	5	5	4	8	7	5	5	4
	50	80	16	14	9	7		13	11	7	5	4	10	8	7	5	4
	80	120	19	16	10	8		19	16	8	6	5	11	10	8	6	5
	120	150	23	19	11	9		23	19	8	7	5	14	11	8	7	5
	150	180	31	23	13	10		31	23	10	8	7	19	14	10	8	7
	180	250	38	25	15	11		38	25	11	8	8	23	15	11	8	8
	250	315	44	31	18	13		44	31	14	10	8	26	19	14	10	8
	315	400	50	35	20	15		50	35	15	11	10	30	21	15	11	10
	400	500	56	41	23	-		56	41	17	-	-	34	25	17	-	-
	500	630	63	48	28	-		63	48	21	-	-	38	29	21	-	-
	630	800	94	56	35	-		94	56	26	-	-	55	34	26	-	-
	800	1000	125	75	-	-		125	75	-	-	-	75	45	-	-	-

Inch tolerance in .0001 inches

Metric tolerance in micrometers

OUTER RING

	Outside Diameter (O.D.)		Radial Runout, Max ABEC/RBEC Classes					Axial Runout, Max ABEC/RBEC Classes				
	Over	**Includ.**	**1**	**3**	**5**	**7**	**9**	**1**	**3**	**5**	**7**	**9**
INCHES	0.7087	1.1811	6	3.5	2.5	1.5	1	10	6	3	2	1
	1.1811	1.9685	8	4	3	2	1	12	8	3	2	1
	1.9685	3.1496	10	5	3	2	1.5	14	8	4	2	1.5
	3.1496	4.7244	14	7	4	2.5	2	16	10	4.5	2.5	2
	4.7244	5.9055	16	8	4.5	3	2	18	12	5	3	2
	5.9055	7.0866	18	9	5	3	2	22	14	5.5	3	2
	7.0866	9.8425	20	10	6	4	3	26	16	6	4	3
	9.8425	12.4016	24	12	7	4.5	3	30	18	7	4	3
	12.4016	15.7480	28	14	8	5	3	35	20	8	5	3
	15.7480	19.6850	31	16	9	-	-	39	22	9	-	-
	19.6850	24.8032	39	20	10	-	-	43	24	10	-	-
	24.8032	31.4961	47	24	12	-	-	47	26	12	-	-
	31.4961	39.3701	55	30	-	-	-	49	28	-	-	-
MILLIMETERS	18	30	15	9	6	4	2.5	25	15	8	5	2.5
	30	50	20	10	7	5	2.5	30	20	8	5	2.5
	50	80	25	13	8	5	4	35	20	10	5	4
	80	120	35	18	10	6	5	40	25	11	6	5
	120	150	40	20	11	7	5	45	30	13	7	5
	150	180	45	23	13	8	5	55	35	14	8	5
	180	250	50	25	15	10	7	65	40	15	10	7
	250	315	60	30	18	11	7	75	45	18	10	7
	315	400	70	35	20	13	8	90	50	20	13	8
	400	500	80	40	23	-	-	100	55	23	-	-
	500	630	100	50	25	-	-	110	60	25	-	-
	630	800	120	60	30	-	-	120	65	30	-	-
	800	1000	140	75	-	-	-	125	70	-	-	-

Inch tolerance in .0001 inches

Metric tolerance in micrometers

	Outside Diameter (O.D.)		OD to Face Runout, Max ABEC/RBEC Classes					Face Parallelism, Max ABEC/RBEC Classes				
	Over	**Includ.**	**1**	**3**	**5**	**7**	**9**	**1**	**3**	**5**	**7**	**9**
INCHES	0.7087	1.1811	NR	NR	3	1.5	0.5	8	8	2	1	0.5
	1.1811	1.9685	NR	NR	3	1.5	0.5	8	8	2	1	0.5
	1.9685	3.1496	NR	NR	3	1.5	0.5	8	8	2.5	1	0.5
	3.1496	4.7244	NR	NR	3.5	2	1	10	10	3	1.5	1
	4.7244	5.9055	NR	NR	4	2	1	10	10	3	2	1
	5.9055	7.0866	NR	NR	4	2	1	12	12	3	2	1
	7.0866	9.8425	NR	NR	4.5	3	1.5	12	12	4	3	1.5
	9.8425	12.4016	NR	NR	5	3	2	12	12	4.5	3	2
	12.4016	15.7480	NR	NR	5	4	3	14	14	5	3	3
	15.7480	19.6850	NR	NR	6	-	-	16	16	6	-	-
	19.6850	24.8032	NR	NR	7	-	-	20	18	7	-	-
	24.8032	31.4961	NR	NR	8	-	-	24	20	8	-	-
	31.4961	39.3701	-	-	-	-	-	28	-	-	-	-
MILLIMETERS	18	30	NR	NR	8	4	1.5	20	20	5	2.5	1.5
	30	50	NR	NR	8	4	1.5	20	20	5	2.5	1.5
	50	80	NR	NR	8	4	1.5	20	20	6	3	1.5
	80	120	NR	NR	9	5	2.5	25	25	8	4	2.5
	120	150	NR	NR	10	5	2.5	25	25	8	5	2.5
	150	180	NR	NR	10	5	2.5	30	30	8	5	2.5
	180	250	NR	NR	11	7	4	30	30	10	7	4
	250	315	NR	NR	13	8	5	30	30	11	7	5
	315	400	NR	NR	13	10	7	35	35	13	8	7
	400	500	NR	NR	15	-	-	40	40	15	-	-
	500	630	NR	NR	18	-	-	50	45	18	-	-
	630	800	NR	NR	20	-	-	60	50	20	-	-
	800	1000	-	-	-	-	-	70	-	-	-	-

Inch tolerance in .0001 inches

Metric tolerance in micrometers

Non-Destructive Testing

In addition to the basic dimensional characteristics defined by the ABMA, many aspects of quality and reliability assurance are dependent upon the integrity of the manufacturer as well as supplemental tests that are agreed upon in the final specification. Controls on finish, raceway waviness, lobing, roller-path flatness and many other minute variables are carefully defined as a function of tolerance level by Timken. Non-destructive testing techniques are used on a sample basis to ensure reliability against cracks, material defects and grinding temper marks.

For critical bearings, 100 percent non-destructive testing using fluorescent penetrant, magnetic particle inspection, nital etch testing, Barkhausen noise testing or Eddy Current testing is available on a contract basis to ensure ultimate reliability of all components.

Materials and Operating Temperatures

Standard Material—
High Chrome 52100 Bearing Steel (AMS 6440)

Unless otherwise indicated, all bearings listed in this design guide are manufactured from vacuum-degassed, bearing-quality, 52100 steel (AMS 6440). Rings and rolling elements are thoroughly heat treated under controlled atmospheres to provide the uniform stable structure required for antifriction bearings. All ABEC/RBEC 3 and better bearings are stabilized with special tempers and 120°F (-84°C) sub-cooling cycles. This permits operating temperatures ranging from cryogenic temperatures to 375°F (190°C) with a hardness of Rockwell C60 minimum on most standard configurations and Rockwell C58 minimum on more complex shapes or where higher temperatures are required. Retained austenite is held well within 5 percent.

Special Materials

CEVM 52100 (AMS 6444) consumable electrode vacuum remelt improves reliability and fatigue life over 52100 at temperatures under 375°F (190°C). A life improvement factor of 5 can be applied in most applications. Timken generally recommends that in an application critical enough to require CEVM 52100, the slight additional cost of VIM-VAR M-50 is more than justified by its many additional benefits.

VIM-VAR 52100 (AMS 6444) vacuum induction melt, followed by a vacuum arc remelt, further improves reliability and fatigue life. Hardness and heat treatment are similar to other 52100 grades.

VIM-VAR M-50 High-Speed (AMS 6491)
Vacuum induction melt-vacuum arc remelt M-50 has proven to be the most satisfactory advanced performance material for demanding aircraft engine and accessory positions. VIM-VAR M-50 provides four specific areas of improved performance:

1) M-50 permits operation at or exposure to temperatures to 900°F (482°C) with no permanent size change or loss of hardness. Retained austenite is under 3 percent.
2) M-50 provides extended fatigue life (more than 10 times that of air melt 52100) in the 150° to 400°F (66° to 204°C) range common to most aircraft applications. It compensates for application conditions that may cause severe reduction in experienced life, e.g., rapid acceleration, marginal housing or shaft support, differential temperatures, misalignment and other unavoidable conditions.
3) M-50 extends life in "oil out" or marginal lubricant conditions. Under these conditions, surface temperatures immediately rise causing surface tempering, deformation and seizure. Even after exposure to temperatures as high as 1100°F (593°C) M-50 will not soften significantly (compared to 500°F [260°C] for 52100) providing an extra margin of fail-safe life.
4) M-50's moly-carbides provide greater hardness to reduce fretting and wear under slow-speed or oscillating conditions.

VIM-VAR M-50 NIL (AMS 6278) is a carburized case-hardened variation of M-50 which provides improved fracture toughness due to its softer core. All properties of conventional M-50, including high-temperature stability and rolling contact fatigue life, are retained. Potential applications include ultra-high-speed (2.4 million dn and above) mainshaft and other applications limited by low fractures toughness.

440C Stainless steel (AMS 5880), a 16 percent chromium steel common to miniature and instrument bearings, is also used in special metric bearings requiring corrosion resistance. Special tempering and subcooling cycles provide stable operating temperatures through 375°F (190°C). Optional high-temperature draw cycles provide stability at temperatures to 800°F (425°C). However, this option reduces corrosion resistance. Typical applications include large instrument bearings, reactor control bearings, bearings immersed in jet fuel and lightly loaded high-temperature thrust reverse controls.

Modified 440C alloys, similar to 440C, contain additional molybdenum to improve hot hardness at high tempering temperatures for applications requiring corrosion and oxidation resistance. In some applications, they provide the best features of both 440C and M-50. However, their high alloy content has led to unpredictable variations in experienced fatigue life. Examples of modified 440C include BG 42 and CRB7.

CSS42L® (AMS 5932) is a case-carburized, stainless-steel alloy suitable for use up to 800°F (427°C) in high-performance, rolling-element bearings. This alloy combines high hardness, fracture toughness, corrosion resistance ands rolling contact fatigue resistance to optimize bearing performance for demanding application. This alloy was developed by Timken Latrobe Steel Co. The room temperature case hardness is 68 Rc minimum, maintaining case hardness of 62 Rc at 800°F (427°C).

BG-42® (AMS 5749) VIM-VAR, a high-performance Cr-Mo-V alloy, is ideal for bearing applications where a hardenable martensitic stainless steel is needed for corrosion resistance, with a combined hot hardness less than 440°C. It performs similar to M-50 but with added properties described above. Multiple remelting enhances material cleanliness and provides a more reliable performance and fatigue life. It is suitable for use where application temperatures are up to 800°F (427°C).

Pyrowear 675® (AMS 5930) is a carburizing grade of stainless, corrosion-resistant steel developing a HRc 60 case with a tough ductile core. It has corrosion resistance equivalent to 440C steel.

Ceramics, Norton Noralide, NBD 200 is available for full ceramic and hybrid bearings. This is a high-performance ceramic, proven to be beneficial for certain high-temperature, high-corrosive environments. When corrosive environments or exceptionally non-typical bearing temperatures or very high speeds are anticipated in a design, it may be useful to apply a "hybrid" construction, whereby properly designed race and cage materials can be mated with ceramic rolling elements – balls or rollers – to obtain the maximum benefits of each. These special applications should be discussed with a Timken engineer for guidance.

How to specify

To select material, choose one of the following as the prefix to the Timken part number:

None – 52100
3 – 440C
5 – VIM-VAR M50
25 – BG42®
26 – CEVM 52100
34 – CEVM 440C
35 – VIM-VAR M50 Nil
58 – Pyrowear 675®
59 – CSS42L®
303 – Noralide, NBD 200

Radial Play and Contact Angle

Radial play or free internal clearance is one of the most critical bearing design parameters. Contrary to a common misconception, it has nothing to do with quality or ABEC tolerance level. In both ball and roller bearings, radial play is defined as the free radial displacement of the outer ring with respect to a fixed inner ring. In ball bearings, it directly affects and controls the operating contact angle and free axial or end play. In some ball bearing applications, contact angle or end play may be the controlling specification. In these cases, radial play is not designated but is offered as a "reference."

Radial Play Selection – HK, HD and R Types

Ball bearings are normally manufactured to one of the five standard ABMA ranges shown in the chart, page 18. Unless otherwise specified, Timken HK (Conrad) and HD (fractured outer race) ball bearings and R-series roller bearings are supplied with ABMA Group N standard clearances. This standard range has excellent radial stability and load capacity. In ball bearings, Group N provides good resistance to cocking loads and a reasonable degree of axial location without preloading. It also allows for a light press fit on the inner ring for normal rotating shaft applications.

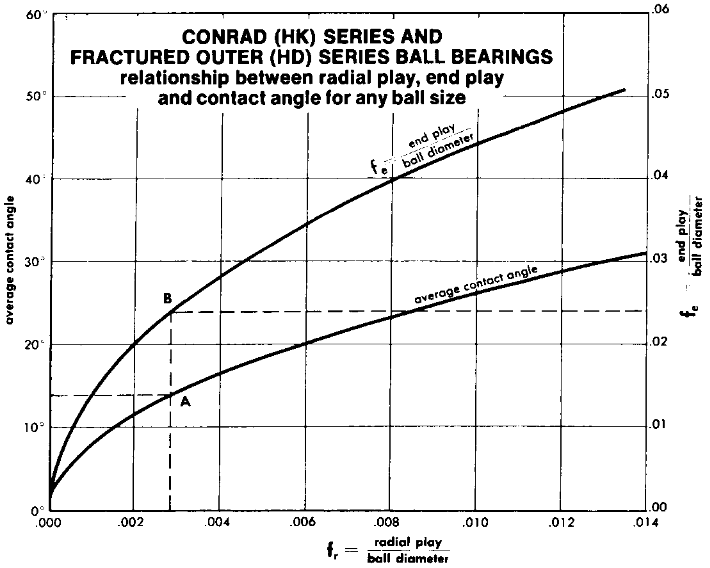
Looser fits – Group 3 and Group 4 clearances may be specified in a bearing for a number of reasons:

1) To allow for a press fit on the outer race and where necessary on both races. Keep in mind that 50 to 75 percent of an interference fit is reflected in loss of radial play. Temperature extremes cause additional changes in radial play occur when dissimilar materials are used for shaft and housing materials.
2) To provide higher contact angles under thrust loads thereby reducing stress level which increases fatigue life, reduces torque and improves operating efficiency.
3) To provide greater axial stability, particularly in preloaded bearings.
4) To allow greater static and dynamic misalignment.

Tighter fits – Group 2 clearance may be specified for a bearing slip-fit mounted in both the housing and on the shaft and operating under straight radial loads. If cocking loads are unavoidable, Group 2 provides the greatest resistance and angular control. If preloading between two bearings is impractical it also provides the most precise axial location.

Relationship Between Radial Play, End Play and Contact Angle (HK and HD Series Ball Bearings)

The following graph provides the designer with the means to calculate the relationship between radial play, contact angle and end play for Timken bearings with standard inner and outer race curvatures. Since curvature significantly affects this relationship, any bearing with inverse curvature or reduced curvature for extra-high load capacity will have a different relationship. The values obtained with this graph are averages and should not be interpreted as acceptance or manufacturing limits.



Example: Determine the average contact angle and the average end play on an HD 106 bearing with Group 3 (loose) internal clearance:

1) From table of dimensions (see Ball Bearing Specifications page 9) the ball diameter is found to be $\frac{9}{32}$" (0.28125").

Radial Play and Contact Angle continued

	Bore Diameter		Group 2		Group N		Group 3		Group 4		Group 5	
	Over	Includ.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
INCHES	0.2362	0.3937	0	3	1	5	3	9	6	11	8	15
	0.3937	0.7087	0	3.5	1	7	4.5	10	7	13	10	18
	0.7087	0.9449	0	4	2	8	5	11	8	14	11	19
	0.9449	1.1811	0.5	4.5	2	8	5	11	9	16	12	21
	1.1811	1.5748	0.5	4.5	2.5	8	6	13	11	18	16	25
	1.5748	1.9685	0.5	4.5	2.5	9	7	14	12	20	18	29
	1.9685	2.5591	0.5	6	3	11	9	17	15	24	22	35
	2.5591	3.1496	0.5	0.5	6	4	12	10	20	18	28	26
	3.1496	3.9370	0.5	7	4.5	14	12	23	21	33	30	47
	3.9370	4.7244	1	8	6	16	14	26	24	38	35	55
	4.7244	5.5118	1	9	7	19	16	32	28	45	41	63
	5.5118	6.2992	1	9	7	21	18	36	32	51	47	71
	6.2992	7.0866	1	10	8	24	21	40	36	58	53	79
	7.0886	7.8740	1	12	10	28	25	46	42	64	59	91
	7.8740	8.8583	1	14	10	33	30	55	49	77	69	104
	8.8583	9.8425	1	16	12	37	33	63	57	89	81	118
	9.8425	11.0236	1	18	14	41	35	67	61	96	89	134
	11.0236	12.4016	1	22	16	45	39	75	69	106	96	146
	12.4016	13.9764	1	24	18	49	43	83	77	118	108	161
	13.9764	15.7480	1	28	22	57	51	94	89	134	124	181
	15.7480	17.7165	1	31	24	67	59	106	98	150	138	201
	17.7165	19.6850	1	35	28	75	67	118	110	165	154	224
	19.6850	22.0472	4	39	31	83	75	130	122	185	173	248
	22.0472	24.8031	4	43	35	91	83	142	134	205	193	272
	24.8031	27.9528	8	51	43	102	94	157	150	224	213	299
	27.9528	31.4961	8	55	47	114	106	177	169	248	236	331
	31.4961	35.4331	8	63	55	126	118	197	189	276	264	370
	35.4331	39.3701	8	67	59	138	130	217	209	303	291	409
	39.3701	44.0945	8	71	63	150	142	236	228	335	323	453
	44.0945	49.2126	8	75	67	161	z	256	248	362	350	496
MILLIMETERS	6	10	0	7	2	13	8	23	14	29	20	37
	10	18	0	9	3	18	11	25	18	33	25	45
	18	24	0	10	5	20	13	28	20	36	28	48
	24	30	1	11	5	20	13	28	23	41	30	53
	30	40	1	11	6	20	15	33	28	46	40	64
	40	50	1	11	6	23	18	36	30	51	45	73
	50	65	1	15	8	28	23	43	38	61	55	90
	65	80	1	15	10	30	25	51	46	71	65	105
	80	100	1	18	12	36	30	58	53	84	75	120
	100	120	2	20	15	41	36	66	61	97	90	140
	120	140	2	23	18	48	41	81	71	114	105	160
	140	160	2	23	18	53	46	91	81	130	120	180
	160	180	2	25	20	61	53	102	91	147	135	200
	180	200	2	30	25	71	63	117	107	163	150	230
	200	225	2	35	25	85	75	140	125	195	175	265
	225	250	2	40	30	95	85	160	145	225	205	300
	250	280	2	45	35	105	90	170	155	245	225	340
	280	315	2	55	40	115	100	190	175	270	245	370
	315	355	3	60	45	125	110	210	195	300	275	410
	355	400	3	70	55	145	130	240	225	340	315	460
	400	450	3	80	60	170	150	270	250	380	350	510
	450	500	3	90	70	190	170	300	280	420	390	570
	500	560	10	100	80	210	190	330	310	470	440	630
	560	630	10	110	90	230	210	360	340	520	490	690
	630	710	20	130	110	260	240	400	380	570	540	760
	710	800	20	140	120	290	270	450	430	630	600	840
	800	900	20	160	140	320	300	500	480	700	670	940
	900	1000	20	170	150	350	330	550	530	770	740	1040
	1000	1120	20	180	160	380	360	600	580	850	820	1150
	1120	1250	20	190	170	410	390	650	630	920	890	1260

2) From the chart on page 17, the internal clearance for range 3 for a 106 bearing is .0005” to .0011”.

3) The conditions for average internal clearance (.0008”) or the extremes (.0005” and .0011”) may be read off the graph on page 17. First determine the value of f_r.

$$f_r = \frac{\text{radial play}}{\text{ball diameter}} = \frac{.0008}{.28125} = .00285$$

4) Extend a vertical line from $f_r = .00285$ through curves labeled “Contact Angle” and “f_e” to determine intersection points “A” and “B”.

5) Extend horizontal line to left from “A” to determine average contact angle of 14 degrees.

6) To obtain end play, extend horizontal line to right from point “B” to determine value; $f_e = .024$. Solve equation

$$f_e = \frac{\text{end play}}{\text{ball diameter}}$$

$$\text{end play} = \text{ball diameter} \times f_e = .28125 \times .024 = .0067''$$

Note: An interference fit will reduce the internal clearance by approximately 50 to 75 percent of the amount of interference, giving operating conditions of a tighter internal fit-up. If interference fits are used, first determine the reduced internal clearance, then the contact angle or the average end play of the bearing.

The graph may also be used to determine the required internal clearance range from predetermined axial play or contact angle values.

Radial Play Selection – HA and HT Types

Angular contact (HA) bearings are normally manufactured to a contact angle tolerance, rather than a specified radial play. The two standard contact angles are 15° and 25°; 15° should be used for radial load applications and 25° for high-thrust-load applications.

Split inner race (HT) series bearing are normally manufactured to a contact angle of 25° or higher. Due to the special nature of these bearings, your Timken engineer should be consulted before specifying.

How to specify:

To specify radial play or contact angle choose one of the following alternatives. Then add the suffix to the basic bearing part number. For standard ABMA Range O, code may be omitted.

1) To specify an ABMA radial play range: select code number from table on page 18. Example: Indicates Group 3

2) To specify radial play: Express in ten thousandths (.0001) of an inch x 10,000. Example: (5/15) indicates .0005/.0015 radial play.

3) To specify contact angle code (HA type angular contact bearings only) use letter code in parentheses. Suffix (D) is equivalent to normal contact angle of 25°.

Preloading

There are three basic reasons for preloading a ball bearing:

1) to define more precisely a shaft position.
2) to keep the balls in contact with the race to prevent skidding and reduce noise.
3) to share a load, thrust or radial equally between two bearings.

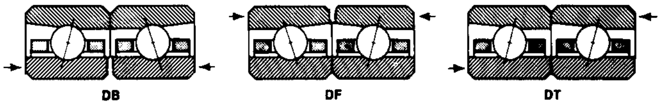
Preloading methods

Conventional radial separator (HK) or angular contact (HA) bearings may be preloaded in an application using one of the following basic techniques:

1) Increase axial load to a predetermined torque range by using adjustable face clamping, for example a nut or screw.
2) Select a shim to create a predetermined torque value or axial deflection value under reversing gage load.
3) Mount bearings with a preload spring, either between inner or outer rings or at one end of the assembly.
4) Use factory preloaded duplex pairs of bearings which provide exact “built-in” preload when face-clamped in a DB, DF or DT configuration.

In categories 1 through 3, where opposed single bearings are involved, two types of preload mounts are possible: “DB” (back- to-back) and “DF” (face-to-face). The type of mount is usually predicated on unit assembly considerations. “DB” mounts are most desirable where overturning moment loading is encountered.

Factory duplexed pairs – Timken supplies pairs of radial bearings that have precision-matched offset. When face-clamped together or against equal length spacers, a predetermined preload value is obtained. Duplex pairs are available in “DB” or “DT” configurations with preload values as selected for individual applications. To avoid unloading of either bearing in a two bearing “DB” or “DF” set, the minimum preload value should equal 1/3 of the applied axial load. The maximum preload limit should then be specified as at least 1.5 times the minimum preload.



Advantage of Each Method

DB – Provides excellent radial, axial and moment stability when there are no additional bearings on the shaft.

DF – Provides radial and axial stability and aligns readily with additional bearings mounted on the same shaft.

DT – Shares extra-high thrust loads equally between two bearings. Does not provide stability unless further preloaded with additional bearings.

Marking

Bearings of DB, DF, and DT duplex sets have two axial lines forming a 30° included angle “V” etched across the outer rings of the pair (with the point of the “V” at the outer ring face to which the load is applied in the case of DT pairs).

How to specify

To specify preload, show preload type DB, DF or DT and min/max preload value desired.
Example: “DB” preload, 8 lbs. min. to 12 lbs. max.
Specify as: DB 8/12
Add this suffix to the standard chassis part number.

Roller bearings may be radially preloaded by application of bi-lobe or tri-lobe geometry to the outer ring, through use of specialized grinding techniques: consult The Timken Company for advice and applicability.

Bearing Mounting Practices

Bearing fits are generally established based upon the application data such as loads, materials, temperatures and speed. Every bearing must be properly fitted before it can meet its performance requirements. Preferably, housing and shaft tolerances should be selected in magnitude approximately equal to the diameter tolerances of the bearing (see tolerance chart on pages 12-15). The normal fitting procedure is to press fit the rotating member from line to tight. The non-rotating member is usually slip fitted from line to loose.

Heavier or out-of-balance loads may require tighter fits to avoid fretting damage to housing or shaft. In these cases, additional radial play is required to compensate for the press fit.

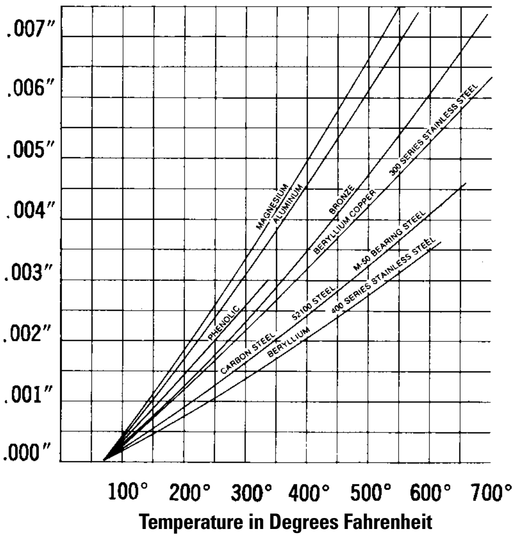
Shaft and housing shoulders should be of adequate height to properly support the face of the bearing. See suggested minimum shaft and maximum housing dimensions in the bearing specifications tables. Shoulders should be carefully machined to prevent misalignment and have a corner fillet radius not exceeding the radius dimension listed in the specifications.

It is always preferable to use shaft and housing materials having compatible coefficients of expansion with the bearing. Whenever this is impractical due to weight or other material consideration, use the adjacent chart to determine the possible degree of looseness or interference at temperature extremes. This additional looseness or tightness can be partially compensated for by adjusting fits and radial play.

Effect of Fitting Practice on Radial Play and Preload

Keep in mind that 50 to 75 percent of the interference fit at any temperature extreme is reflected in loss of radial play. Press fits are even more significant in their effect on increasing preload in factory-duplexed fits. For example, with an HA 107 having a 10-pound preload, a .0006″ press fit of the inner race on a solid steel shaft would increase the preload in excess of 100 pounds. To avoid excessive as-mounted preloads, pairs are either mounted with loose fits or specified as “matched and coded” on the bores and/or O.D.s so that a fit of .0001″ tight on the rotating member can be established. Contact Timken for specific application assistance.

Linear or diametral expansion in inches from 70°F.



To determine expansion or potential fit variation for dissimilar materials: Multiply bore or O.D. diameter times the expansion for each material at the maximum temperature required. Contraction at temperatures below 70°F is equal to the expansion for a comparable temperature differential above 70°F.

Dynamic Load Rating and Life Calculations

The dynamic load rating for all ball and roller bearings described in this design guide (see bearing specification tables) are based on an *average (L_{50}) life* of 2500 hours or a *minimum (L_{10}) life* of 500 hours when rotating at 33⅓ RPM. In a large group of bearings operating at 33⅓ RPM at the rated load, approximately 90 percent would still be operating at the end of 500 hours and 50 percent at the end of 2500 hours. Reference: ABMA Std. 9 and 10.

To calculate L_{10} rating life for other loads and speeds:

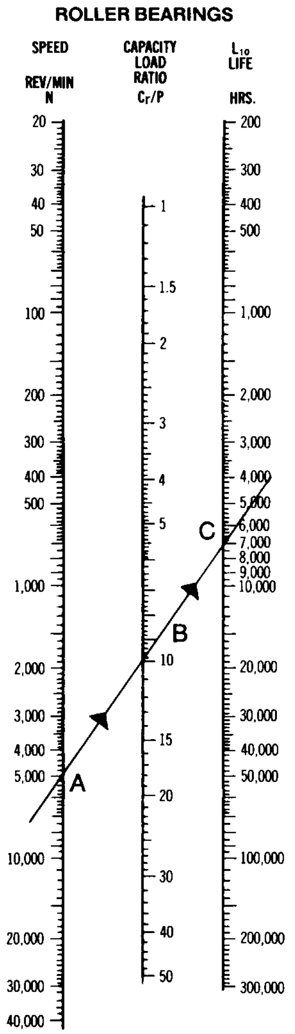
Determine $\frac{C_r}{P}$

C_r = rated dynamic capacity (see bearing specification tables pages 5, 6, 9, 10 and 11)

P = equivalent radial load (see page 22)

Enter the nomogram at N (the desired RPM). Draw a straight line through the $\frac{C_r}{P}$ value. The intersection point with the right hand line equals the L_{10} life.

To select a bearing size:
Knowing the required L_{10} life, RPM and load, the nomograms can be solved for $\frac{C_r}{P}$. Enter the nomogram at N RPM and draw a straight line to the L_{10} value. The intersection with the center line is the $\frac{C_r}{P}$ ratio. Multiply $\frac{C_r}{P}$ by P (equivalent load) and obtain C_r. Using this value, enter the C_r column in the bearing dimension and capacity tables and select a bearing with the proper capacity to suit the shaft and housing requirements.



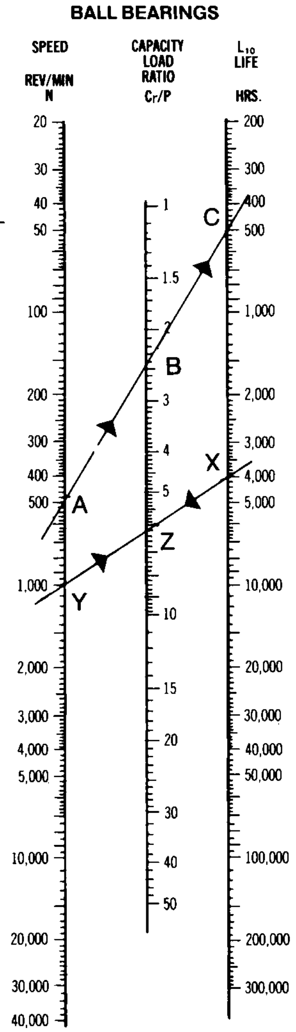
NOMOGRAPH EXAMPLES

To find L_{10} life of
ROLLER BEARINGS
(A) N = 5000 RPM
(B) Cr/P = 10
(C) then L_{10} = 7300 hours

To find L_{10} life of
BALL BEARINGS
(A) N = 500 RPM
(B) Cr/P = 2.45
(C) then L_{10} = 500 hours

To find *Bearing Size*
(with the following
requirements)
(X) Shaft = 35 mm (1.3780")
Load = 550 lbs.
L_{10} = 4000 hours
(Y) Speed = 1000 RPM
(Z) then Cr/P = 6.3
C = 6.3 x 550 = 3465

Select HDB 107 where
Cr = 4450 and shaft
diameter is compatible.



Alternate Direct Calculation Method

Roller Bearings

Cylindrical bearing L_{10} life

$$L_{10} = \frac{((C_r/P)^{10/3} \times 10^6)}{N \times 60}$$

Basic dynamic capacity

$C_r = fcm\ (i\ L_w \cos \alpha)^{7/9}\ Z^{3/4}\ D_{we}{}^{29/27}$

Basic static capacity

$C_{or} = 6430\ (1 - D_{we} \cos \alpha / D_{pw})\ i\ Zl_{we}\ D_{we} \cos \alpha$

See ABMA std 11 for use or contact application engineer

Ball Bearings

Radial and angular contact bearing L_{10} life

$$L_{10} = \frac{((C_r/P)^3 \times 10^6)}{N \times 60}$$

Basic dynamic capacity

$C_r = fcm\ (i \cos \alpha)^{.7}\ Z^{2/3}\ D_w{}^{1.8}$

Basic static capacity

$C_{or} = f_{oiz}\ D_w{}^2 \cos \alpha$

See ABMA std 9 for use or contact application engineer

Where:
1) L = rating life in hours
2) N = bearing speed in RPM
3) C_r = rated dynamic capacity (see Column Cr bearing specifications table, pages 5, 6, 9, 10 and 11)
4) P = equivalent radial load (see next page)

Dynamic Load Rating and Life Calculations continued

Variable Mean Cubic Load Calculation

Variable load constant speed

$$P = \sqrt[3]{P_1^3 \left(\left(\frac{(f_1)}{{}^n\Sigma f}\right) + P_2^3 \left(\frac{(f_2)}{{}^n\Sigma f}\right) + P_3^3 \left(\frac{(f_3)}{{}^n\Sigma f}\right) + \text{- - -} + P_n^3 \left(\frac{(f_3)}{{}^n\Sigma f}\right)\right)}$$

Variable load and variable speed

$$P = \sqrt[3]{\left(P_1^3 \ (f_1) \left(\frac{(S_1)}{(S_m)}\right) \left(\frac{(f_1)}{{}^n\Sigma_1 f}\right) + P_2^3 \left(\frac{(f_2)}{{}^n\Sigma f}\right) + P_3^3 \left(\frac{(f_3)}{{}^n\Sigma f}\right) + \left(\frac{(f_n)}{{}^n\Sigma f}\right)\right)}$$

S_m is the mean speed equivalence where:

$$S_m = S_1 \left(\frac{(f_1)}{{}^n\Sigma_1 f}\right) + S_2 \left(\frac{(f_2)}{{}^n\Sigma_2 f}\right) + S_3 \left(\frac{(f_3)}{{}^n\Sigma_3 f}\right) \ .... \ S_n \left(\frac{(f_3)}{{}^n\Sigma_3 f}\right) \left(\frac{\text{rev}}{\text{min}}\right)$$

where: P_1, P_2, etc., equals each discrete load (lbs)
f1, f2, etc., equals time in constant units when load is applied.
The complete fraction sums must equal 1.0 exactly.
Resulting value P is then the cubic equivalent mean load to be used for life calculation.
This format can be used for both radial and axial loads individually.

Example: A roller bearing has a variable load of 50 lbs. radial for 2 minutes, 25 lbs. for 3 minutes and 100 lbs. for 5 minutes.

The equivalent load given the speed is constant is calculated as follows:

$$P = \sqrt[3]{50^3 \left(\frac{2}{10}\right) + 25^3 \left(\frac{3}{10}\right) + 100^3 \left(\frac{5}{10}\right)} = 80.88 \text{ lbs.}$$

In the given example, each load has a varying speed of 2000 RPM; 5000 RPM; 3000 RPM respectively.

$$S_m = 2000 \left(\frac{2}{10}\right) + 5000 \left(\frac{3}{10}\right) + 3000 \left(\frac{5}{10}\right) = 3400 \text{ RPM}$$

$$P = \sqrt[3]{50^3 \left(\frac{2000}{3400}\right)\left(\frac{2}{10}\right) + 25^3 \left(\frac{5000}{3400}\right)\left(\frac{3}{10}\right) + 100^3 \left(\frac{3000}{3400}\right)\left(\frac{5}{10}\right)}$$

P = 77.32 lbs.

If this were a ball bearing, a similar analysis could be made for the axial loads.

Equivalent Radial Load (P) –

In both rating life formulas, the equivalent radial load (P) equals the constant stationary radial load, which, if applied to a bearing with a rotating inner ring and stationary outer ring, would give the same life as that which the bearing will attain under actual conditions of load and rotation.

Roller Bearings
(cylindrical)
$P = F_R$

Ball Bearings:
$P = F_R$ (radial loads)
$P = XF_R + YF_A$
(radial and axial combined loads)
Check both formulas.
Use the largest value of P as the equivalent radial load.

Where

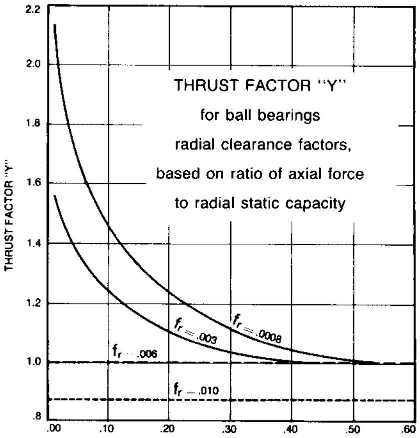
1) F_R = calculated radial load
2) F_a = calculated axial thrust load
3) X = 0.50 radial factor
4) Y = thrust factor

for ball bearings under combined loads

Y is a function of F_a/C_o (axial force divided by the radial static capacity) and the radial clearance factor, f_r.

where $f_r = \frac{\text{average radial play in inches}}{\text{ball diameter in inches}}$

To determine the value of Y for single-row ball bearings, compute f_r and select the curve closest to this value in the chart at right. Solve for F_a/C_o and determine Y using the selected curve.



$$\frac{F_a = \text{Axial Force}}{C_{or} = \text{Radial Static Capacity}}$$

Care must be used to select bearings, which are of sufficient size for the application. A bearing, which appears to have adequate life, may require a shaft so small that shaft deflection could lead to misalignment and fitting problems. A further analysis is sometimes required.

Static Load Ratings

Radial

The radial static capacity Cor is defined by the ABMA as the maximum static radial load that may be imposed on a bearing without causing total permanent deformation in excess of .0001″ of the ball or roller diameter. Experience shows that this load can be tolerated without impairing performance under subsequent operation. Where smooth operation is not critical, the Cor value may be exceeded. For example, air frame bearings are frequently rated at 5.7 times the Timken Cor limits. Contact your Timken representative for specific application information.

Thrust

The static thrust capacity of metric series ball bearings is generally higher than their radial static capacity. The specific value depends upon the initial contact angle (radial play), groove depth and race curvature (conformity).

The use of fractured outer-race bearings (HD series) under axial loads is also determined by the ability of the holding wire to keep the fracture closed. Thrust loads in excess of approximately 200 pounds (depending on bearing size) may tend to open the fracture causing early failure. Where the housing fit can be maintained line to line to tight, the holding wires are no longer the limiting factor and higher thrust loads may be applied equivalent to HK construction.

The static thrust capacity of cylindrical roller bearings (where guide flange configuration allows thrust) is also higher than the radial capacity. However, the use of this type of bearing under dynamic thrust loading is restricted to less than 10 percent of the radial Cr value because of the sliding rather than rolling contract between the ends of the rollers and the guide flanges. Continuous operation under thrust should be avoided.

If the static load (radial or thrust) exceeds the catalog Cor rating, Timken should be consulted.

Life Adjustment Factors

Life adjustment factors can be used to further define the rating life in terms of (1) reliability, (2) material and (3) application conditions. The fatigue life formula embodying these adjustment factors is:

$$Ln = a1 \times a2 \times a3 \times L10$$

A_1 = Reliability Factor

It may be desirable for reliability (a_1) to determine the life when more than 90 percent of the bearings must still be operating.

Reliability L_{10} (Rating Life)	Reliability Factor (a_1)
90% L10	1.00
95% L5	.62
96% L4	.53
97% L3	.44
98% L2	.33
99% L1	.21

Example – If the L_{10} rating life of a bearing in a specific application is 4000 hours, the L_1 life for 99% reliability would be $a_1 \times L_{10} = .21 \times 4000 = 810$ hours.

A_2 = Material Factor

Certain materials have proven to have greater fatigue life than others operating under identical conditions. The theoretical L_{10} dynamic life is based on air-melt steel and standard ABMA formulas. The life adjustment factors for materials frequently used are shown below. These are conservative values for use in critical aircraft applications.

Material	Material Factor (a_2)
Air Melt 440C	1
Std. Vacuum Degassed 52100	3
BG 42	5
CEVM 52100	5
VIM-VAR M-50	10
VIM-VAR 52100	10
CSS 42L	20

A_3 = Application Factor

Life adjustment factors for application conditions, such as lubrication, quality, misalignment, temperature, etc., are more complex and may require more discreet analysis. For example, low viscosity oil (less than 70 ssu) and high temperatures (varies with steel) and speeds insufficient to generate a hydrodynamic oil film will require the use of an a_3 value of less than 1. Actual test experience in a particular application is the best way to develop accurate a_3 factors.

Modes of Failure

In all discussions of the calculated dynamic capacity and L_{10} life, the mode of failure is always considered to be fatigue spalling of the inner or outer raceway or one of the rolling elements. Fatigue results from cyclic stress reversals on the rolling contact surfaces and is characterized by actual loss of metal. Initially, only the vibration level of the bearing increases but more catastrophic failure may follow if operation is allowed to continue. The wear rate of the separator substantially increases and the ring or one of the balls may fracture causing a total lock-up. For this reason, magnetic chip detectors are used in many critical applications to highlight early stages of fatigue in gear or bearing components.

Other modes of failure that are not statistically predictable by the conventional ABMA formulas can affect performance. Depending on the criticality of torque and noise level, they may cause a “failure” long before the L_{10} rating has been achieved.

These include:

- True load brinells caused by either radial or axial impacts in excess of the static rating. Results: roughness and noise
- False brinells (fretting corrosion) caused by vibration under static conditions with inadequate lubrications.
- Wear caused by loss of lubrication or introduction of abrasive particles (contamination).
- Ball skidding caused by rapid acceleration with inadequate preload. Results: flats and noisy bearings
- Ring or ball fracture or separator fracture caused by improper mounting techniques or extreme loads.
- Rotational interference caused by debris, lubricant oxidation, loss of radial play due to improper fitting procedures, corrosion, etc.

In summary, to achieve rated fatigue life the bearing must be given an adequate chance. Most premature failures are the results of improper use. An in-depth analysis will usually reveal steps that can be taken both in the application and in the design of the bearing to remedy the cause.

Lubrication

Selection of the lubricant type and the method of distribution are critical in achieving successful life. Lubrication has four basic purposes:

1) To provide fluid film or boundary layer separation between the bearing components.
2) To cool the bearing.
3) To clean the bearing.
4) To prevent corrosion.

The relative importance of each depends upon the application, particularly on the speed and load. Effect of speed on different bearings can be related by the dn value (bore diameter mm x RPM).

High-Speed Applications (Over 1 Million dn)

Lubrication of high-speed (over 1 million dn) applications is most critical. Centrifugal force tends to throw lubricant from the heavily stressed inner ring into the outer race. Lubricant accumulation creates additional drag and heat causing slippage or wear on the inner race. In high-speed applications, the most effective means of lubrication uses one or more high-velocity jets of oil directed at the inner race contact area with adequate escape for used lubrication around the outer ring shoulders. In some applications this can be achieved by bringing oil through holes at critical locations in the inner ring. If loads are not severe, air can be mixed with oil in a non-recirculating oil mist system. With mist lubrication, air provides the cooling and cleaning functions.

Medium-Speed Applications (10,000 to 1 Million dn)

In this broad range, which encompasses most bearing applications, the lubricant’s cooling function is less critical. A circulating or replenishment oil system is still preferable for optimum life, but a controlled quantity of grease may be used if temperatures are low. With above ambient temperatures, grease frequently deteriorates long before the predicted fatigue life of the bearing. Unless the bearings are periodically regreased with the proper amount of lubricant, early failure may result. New developments in high-temperature greases provide a partial solution to the problem.

Bearing fatigue life can be prolonged beyond that predicted in this design guide if full fluid film elastohydrodynamic lubrication is established at the contact surface. To achieve this, the fluid film thickness must be equal to or greater than contact surface finish or microgeometry variations at the most heavily loaded contact area. Without full fluid separation, metal contact occurs causing higher surface sheer stress, possible wear and reduced life.

Fluid film separation is influenced by: 1) size design and quality of the bearing; 2) speed; 3) applied load; and 4) viscosity characteristics of the oil at operating temperatures.

Most medium-speed bearings operating with high-quality mineral oils under average loads establish full fluid film separation. However, where low viscosity fluids or lubricants are required, fluid film may not be established resulting in reduced life (e.g., hydraulic pumps and fuel control systems). Bearings operating in JP4 or higher fuel will function at less than 10 percent of predicted life. Timken aerospace computer programs utilizing the above variables are available to assist designers in determining adequacy of the lubricant. Then, design or application modifications can be reviewed to compensate for or accept potential life reductions.

Where fluid film cannot be maintained due to low speeds and bearing loads, grease lubrication may prove advantageous. Extreme pressure additives in some greases provide good boundary lubrication and lubricity even though the viscosity characteristics of the oil provide marginal fluid film support.

In lubrication, the most important property is viscosity. Within limits, the higher the better, the lower the worse. Since viscosity is affected by temperature and bearing loads, it is important to supply the proper “consistency” (viscosity) in the proper quantity and to remove built up heat effectively.

The measure of viscosity uses multiple units that depend upon the test method used in the evaluation. There are several viscosity terms, such as absolute, kinematic and apparent. The units used in most modern analysis programs are the kinematic viscosity expressed in centistokes (CS). It can be related to the absolute viscosity, expressed in centipoise (CP) by the oil density. The purpose of the lubrication ideally is to interact by separating the moving elements in a bearing by developing a protective film, thereby keeping metal-to-metal contact at the surface finish asperities from coming into contact. Lubricants are temperature limited where the mineral oils may be utilized at temperatures not exceeding -40°F to 225°F (-40°C to 107°C).

Synthetic esters and di-esters may be utilized at temperatures not exceeding -65°F to 350°F (-54°C to 176°C).

Degradation of the lubrication film is most affected by oxidation and is accelerated at higher temperatures.

Lubrication Filtration

To obtain the greatest benefit from the lubrication supplied, it is of the utmost importance that the lubrication system is properly filtered. For oil lubrication in critical applications where speeds are moderate to high, use of a $^{3}/_{5}$ micron filter is advised. Be aware that a hard particle greater than $^{.0001}/_{.0003}$ inches ($^{2.5}/_{7.5}$ microns) can cause wear, scuffing and other surface distress. When grease is used, it should also be filtered prior to installation, since unfiltered grease may be highly contaminated. Filtering the grease with a 5 micron filter is recommended.

Low-Speed Applications

Under slow speed or oscillating conditions, bearings no longer depend on fluid film separation but operate with metal-to-metal contact. Wear is minimized by grease lubricants with high lubricity and extreme pressure additives providing effective “boundary layer” separation. Thin, dry-film coatings may be added to further improve wear resistance.

Standard lubrication – Most aircraft turbine and transmission bearings operate with supplemental replenishment lubricant systems. Therefore, unless otherwise specified, all open bearings with separators will be supplied with a preservative coating meeting MIL-PRF-32033. Open bearings with nonmetallic separators will be supplied with a light oil preservative per MIL-PRF-6085. These are non-operating coatings rather than lubricants. They are, however, compatible with most lubricants and do not need to be removed prior to mounting.

Sealed HKMZZ bearings are normally lubricated with a controlled quantity of long-life sodium soap grease. This provides excellent channeling characteristics resulting in minimum torque and heat generation.

Special lubricants – Timken maintains a large inventory of oils and grease for use in special applications exposed to extreme conditions of temperature, vacuum, moisture or radiation. Where initial lubrication must last the life of the bearing, grease is preferable to oil (except for instrument-type applications having sensitive torque requirements). The choice of grease is a function of oil and thickener type as well as the additive package to meet many special requirements.

How to Specify

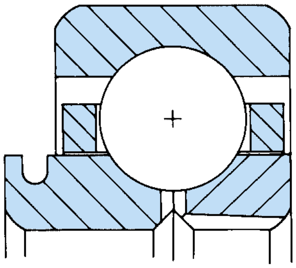
The greases listed with the Timken lubricant code are typical of those frequently specified. The lubricant code should be added as a suffix to the end of standard bearing part numbers when required. For a more complete list, consult with your Timken sales engineer.

Lubrication continued

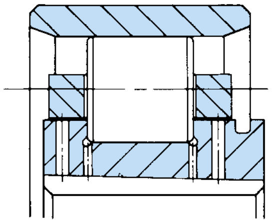
Timken Lubrication Code	Brand Name	Manufacturers' Suggected Temp. Range	Comments
LY 263	Aeroshell 22	-85 to +400°F -65 to +204°C	Non-melting, inorganic thickener with synthetic hydrocarbon oil for excellent fatigue life over wide temperature ranges. General-purpose lubricant, meets the MIL-PRF-81322.
LY 231	Mobil 28	-85 to +350°F -65 to +177°C	Organic Bentonite clay binder with synthetic hydrocarbon oil. Has EP additives. Meets the MIL-PRF-81322.
LY 240	Shell Darina E P 2	-20 to +350°F -30 to +175°C	Similar to LY 270 except uses non-melting, inorganic thickener to enhance high-temperature operation.
LY 270	Shell Alvania E P 2	-20 to +300°F -30 to +149°C	Lithium soap, mineral oil, extreme pressure lubricant. Excellent water resistance for long life under adverse operating conditions.
LG 38	Exxon Andok B	-20 to +225°F -30 to +110°C	Long life, sodium soap, mineral oil grease with excellent channeling characteristics for low torque after run in at all speeds. Limited operating temperature range.
LY 189	Dupont Krytox 240 AC	-10 to +600°F -25 to +315°C	Teflon®-type thickener with fluorocarbon oil for maximum high-end temperatures. Chemically inert and insoluable in all fuels and most solvents. Premium price. Meets the MIL-PRF-27617.

Ultra-High-Speed Performance Features

To successfully break the 2 million dn barrier, specifically engineered designs are developed through close cooperation between the manufacturer and the bearing user. Lubrication flow pattern is one of the most important factors. Timken has the manufacturing technology to fabricate both ball and roller bearings in VIM-VAR M-50 steel with integral inner race lubrication. Two-piece inner race mainshaft bearings with lubricant directed between the halves, and mainshaft roller bearings with lubrication holes in precision undercuts (adjacent to guide flanges and to the separator pilot surface) efficiently provide lubricant to critical locations. Both wear and fatigue life are improved while less oil is needed resulting in higher efficiency and less heat generation.



Two-piece, inner-race mainshaft bearing



Mainshaft roller bearing

Where the application warrants:

1) Ultraprecise rollers can be manufactured by Timken with end squareness as low as 50 millionths of an inch and corner radius runout as low as .0005".
2) Slight roller end crown, low guide flange angles and reduced clearances can be combined to further improve roller tracking and permit even higher speeds.
3) Special roller crowns can be used to allow for greater misalignment.
4) The one-piece broached separator can be modified with relieved areas to improve lubrication and reduce wear.

The extensive use of VIM-VAR M-50 in many turbine and accessory positions testifies to its value as the preferred material for ultra high speed bearings.

In all cases where special designs are required, consult your Timken field sales engineer for assistance in selecting the necessary features.

Millimeter to Inch Equivalents

One inch = 25.4 millimeters

mm	(Decimal) Inch	mm	(Decimal) Inch	mm	(Decimal) Inch	mm	(Decimal) Inch	mm	(Decimal) Inch	mm	(Decimal) Inch	mm	(Decimal) Inch	mm	(Decimal) Inch
1	0.0394	56	2.2047	111	4.3701	166	6.5354	221	8.7008	276	10.8661	331	13.0315	386	15.1969
2	0.0787	57	2.2441	112	4.4094	167	6.5748	222	8.7402	277	10.9055	332	13.0709	387	15.2362
3	0.1181	58	2.2835	113	4.4488	168	6.6142	223	8.7795	278	10.9449	333	13.1102	388	15.2756
4	0.1575	59	2.3228	114	4.4882	169	6.6535	224	8.8189	279	10.9843	334	13.1496	389	15.3150
5	0.1969	60	2.3622	115	4.5276	170	6.6929	225	8.8583	280	11.0236	335	13.1890	390	15.3543
6	0.2362	61	2.4016	116	4.5669	171	6.7323	226	8.8976	281	11.0630	336	13.2283	391	15.3937
7	0.2756	62	2.4409	117	4.6063	172	6.7717	227	8.9370	282	11.1024	337	13.2677	392	15.4331
8	0.3150	63	2.4803	118	4.6457	173	6.8110	228	8.9764	283	11.1417	338	13.3071	393	15.4724
9	0.3543	64	2.5197	119	4.6850	174	6.8504	229	9.0157	284	11.1811	339	13.3465	394	15.5118
10	0.3937	65	2.5591	120	4.7244	175	6.8898	230	9.0551	285	11.2205	340	13.3858	395	15.5512
11	0.4331	66	2.5984	121	4.7638	176	6.9291	231	9.0945	286	11.2598	341	13.4252	396	15.5906
12	0.4724	67	2.6378	122	4.8031	177	6.9685	232	9.1339	287	11.2992	342	13.4646	397	15.6299
13	0.5118	68	2.6772	123	4.8425	178	7.0079	233	9.1732	288	11.3386	343	13.5039	398	15.6693
14	0.5512	69	2.7165	124	4.8819	179	7.0472	234	9.2126	289	11.3780	344	13.5433	399	15.7087
15	0.5906	70	2.7559	125	4.9213	180	7.0866	235	9.2520	290	11.4173	345	13.5827	400	15.7480
16	0.6299	71	2.7953	126	4.9606	181	7.1260	236	9.2913	291	11.4567	346	13.6220	401	15.7874
17	0.6693	72	2.8346	127	5.0000	182	7.1654	237	9.3307	292	11.4961	347	13.6614	402	15.8268
18	0.7087	73	2.8740	128	5.0394	183	7.2047	238	9.3701	293	11.5354	348	13.7008	403	15.8661
19	0.7480	74	2.9134	129	5.0787	184	7.2441	239	9.4094	294	11.5748	349	13.7402	404	15.9055
20	0.7874	75	2.9528	130	5.1181	185	7.2835	240	9.4488	295	11.6142	350	13.7795	405	15.9449
21	0.8268	76	2.9921	131	5.1575	186	7.3228	241	9.4882	296	11.6535	351	13.8189	406	15.9843
22	0.8661	77	3.0315	132	5.1969	187	7.3622	242	9.5276	297	11.6929	352	13.8583	407	16.0236
23	0.9055	78	3.0709	133	5.2362	188	7.4016	243	9.5669	298	11.7323	353	13.8976	408	16.0630
24	0.9449	79	3.1102	134	5.2756	189	7.4409	244	9.6063	299	11.7717	354	13.9370	409	16.1024
25	0.9843	80	3.1496	135	5.3150	190	7.4803	245	9.6457	300	11.8110	355	13.9764	410	16.1417
26	1.0236	81	3.1890	136	5.3543	191	7.5197	246	9.6850	301	11.8504	356	14.0157	411	16.1811
27	1.0630	82	3.2283	137	5.3937	192	7.5591	247	9.7244	302	11.8898	357	14.0551	412	16.2205
28	1.1024	83	3.2677	138	5.4331	193	7.5984	248	9.7638	303	11.9291	358	14.0945	413	16.2598
29	1.1417	84	3.3071	139	5.4724	194	7.6378	249	9.8031	304	11.9685	359	14.1339	414	16.2992
30	1.1811	85	3.3465	140	5.5118	195	7.6772	250	9.8425	305	12.0079	360	14.1732	415	16.3386
31	1.2205	86	3.3858	141	5.5512	196	7.7165	251	9.8819	306	12.0472	361	14.2126	416	16.3780
32	1.2598	87	3.4252	142	5.5906	197	7.7559	252	9.9213	307	12.0866	362	14.2520	417	16.4173
33	1.2992	88	3.4646	143	5.6299	198	7.7953	253	9.9606	308	12.1260	363	14.2913	418	16.4567
34	1.3386	89	3.5039	144	5.6693	199	7.8346	254	10.0000	309	12.1654	364	14.3307	419	16.4961
35	1.3780	90	3.5433	145	5.7087	200	7.8740	255	10.0394	310	12.2047	365	14.3701	420	16.5354
36	1.4173	91	3.5827	146	5.7480	201	7.9134	256	10.0787	311	12.2441	366	14.4094	421	16.5748
37	1.4567	92	3.6220	147	5.7874	202	7.9528	257	10.1181	312	12.2835	367	14.4488	422	16.6142
38	1.4961	93	3.6614	148	5.8268	203	7.9921	258	10.1575	313	12.3228	368	14.4882	423	16.6535
39	1.5354	94	3.7008	149	5.8661	204	8.0315	259	10.1969	314	12.3622	369	14.5276	424	16.6929
40	1.5748	95	3.7402	150	5.9055	205	8.0709	260	10.2362	315	12.4016	370	14.5669	425	16.7323
41	1.6142	96	3.7795	151	5.9449	206	8.1102	261	10.2756	316	12.4409	371	14.6063	426	16.7717
42	1.6535	97	3.8189	152	5.9843	207	8.1496	262	10.3150	317	12.4803	372	14.6457	427	16.8110
43	1.6929	98	3.8583	153	6.0236	208	8.1890	263	10.3543	318	12.5197	373	14.6850	428	16.8504
44	1.7323	99	3.8976	154	6.0630	209	8.2283	264	10.3937	319	12.5591	374	14.7244	429	16.8898
45	1.7717	100	3.9370	155	6.1024	210	8.2677	265	10.4331	320	12.5984	375	14.7638	430	16.9291
46	1.8110	101	3.9764	156	6.1417	211	8.3071	266	10.4724	321	12.6378	376	14.8031	431	16.9685
47	1.8504	102	4.0157	157	6.1811	212	8.3465	267	10.5118	322	12.6772	377	14.8425	432	17.0079
48	1.8898	103	4.0551	158	6.2205	213	8.3858	268	10.5512	323	12.7165	378	14.8819	433	17.0472
49	1.9291	104	4.0945	159	6.2598	214	8.4252	269	10.5906	324	12.7559	379	14.9213	434	17.0866
50	1.9685	105	4.1339	160	6.2992	215	8.4646	270	10.6299	325	12.7953	380	14.9606	435	17.1260
51	2.0079	106	4.1732	161	6.3386	216	8.5039	271	10.6693	326	12.8346	381	15.0000	436	17.1654
52	2.0472	107	4.2126	162	6.3780	217	8.5433	272	10.7087	327	12.8740	382	15.0394	437	17.2047
53	2.0866	108	4.2520	163	6.4173	218	8.5827	273	10.7480	328	12.9134	383	15.0787	438	17.2441
54	2.1260	109	4.2913	164	6.4567	219	8.6220	274	10.7874	329	12.9528	384	15.1181	439	17.2835
55	2.1654	110	4.3307	165	6.4961	220	8.6614	275	10.8268	330	12.9921	385	15.1575	440	17.3228

Decimal Equivalents of Fractions of an Inch

Fraction	Inch
1/64	.0156
1/32	.0313
3/64	.0469
1/16	.0625
5/64	.0781
3/32	.0938
7/64	.1094
1/8	.1250
9/64	.1406
5/32	.1563
11/64	.1719
3/16	.1875
13/64	.2031
7/32	.2188
15/64	.2344
1/4	.2500
17/64	.2656
9/32	.2813
19/64	.2969
5/16	.3125
21/64	.3281
11/32	.3438
23/64	.3594
3/8	.3750
25/64	.3906
13/32	.4063
27/64	.4219
7/16	.4375
29/64	.4531
15/32	.4688
31/64	.4844
1/2	.5000
33/64	.5156
17/32	.5313
35/64	.5469
9/16	.5625
37/64	.5781
19/32	.5938
39/64	.6094
5/8	.6250
41/64	.6406
21/32	.6563
43/64	.6719
11/16	.6875
45/64	.7031
23/32	.7188
47/64	.7344
3/4	.7500
49/64	.7656
25/32	.7813
51/64	.7969
13/16	.8125
53/64	.8281
27/32	.8438
55/64	.8594
7/8	.8750
57/64	.8906
29/32	.9063
59/64	.9219
15/16	.9375
61/64	.9531
31/32	.9688
63/64	.9844
1	1

Metric Conversion Factors

Multiply	by	to obtain
British thermal unit (Btu)	1055.056	Joule (J)
British thermal unit (Btu)	0.2930711	Watt (W)
Celsius temperature (t_C)	$1.8t_C + 32 = t_F$	Fahrenheit temperature (t_F)
Celsius temperature (t_C)	$t_C + 273.15 = t_K$	Kelvin temperature (t_K)
Centimeter (cm)	0.03280840	Foot (ft)
Centimeter (cm)	0.3937	Inch (in.)
Centimeter (cm)	0.01	Meter (m)
Centimeter (cm)	10	Millimeter (mm)
Centimeter per minute (cm/min)	0.3937008	Inch per minute (ipm)
Centimeter per second (cm/s)	1.968504	Foot per minute (fpm)
Centimeter per second (cm/s)	0.03280840	Foot per second (fps)
Cubic centimeter (cm^3)	0.061023	Cubic Inch (in.^{3})
Cubic foot (ft^3)	0.02832	Cubic meter (m^3)
Cubic foot (ft^3)	28.31685	Liter (l)
Cubic foot per minute (ft^3/min)	0.004719474	Cubic meter per second (m^3/s)
Cubic foot per minute (ft^3/min)	28.31685	Liter per minute (l/min)
Cubic inch (in.^{3})	16.38706	Cubic centimeter (cm^3)
Cubic inch (in.^{3})	0.00001638706	Cubic meter (m^3)
Cubic inch (in.^{3})	16.387.06	Cubic millimeter (mm^3)
Cubic meter (m^3)	61,023.76	Cubic inch (in.^{3})
Cubic meter (m^3)	35.3147	Cubic foot (ft^3)
Cubic meter (m^3)	264.1720	Gallon, U.S. liquid (gal)
Cubic meter (m^3)	1000.0	Liter (l)
Cubic meter per minute (m^3/min)	264.1720	Gallon per minute, U.S. liquid (gpm)
Cubic meter per second (m^3/s)	2118.880	Cubic foot per minute (ft^3/min)
Cubic meter per second (m^3/s)	15,850.32	Gallon per minute, U.S. liquid (gpm)
Cubic millimeter (mm^3)	0.00006102376	Cubic inch (in.^{3})
Dyne	0.00001	Newton (N)
Dyne-centimeter	0.0000001	Newton-meter (N-m)
Fahrenheit temperature (t_F)	$(T_F - 32)/1.8 = T_C$	Celcius temperature (t_C)
Fahrenheit temperature (t_F)	$(t_F + 459.67)/1.8 = t_K$	Kelvin temperature (t_K)
Foot (ft)	30.48	Centimeter (cm)
Foot (ft)	0.3048	Meter (m)
Foot per hour (fph)	0.3048	Meter per hour (m/hr)
Foot per hour (fph)	0.00508	Meter per minute (m/min)
Foot per hour (fph)	0.00008466667	Meter per second (m/s)
Foot per minute (fpm)	0.508	Centimeter per second (cm/s)
Foot per minute (fpm)	18.288	Meter per hour (m/hr)
Foot per minute (fpm)	0.3048	Meter per minute (m/min)
Foot per minute (fpm)	0.00508	Meter per second (m/s)
Foot per second (fps)	30.48	Centimeter per second (cm/s)
Foot per second (fps)	18.288	Meter per minute (m/min)
Foot per second (fps)	0.3048	Meter per second (m/s)
Foot per second per second	0.3048	Meter per second per second (m/s^2)
Foot-pound-force (ft-lbf)	1.3558:8	Joule (J)
Foot-poundal	0.04214011	Joule (J)
Foot-pound per hour (ft-lb/hr)	0.0003766161	Watt (W)
Foot-pound per minute (ft-lb/min)	0.02259697	Watt (W)
Gallon, U.S. liquid (gal)	0.003785412	Cubic meter (m^3)
Gallon, U.S. liquid (gal)	3.785412	Liter (l)
Gallon per minute, U.S. liquid (gpm)	3.785412	Liter per minute (l/min)
Gallon per minute, U.S. liquid (gpm)	0.06309020	Liter per second (l/s)
Gallon per minute, U.S. liquid (gpm)	0.003785412	Cubic meter per minute (m^3/min)
Gallon per minute, U.S. liquid (gpm)	0.00006309020	Cubic meter per second (m^3/s)
Gram (g)	0.03527397	Ounce (Av) (oz)
Gram (g)	0.03215074	Ounce, (troy) (oz)
Gram per cubic centimeter (g/cm$_3$)	0.3612730	Pound per cubic inch (lb./in.^{3})
Horsepower (hp)	0.7456999	Kilowatt (kW)
Horsepower (hp)	745.6999	Watt (W)
Horsepower, Metric (hp)	735.499	Watt (W)
Inch (in.)	2.540	Centimeter (cm)
Inch (in.)	0.0254	Meter (m)
Inch (in.)	25.4	Millimeter (mm)
Inch of mercury, 32°F	3386.39	Newton per square meter (N/m^2)
Inch per minute (Ipm)	2.54	Centimeter per minute (cm/min)
Inch per minute (Ipm)	0.0254	Meter per minute (m/min)
Inch per minute (Ipm)	25.4	Millimeter per minute (mm/min)
Joule (J)	0.0009478170	British thermal unit (Btu)
Joule (J)	0.7375621	Foot-pound-force (ft-lbf)
Joule (J)	23.73036	Foot-Poundal
Joule (J)	0.0002777778	Watt-hour (W-h)
Kelvin temperature (t_K)	$t_K - 273.15 = t_C$	Celsius temperature (t_C)
Kelvin temperature (t_K)	$1.8t_K - 459.67 = t_F$	Fahrenheit temperature (t_F)

Multiply	by	to obtain
Kilogram (kg)	0.0009842064	Ton (long)
Kilogram (kg)	0.001	Ton (metric)
Kilogram (kg)	0.001102311	Ton (short)
Kilogram (kg)	35.27397	Ounce, (Av) (oz)
Kilogram (kg)	32.15074	Ounce, (Troy) (oz)
Kilogram (kg)	2.20462	Pound, (Av) (lb)
Kilogram-force (kgf) or kilopound	9.80665	Newton (N)
Kilogram force per square millimeter (kgf/mm2)	9.806650	Megapascal (Mpa) or (MN/m^2)
Kilogram-force-meter (kgf-m)	9.806650	Newton-meter (N-m)
Kilogram-meter per second (kg-m/s)	7.233011	Pound-foot per second (lb-ft/s)
Kilogram-meter per second (kg-m/s)	86.79614	Pound-inch per second (lb-in./s)
Kilogram per cubic meter (kg/m^3)	0.06242797	Pound per cubic foot (lb/ft^3)
Kilometer (km)	0.6213712	Mile, (U.S. Statute)
Kilometer per hour (kph)	0.6213712	Mile per hour, (U.S. statute) (mph)
Kilogram-force per square centimeter (kgf/cm^2)	14.22334	Pound per square inch (psi)
Kilogram-force per square meter (kgf/m^2)	9.806650	Newton per square meter (N/m^2)
Kilogram-force per square meter (kgf/m^2)	9.806650	Pascal (Pa)
Kilogram-force per square meter (kgf/m^2)	0.2048161	Pound per square foot (lb/ft^2)
Kilogram-force per square meter (kgf/m^2)	0.001422	Pound per square inch (psi)
Kilowatt (kW)	1.341022	Horsepower (hp)
Kilowatt-hour (kwh)	3,600,000	Joule (J)
Kilonewton per square meter (kN/m^2)	0.1450377	Pound per square inch (psi)
Liter (l)	0.03531466	Cubic foot (ft^3)
Liter (l)	0.001	Cubic meter (m^3)
Liter (l)	0.2641720	Gallon, U.S. liquid (gal)
Liter per minute (lpm)	0.03531466	Cubic foot per minute (ft^3/min)
Liter per minute (lpm)	0.2641720	Gallon per minute, U.S. liquid (gpm)
Liter per second (lps)	15.85032	Gallon per minute, U.S. liquid (gpm)
Megapascal (Mpa)	145.0377	Pound per square inch (psi)
Meter (m)	39.37008	Inch (in)
Meter (m)	3.280840	Foot (ft)
Meter (m)	1.0936	Yard (yd)
Meter per hour (m/hr)	3.280840	Foot per hour (fph)
Meter per hour (m/hr)	0.5468067	Foot per minute (fpm)
Meter per minute (m/min)	3.280840	Foot per minute (fpm)
Meter per minute (m/min)	0.5468067	Foot per second (fps)
Meter per minute (m/min)	39.37008	Inch per minute (Ipm)
Meter per second (m/s)	11,811.02	Foot per hour (fph)
Meter per second (m/s)	196.8504	Foot per minute (fpm)
Meter per second (m/s)	3.280840	Foot per second (fps)
Microinch	0.0254	Micrometer or Micron
Micron	0.00000132	Atmosphere
Micron	0.0000394	Inch of mercury
Micron	0.001	Millimeter of mercury (Torr)
Micron	0.0000195	Pound per square inch (psi)
Micrometer or micron	39.37008	Microinch
Mile (U.S. Statute)	1.609344	Kilometer (km)
Mile per hour (mph)	1.609344	Kilometer per hour (kph)
Millimeter (mm)	0.03937008	Inch (in.)
Millimeter (mm)	0.003280840	Foot (ft)
Millimeter of Mercury (Torr)	0.00132	Atmosphere
Millimeter of Mercury (Torr)	0.0394	Inch of mercury
Millimeter of Mercury (Torr)	1000	Micron
Millimeter of Mercury (Torr)	0.0195	Pound per square inch (psi)
Millimeter per minute (mm/min)	0.3937008	Inch per minute (ipm)
Newton (N)	100,000	Dyne
Newton (N)	0.1019716	Kilogram-force or kilopound (kgf)
Newton (N)	3.596942	Ounce-force (ozf)
Newton (N)	7.23301	Poundal
Newton (N)	0.2248089	Pound-force (lbf)
Newton-meter (N-m)	10,000,000	Dyne-centimeter
Newton-meter (N-m)	0.1019716	Kilogram-force-meter (kgf-m)
Newton-meter (N-m)	141.6119	Ounce-force-inch (ozf-in.)
Newton-meter (N-m)	0.73756	Pound-force-foot (lbf-ft)
Newton-millimeter (N-mm)	0.1416119	Ounce-force-inch (ozf-in.)
Newton per meter (N/m)	0.06852178	Pound-force per foot (lbf/ft)
Newton per meter (N/m)	0.005710148	Pound-force per inch (lbf/in)
Newton per square centimeter (N/cm^2)	1.450377	Pound per square inch (psi)
Newton per square meter (N/m^2)	0.0002953	Inch of mercury
Newton per square meter (N/m^2)	0.1019716	Kilogram per square meter (kg/m^2)

Metric Conversion Factors continued

Multiply	by	to obtain
Newton per square meter (N/m^2)	1.0	Pascal (Pa)
Newton per square meter (N/m^2)	0.0001450	Pound per square inch (psi)
Newton per square millimeter (N/mm^2)	145.0377	Pound per square inch (psi)
Ounce, (Av) (oz)	28.3495	Gram (g)
Ounce, (troy) (oz)	31.10348	Gram (g)
Ounce, (Av) (oz)	0.02834952	Kilogram (kg)
Ounce, (troy) (oz)	0.03110348	Kilogram (kg)
Ounce-force (ozf)	0.2780139	Newton (N)
Ounce-force-inch (ozf-in.)	0.007061552	Newton-meter (N-m)
Ounce-force-inch (ozf-in.)	7.061552	Newton-millimeter (N-mm)
Pascal (Pa)	0.1019716	Kilogram per square meter (kg/m^2)
Pascal (Pa)	1.0	Newton per square meter (N/m^2)
Pascal (Pa)	0.02088543	Pound per square foot (lb/ft^2)
Pascal (Pa)	0.0001450377	Pound per square inch (psi)
Pound, (Av) (lb)	0.453592	Kilogram (kg)
Poundal	0.1382550	Newton (N)
Pound-foot (lb-ft)	1.355818	Newton-meter (N-m)
Pound-foot per second (lb-ft/s)	0.1382550	Kilogram-meter per second (kg-m/s)
Pound-force (lbf)	4.448222	Newton (N)
Pound-inch per second (lb-in./s)	0.01152125	Kilogram-meter per second (kg-m/s)
Pound per cubic inch (lb/in.^{2})	27.67990	Gram per cubic centimeter (g/cm^3)
Pound per cubic foot (lb/ft^3)	16.01846	Kilogram per cubic meter (kg/m^3)
Pound per foot (lb/ft)	14.59390	Newton per meter (N/m)
Pound per inch (lb/in.)	175.1268	Newton per meter (N/m)
Pound per square foot (lb/ft^2)	4.882429	Kilogram per square meter (kg/m^2)
Pound per square foot (lb/ft^2)	47.88026	Newton per square meter (N/m^2)
Pound per square foot (lb/ft^2)	47.88026	Pascal (Pa)
Pound per square inch (psi)	0.063	Atmosphere
Pound per square inch (psi)	2.036	Inch of Mercury
Pound per square inch (psi)	0.70730697	Kilogram per square centimeter (kg/cm^2)
Pound per square inch (psi)	703.1	Kilogram per square meter (kg/m$_2$)
Pound per square inch (psi)	6.8948	Kilonewton per square meter (kN/m^2)
Pound per square inch (psi)	51,500	Micron
Pound per square inch (psi)	51.5	Millimeter of Mercury (Torr)
Pound per square inch (psi)	0.6894757	Newton per square centimeter (N/cm^2)
Pound per square inch (psi)	6894.76	Newton per square meter (N/m^2)
Pound per square inch (psi)	0.006895	Newton per square millimeter (N/mm^2)
Pound per square inch (psi)	6894.757	Pascal (Pa)
Square centimeter (cm^2)	0.001076391	Square foot (ft^2)
Square centimeter (cm^2)	0.1550003	Square inch (in.^{2})
Square foot (ft^2)	929.0304	Square centimeter (cm^2)
Square foot (ft^2)	0.09290304	Square meter (m^2)
Square foot (ft^2)	92,903.04	Square millimeter (mm^2)
Square foot per second (ft^2/s)	0.092900304	Square meter per second (m^2/s)
Square inch (in.^{2})	6.4516	Square centimeter (cm^2)
Square inch (in.^{2})	0.00064516	Square meter (m^2)
Square inch (in.^{2})	645.16	Square millimeter (mm^2)
Square meter (m^2)	10.763910	Square foot (ft^2)
Square meter (m^2)	1550.003	Square inch (in.^{2})
Square millimeter (mm^2)	0.0001076387	Square foot (ft^2)
Square millimeter (mm^2)	0.001550003	Square inch (in.^{2})
Ton (metric)	1000	Kilogram (kg)
Ton (long)	1016.047	Kilogram (kg)
Ton (short)	907.1847	Kilogram (kg)
Torr (mm Hg)	133.322	Pascal (Pa)
Watt (W)	3.412141	British thermal unit (Btu)
Watt (W)	2655.224	Foot-pound per hour (ft-lb/hour)
Watt (W)	44.25372	Foot-pound per minute (ft-lb/min)
Watt (W)	0.001341022	Horsepower (hp)
Watt (W)	0.001359621	Horsepower (metric) (hp)
Watt-hour (W-h)	3600.	Joule (J)
Yard (yd)	0.9144	Meter (m)

Celsius/Fahrenheit Temperature Conversion

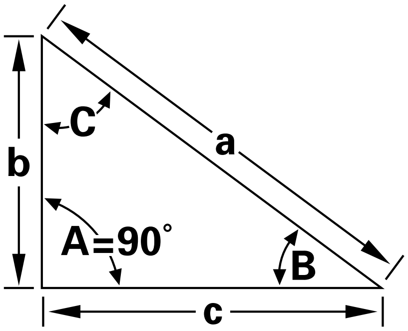
Degrees C°/ or Degrees F°	F°	C°	Degrees C°/ or Degrees F°	F°	C°	Degrees C°/ or Degrees F°	F°	C°	Degrees C°/ or Degrees F°	F°	C°
-110	-166	-79	100	212	37.7	400	752	204	700	1292	371
-100	-148	-73	110	230	43	410	770	210	710	1310	376
-90	-130	-68	120	248	49	420	788	215	720	1328	382
-80	-112	-62	130	266	54	430	806	221	730	1346	387
-70	-94	-57	140	284	60	440	824	226	740	1364	393
-60	-76	-51	150	302	65	450	842	232	1050	1922	565
-50	-58	-46	160	320	71	460	860	238	1060	1940	571
-40	-40	-40	170	338	76	470	878	243	1070	1958	576
-30	-22	-34	180	356	83	480	896	249	1080	1976	582
-20	-4	-29	190	374	88	490	914	254	1090	1994	587
-10	14	-23	200	392	93	500	932	260	1100	2012	593
0	32	-17.7	210	410	99	510	950	265	1110	2030	598
1	33.8	-17.2	220	428	104	520	968	271	1120	2048	604
2	35.6	-16.6	230	446	110	530	986	276	1130	2066	609
3	37.4	-16.1	240	464	115	540	1004	282	1140	2084	615
4	39.2	-15.5	250	482	121	550	1022	288	1150	2102	620
5	41.0	-15.0	260	500	127	560	1040	293	1160	2120	626
6	42.8	-14.4	270	518	132	570	1058	299	1170	2138	631
7	44.6	-13.9	280	536	138	580	1076	304	1180	2156	637
8	46.4	-13.3	290	554	143	590	1094	310	1190	2174	642
9	48.2	-12.7	300	572	149	600	1112	315	1200	2192	648
10	50.0	-12.2	310	590	154	610	1130	321	1210	2210	653
20	68.0	-6.6	320	608	160	620	1148	326	1220	2228	659
30	86.0	-1.1	330	626	165	630	1166	332	1230	2246	664
40	104.0	4.4	340	644	171	640	1184	338	1240	2264	670
50	122.0	9.9	350	662	177	650	1202	343	1250	2282	675
60	140.0	15.6	360	680	182	660	1220	349	1260	2300	681
70	158.0	21.0	370	698	188	670	1238	354	1270	2318	686
80	176.0	26.8	380	716	193	680	1256	360	1280	2336	692
90	194.0	32.1	390	734	199	690	1274	365	1290	2354	697

Torque Tension for Bolts, Capscrews, Studs and Nuts

Bolt Diameter	Number of Threads	Required 1000 lb. Tension	Torque for 60,000 lb. Stress
	28	53	98
	20	55	87
5⁄16	24	67	199
5⁄16	18	68	178
3⁄8	24	79	356
3⁄8	16	81	319
7⁄16	20	93	565
7⁄16	14	93	501
	20	105	864
½	13	107	771
9⁄16	18	118	1234
9⁄16	12	121	1124
3⁄8	18	128	1688
3⁄8	11	134	1538
	16	156	3015
¾	10	160	2730
7⁄8	14	182	4768
7⁄8	9	186	4371
1	14	206	7276
1	8	212	6554
1⅛	12	233	10325
1⅛	7	239	9295
1 _	12	257	14202
1¼	7	264	13086
1 _	12	307	25102
1½	6	315	22686

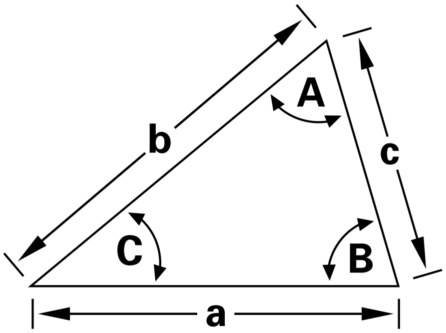
Trigonometric Solutions

Solutions of Triangles



Right-angled Triangles

Sides and Angles Known	Formulas for Sides and Angles to be Found		
Sides a and b	$c = \sqrt{a^2 - b^2}$	$\sin B = \frac{b}{a}$	$C = 90° - B$
Sides a and c	$b = \sqrt{a^2 - c^2}$	$\sin C = \frac{c}{a}$	$B = 90° - C$
Sides b and c	$a = \sqrt{b^2 + c^2}$	$\tan B = \frac{b}{c}$	$C = 90° - B$
Side a; angle B	$b = a \text{ X } \sin B$	$c = a \text{ X } \cos B$	$C = 90° - B$
Side b; angle B	$a = \frac{b}{\text{sib } B}$	$c = b \text{ X } \cot B$	$C = 90° - B$
Side c; angle B	$a = \frac{c}{\cos B}$	$b = c \text{ X } \tan B$	$C = 90° - B$

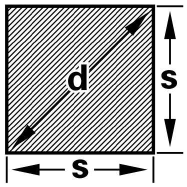


Oblique-angled Triangles

Sides and Angles Known	Formulas for Sides and Angles to be Found		
Side a; angles A, B	$C = 180° - (A + B)$	$b = \frac{a \text{ X } \sin B}{\sin A}$	$c = \frac{a \text{ X } \sin C}{\sin A}$
Sides a, b; angle C	$\tan A = \frac{a \text{ X } \sin C}{b - a \text{ X } \cos C}$	$c = \frac{a \text{ X } \sin C}{\sin A}$	$B = 180° - (A + C)$
Sides a, b; angle A	$\sin B = \frac{b \text{ X } \sin A}{a}$	$C = 180° - (A + B)$	$c = \frac{a \text{ X } \sin C}{\sin A}$
Sides a, b, c	$\cos A = \frac{b^2 + c^2 - a^2}{2\,bc}$	$\sin B = \frac{b \text{ X } \sin A}{a}$	$C = 180° - (A + B)$

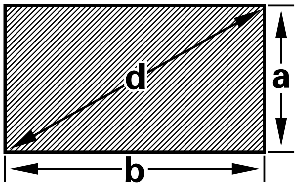
Areas of Plane Figures

A = area



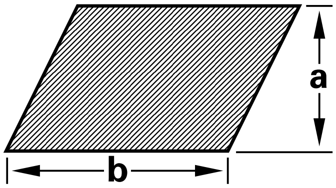
Square

$$A = s^2$$
$$A = \frac{1}{2}d^2$$
$$s = 0.7071d = \sqrt{A}$$
$$d = 1.414s = 1.414\sqrt{A}$$



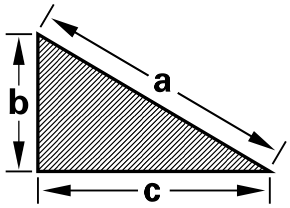
Rectangle

$$A = ab$$
$$A = a\sqrt{d^2 - a^2} = b\sqrt{d^2 - b^2}$$
$$d = \sqrt{a^2 + b^2}$$
$$a = \sqrt{d^2 - b^2} = A \div b$$
$$b = \sqrt{d^2 - a^2} = A \div a$$



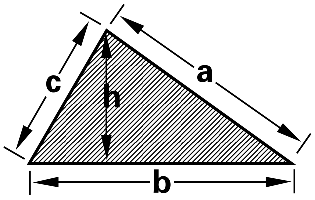
Parallelogram

$$A = ab$$
$$a = A \div b$$
$$b = A \div a$$



Right-angled Triangle

$$A = \frac{bc}{2}$$
$$a = \sqrt{b^2 + c^2}$$
$$b = \sqrt{a^2 - c^2}$$
$$c = \sqrt{a^2 - b^2}$$

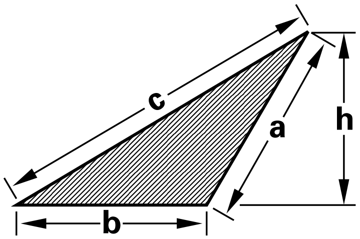


Acute-angled Triangle

$$A = \frac{bh}{2} = \frac{b}{2}\sqrt{c^2 - \left(\frac{a^2 + b^2 + c^2}{2b}\right)^2}$$

If $S = \frac{1}{2}(a + b + c)$, then

$$A = \sqrt{S(S - a)(S - b)(S - c)}$$



Obtuse-angled Triangle

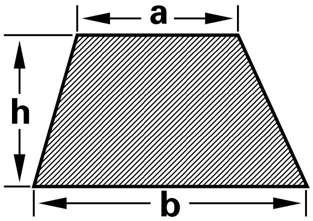
$$A = \frac{bh}{2} = \frac{b}{2}\sqrt{a^2 - \left(\frac{c^2 + a^2 + b^2}{2b}\right)^2}$$

If $S = \frac{1}{2}(a + b + c)$, then

$$A = \sqrt{S(S - a)(S - b)(S - c)}$$

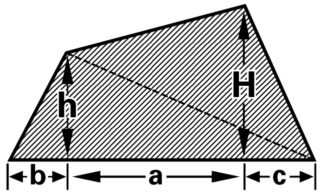
Areas of Plane Figures

***A* = area**



Trapezoid

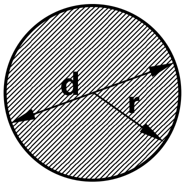
$$A = \frac{(a + b)\,h}{2}$$



Trapezium

$$A = \frac{(H + h)\,a + bh + cH}{2}$$

A trapezium can also be divided into two triangles as indicated by the dotted line. The area of each of the triangles is computed, and the results added to find the area of the trapezium.



Circle

C = circumference

$A = \pi r^2 = 3.1416 r^2 = 0.7854\ d^2$

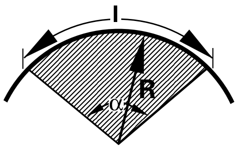
$C = 2\pi r = 6.2832\ r = 3.1416\ d$

$r = C \div 6.2832 = \sqrt{A \div 3.1416} = 0.564\ \sqrt{A}$

$d = C \div 3.1416 = \sqrt{A \div 0.7854} = 1.128\ \sqrt{A}$

Length of arc for center-angle of 1° = 0.008727 *d*

Length of arc for center-angle of n° = 0.008727 *nd*



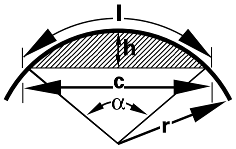
Circular Sector

l = length of arc; α = angle, in degrees.

$l = \frac{r \times \alpha \times 3.1416}{180} = 0.1745\ r\alpha = \frac{2A}{r}$

$A = \frac{1}{2}\ rl = 0.008727\ \alpha r^2$

$\alpha = \frac{57.296\ l}{r} \quad r = \frac{2\ A}{l} = \frac{57.296\ l}{\alpha}$



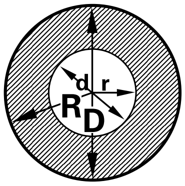
Circular Segment

l = length of arc; α = angle, in degrees.

$c = 2\sqrt{h\ (2\ r - h)} \quad A = \frac{1}{2}\left[rl - c\ (r - h)\right]$

$r = \frac{c^2 + 4\ h^2}{8\ h} \quad l = 0.01745\ r\alpha$

$h = r - \frac{1}{2}\sqrt{4\ r^2 - c^2} \quad \alpha = \frac{57.296\ l}{r}$



Circular Ring

$A = \pi\ (R^2 - r^2) = 3.1416\ (R^2 - r^2)$

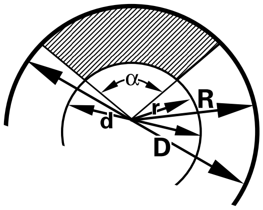
$= 3.1416\ (R + r)\ (R - r)$

$= 0.7854\ (D^2 - d^2) = 0.7854\ (D + d)\ (D - d)$

Trigonometric Solutions

Areas of Plane Figures

A = area

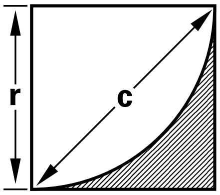


Circular Ring Sector

α = angle, in degrees.

$$A = \frac{\alpha\pi}{360}(R^2 - r^2) = 0.00873\ \alpha\ (R^2 - r^2)$$

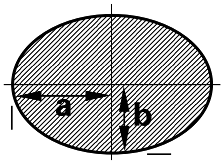
$$= \frac{\alpha\pi}{4 \times 360}(D^2 - d^2) = 0.000.00218873\ \alpha\ (D^2 - d^2)$$



Spandrel or Fillet

$$A = r^2 - \frac{\pi r^2}{4} = 0.215\ r^2$$

$$= 0.1075\ c^2$$



Ellipse

P = perimeter or circumference.

$A = \pi ab = 3.1416\ ab.$

An approximate formula for the perimeter is:

$$P = 3.1416\sqrt{2\,(a^2 + b^2)}$$

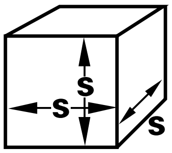
A closer approximate is:

$$P = 3.1416\sqrt{2\,(a^2 + b^2) - \frac{(a - b)^2}{2.2}}$$

Trigonometric Solutions

Volumes of Solids

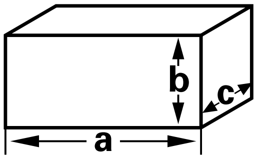
V = volume



Cube

$$V = s^3$$

$$s = \sqrt[3]{V}$$



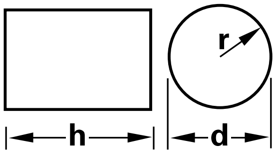
Square Prism

$$V = abc$$

$$a = \frac{V}{bc} \quad b = \frac{V}{ac} \quad c = \frac{V}{ab}$$

Volumes of Solids

V = volume



Cylinder

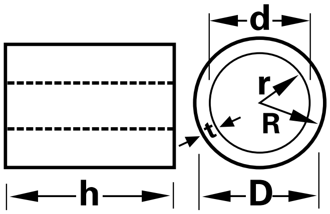
S = area of cylindrical surface.

$V = 3.1416\ r^2h = 0.7854\ d^2h$

$S = 6.2832\ rh = 3.1416$ dh

Total area A of cylindrical surface and end surfaces:

$A = 6.2832\ r\ (r + h) = 3.1416\ d\ (\frac{1}{2}d + h)$



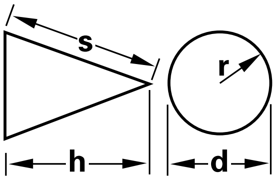
Hollow Cylinder

$V = 3.1416\ h\ (R^2 - r^2) = 0.7854\ h\ (D^2 - d^2)$

$= 3.1416\ ht\ (2\ R - t\ ) = 3.1416\ ht\ (D - t)$

$= 3.1416\ ht\ (2\ r + t\ ) = 3.1416\ ht\ (d + t)$

$= 3.1416\ ht\ (R + r\ ) = 1.5708\ ht\ (D + d)$



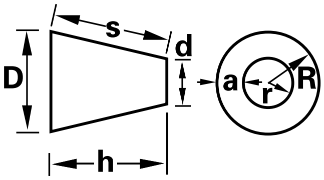
Cone

A = area of conical surface.

$V = \frac{3.1416\ r^2h/3}{3} = 1.0472\ r^2h = 0.2618\ d^2h$

$A = 3.1416\ r\sqrt{r^2 + h^2} = 3.1416\ rs = 1.5708\ ds$

$s = \sqrt{r2 + h^2} = \sqrt{\frac{d^2}{4} + h^2}$



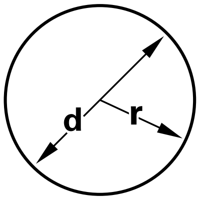
Frustrum of Cone

A = area of conical surface.

$V = 1.0472\ h\ (R^2 + Rr + r^2) = 0.2618\ h\ (D^2 + Dd + d^2)$

$A = 3.1416\ s\ (R + r) = 1.5708\ s\ (D + d)$

$a = R - r \qquad s = \sqrt{a^2 + h^2} = \sqrt{(R - r)^2 + h^2}$



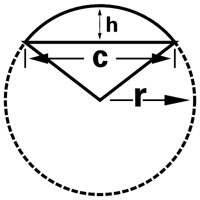
Sphere

A = area of surface.

$V = \frac{4\pi r^3}{3} = \frac{\pi d^3}{6} = 4.1888\ r^3 = 0.5236\ d^3$

$A = 4\pi r^2 = \pi d^2 = 12.5664 r^2 = 3.1416\ d^2$

$r = \sqrt[3]{\frac{3V}{4\pi}} = 0.6204\ \sqrt[3]{V}$



Spherical Sector

A = total area of conical and spherical surface.

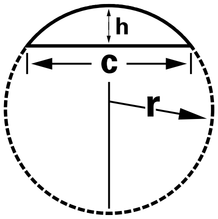
$V = \frac{2\pi r^3 h}{3} = 2.0944\ r^2h$

$\mathrm{A} = 3.1416\ r\ (2\ h + \frac{1}{2}\mathrm{c})$

$\mathrm{c} = 2\sqrt{\mathrm{h}\ (2\ r - h)}$

Volumes of Solids

V = volume



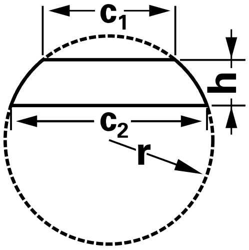
Spherical Segment

A = area of spherical surface.

$V = 3.1416\ h^2 \left(r - \frac{1}{2}\right) = 3.1416\ h \left(\frac{c^2}{8} + \frac{h^2}{6}\right)$

$A = 2\pi rh = 6.2832\ rh = 3.1416 \left(\frac{c^2}{4} + h^2\right)$

$c = 2\sqrt{h\ (2\mathrm{r} - h)}$; $r = \frac{c^2 + 4h^2}{8h}$



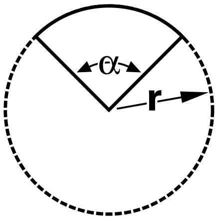
Spherical Zone

A = area of spherical surface.

$V = 0.5236\ h \left(\frac{c^2 + 4h^2}{8h} + \frac{c^2 + 4h^2}{8h} + h^2\right)$

$A = 2\pi rh = 6.2832\ rh$

$r = \sqrt{\frac{c_2{}^2}{4} + \left(\frac{c_2{}^2 - c_1{}^2 - 4h^2}{8h}\right)^2}$



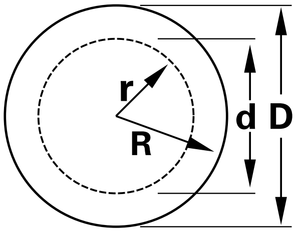
Spherical Wedge

A = area of spherical surface;

a = center angle in degrees.

$V = \frac{\alpha}{360}\ \mathrm{X}\ \frac{4\pi r^3}{3} = 0.0116\ \alpha r3$

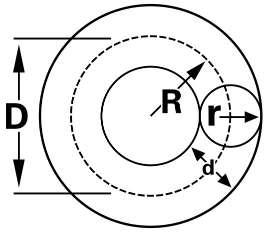
$A = \frac{\alpha}{360}\ \mathrm{X}\ 4\pi r^2 = 0.0349\ \alpha r2$



Hollow Sphere

$V = \frac{4\pi}{3}\ (R^3 - r^3) = 4.1888\ (R^3 - r^3)$

$= \frac{\pi}{6}\ (D^3 - d^3) = 0.5236\ (D^3 - d^3)$



Torus

A = area of surface.

$\mathrm{V} = 2\pi^2\ Rr^2 = 19.739\ Rr^2$

$= \frac{\pi^2}{4}\ Dd^2 = 2.4674\ Dd^2$

$\mathrm{A} = 4\ \pi^2\ Rr = 39.478\ Rr$

$= \pi^2\ Dd = 9.8696\ Dd$

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