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BEARING AND SEAL TECHNOLOGY REVIEW

By
A. F. Niegel

June 1971

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U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

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This report was prepared by Pratt and Whitney Aircraft, Florida Research and Development Center, a Division of United Aircraft Corporation, under the terms of Contract DAAJ02-68-C-0001. It discusses the review of gas turbine engine bearing and seal technology conducted in conjunction with the ST9 Demonstrator Engine program.

The objectives of this portion of the contractual effort were (1) to conduct a design review of advanced technology bearing and seal package concepts for large engines to determine which concepts might be applicable to small engines, (2) to determine suitable scale factors from large bearing and seal technology to small engine applications, (3) to recommend systematic test programs to provide scale factor data where scale factors are in question, and (4) to determine what bearing and seal technology is lacking for advanced small engines.

In general, the above objectives were met and are presented in this report.

Appropriate technical personnel of this Directorate have reviewed this report and concur with the conclusions and recommendations contained herein. The Eustis Directorate project engineer for this effort was David B. Cale, Propulsion Division.

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**BEARING AND SEAL
TECHNOLOGY REVIEW**

Final Report

by

A. F. Hiegel

Prepared By

**Pratt & Whitney Aircraft
Division of United Aircraft Corporation
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**EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH
AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA**

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SUMMARY

Pratt & Whitney Aircraft large and small engine main shaft bearings and seals were reviewed (1) to identify large gas turbine engine bearing and seal concepts or characteristics which are applicable to small gas turbine engines of the 2-10 lb/sec airflow size, (2) to define large engine bearing and seal design standards for applicability to small gas turbine engines, (3) to determine suitable factors for scaling bearing and seal technology concepts from large gas turbine engines to small, 2-10 lb/sec airflow size turbine engines, (4) to recommend test programs to provide scaling data where scale factors are questionable, and (5) to determine what bearing and seal technology is lacking for advanced small engines.

To accomplish this task, bearing and seal characteristics that might define standard design practices or scale factors were selected. After collection and compilation of pertinent data, comparisons were made to establish relationships between engine size and selected bearing and seal characteristics. In addition, comparisons of selected characteristics of large, mostly twin-spool engines versus small engine bearing, seal, and rotor dynamic characteristics were made.

As a result, scale factors were obtained between total corrected airflow into the engine and several low rotor ball bearing characteristics. Similarly, high rotor roller bearings were found to scale with corrected airflow into the high compressor. In general, bearing and seal size was found to increase with engine size.

Although scale factors were obtained, their utilization should be confined to preliminary design only. This recommendation is made because of the many areas which can affect bearing design.

Several research programs are recommended to provide bearing and seal technology which is lacking for advanced engines. These programs include areas such as advanced bearing and seal analysis programs as well as seal wear and roller dynamics studies.

TABLE OF CONTENTS

	<u>Page</u>
SUMMARY	iii
LIST OF ILLUSTRATIONS.	vi
LIST OF TABLES	ix
LIST OF SYMBOLS	xi
COLLECTION AND COMPILATION OF DATA.	1
COMPARISONS	11
ROTOR DYNAMIC CHARACTERISTICS	15
Bearings per Shaft	15
Engine Critical Speeds	15
Damped Bearings.	15
INVESTIGATION OF SCALE FACTORS	16
DISCUSSION OF SCALE FACTORS	22
AREAS WHICH LIMIT THE UTILITY OF SCALE FACTORS	24
RECOMMENDED ADDITIONAL BEARING AND SEAL RESEARCH FOR ADVANCED SMALL ENGINES	26
Bearing Material Improvement Study.	26
Ball Bearing Cage Study	26
Cage Configuration and Vibration Study	26
Analytical Bearing Programs.	27
Roller Dynamics Study	27
Seal Wear Study.	27
Analytical Seal Programs Study	28
CONCLUSIONS	29
DISTRIBUTION	114

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	External Roller Bearing Geometry	83
2	Roller Element Geometry	83
3	Ball Bearing Geometry	84
4	Low Rotor Ball Bearings at Sea Level Takeoff; Bore Diameter vs Total Corrected Airflow Into Engine	85
5	Low Rotor Ball Bearings at Sea Level Takeoff; nd^2 vs Total Corrected Airflow Into Engine	85
6	High Rotor Roller Bearings at Sea Level Takeoff; Bearing Bore Diameter vs Corrected Airflow Into High Compressor	86
7	Low Rotor Seals at Sea Level Takcoff; Seal Pitch Diameter vs Total Corrected Airflow Into Engine	86
8	High Rotor Seals at Sea Level Takeoff; Seal Pitch Diameter vs Corrected Airflow Into High Compressor	87
9	High and Low Rotor Bearings at Sea Level Takeoff; Inner Race Speed vs Bore Diameter	88
10	Low Rotor Bearings at Sea Level Takeoff; Pitch Diameter vs Element Rotational Speed	89
11	High Rotor Ball Bearings at Sea Level Takeoff; Pitch Diameter vs Element Rotational Speed	90
12	High Rotor Roller Bearings at Sea Level Takeoff; Pitch Diameter vs Element Rotational Speed	91
13	High and Low Rotor Bearings; Pitch Diameter vs Bore Diameter	92
14	Low Rctor Ball Bearings; nd^2 vs Pitch Diameter	92
15	High and Low Rotor Roller Bearings; $nd\ell$ vs Pitch Diameter.	93
16	High and Low Rotor Roller Bearings at Sea Level Takeoff; Roller Diameter/Pitch Diameter vs Product of Pitch Diameter and Shaft Speed	94

LIST OF ILLUSTRATIONS (Continued)

<u>Figure</u>		<u>Page</u>
17	High and Low Rotor Ball Bearings at Sea Level Takeoff; Ball Diameter/Pitch Diameter vs Product of Pitch Diameter and Shaft Speed	95
18	High and Low Rotor Roller Bearings; Percent Total Roller Bearings vs L/D Ratio	96
19	High and Low Rotor Seals at Sea Level Takeoff; Total Face Pressure vs Rubbing Velocity	97
20	High and Low Rotor Seals at Sea Level Takeoff; Pitch Diameter vs Pressure Gradient	98
21	Low Rotor Ball Bearings at Sea Level Takeoff; Bearing Bore Diameter Ratio vs Total Corrected Airflow Into Engine	99
22	Low Rotor Ball Bearings at Sea Level Takeoff; nd^2 Ratio vs Total Corrected Airflow Into Engine	100
23	Low Rotor Ball Bearings at Sea Level Takeoff; Pitch Diameter Ratio vs Total Corrected Airflow Into Engine	101
24	High and Low Rotor Roller Bearings at Sea Level Takeoff; d/D_m Ratio vs Total Corrected Airflow Into Engine	102
25	High and Low Rotor Ball Bearings at Sea Level Takeoff; d/D_m Ratio vs Total Corrected Airflow Into Engine	103
26	High Rotor Roller Bearings at Sea Level Takeoff; Bore Diameter Ratio vs Corrected Airflow Into High Compressor. .	104
27	High Rotor Roller Bearings at Sea Level Takeoff; $nd\ell$ Ratio vs Corrected Airflow Into High Compressor	105
28	High Rotor Roller Bearings at Sea Level Takeoff; Pitch Diameter Ratio vs Corrected Airflow Into High Compressor	105
29	High Rotor Roller Bearings at Sea Level Takeoff; Element Diameter Ratio vs Corrected Airflow Into High Compressor	106

LIST OF ILLUSTRATIONS (Continued)

<u>Figure</u>		<u>Page</u>
30	Low Rotor Ball Bearings; nd^2 Ratio vs Pitch Diameter	107
31	High and Low Rotor Roller Bearings; nd^2 Ratio vs Pitch Diameter	108
32	High and Low Rotor Ball Bearings and Low Rotor Roller Bearings; Pitch Diameter Ratio vs Bore Diameter	109
33	High Rotor Roller Bearings; Pitch Diameter Ratio vs Bore Diameter	110
34	Low Rotor Ball and Roller Bearings at Sea Level Takeoff; Element Rotational Speed Ratio vs Pitch Diameter	111
35	High Rotor Ball Bearings at Sea Level Takeoff; Element Rotational Speed Ratio vs Pitch Diameter	112
36	High Rotor Roller Bearings at Sea Level Takeoff; Element Rotational Speed Ratio vs Pitch Diameter	113

LIST OF TABLES

<u>Table</u>		<u>Page</u>
I	Main Shaft Bearing General Characteristics at Sea Level Takeoff for Small Engine No. 1	30
II	Main Shaft Bearing General Characteristics at Sea Level Takeoff for Small Engine No. 2	31
III	Main Shaft Bearing General Characteristics at Sea Level Takeoff for Small Engine No. 3.	32
IV	Main Shaft Bearing General Characteristics at Sea Level Takeoff for Large Engine No. 1	33
V	Main Shaft Bearing General Characteristics at Sea Level Takeoff for Large Engine No. 2	34
VI	Main Shaft Bearing General Characteristics at Sea Level Takeoff for Large Engine No. 3	35
VII	P100 Main Shaft Bearing General Characteristics at Sea Level Takeoff for Large Engine No. 4	36
VIII	Main Shaft Bearing General Characteristics at Sea Level Takeoff for Large Engine No. 5	37
IX	Main Shaft Bearing General Characteristics at Sea Level Takeoff for Large Engine No. 6	38
X	Main Shaft Seals - General Characteristics at Sea Level Takeoff for Small Engine No. 1	39
XI	Main Shaft Seals - General Characteristics at Sea Level Takeoff for Small Engine No. 2	40
XII	Main Shaft Seals - General Characteristics at Sea Level Takeoff for Large Engine No. 1	41
XIII	Main Shaft Seals - General Characteristics at Sea Level Takeoff for Large Engine No. 2	42
XIV	Main Shaft Seals - General Characteristics at Sea Level Takeoff for Large Engine No. 3	43
XV	Main Shaft Seals - General Characteristics at Sea Level Takeoff for Large Engine No. 4	44
XVI	Main Shaft Seals - General Characteristics at Sea Level Takeoff for Large Engine No. 5	45

LIST OF TABLES (Continued)

<u>Table</u>		<u>Page</u>
XVII	Main Shaft Seals - General Characteristics at Sea Level Takeoff for Large Engine No. 6	46
XVIII	Small Engine No. 1 Main Shaft Bearings.	47
XIX	Small Engine No. 2 Main Shaft Bearings.	49
XX	Small Engine No. 3 Main Shaft Bearings.	49
XXI	Large Engine No. 1 Main Shaft Bearings	51
XXII	Large Engine No. 2 Main Shaft Bearings	53
XXIII	Large Engine No. 3 Main Shaft Bearings	55
XXIV	Large Engine No. 4 Main Shaft Bearings	57
XXV	Large Engine No. 5 Main Shaft Bearings	59
XXVI	Large Engine No. 6 Main Shaft Bearings	61
XXVII	Small Engine No. 1 Main Shaft Seals	63
XXVIII	Small Engine No. 2 Main Shaft Seals	63
XXIX	Large Engine No. 1 Main Shaft Seals	64
XXX	Large Engine No. 2 Main Shaft Seals	65
XXXI	Large Engine No. 3 Main Shaft Seals	65
XXXII	Large Engine No. 4 Main Shaft Seals	66
XXXIII	Large Engine No. 5 Main Shaft Seals	67
XXXIV	Large Engine No. 6 Main Shaft Seals	68
XXXV	Small and Large Engine Performance and Rotor Dynamic Characteristics	69
XXXVI	Calculated Bearing Characteristics	71
XXXVII	Calculated Main Shaft Carbon Seal Characteristics	81
XXXVIII	Calculated Ring Seal Characteristics	82

LIST OF SYMBOLS

d	= element diameter
D_m	= pitch diameter
n	= number of elements
ℓ	= roller length
N	= shaft speed in rpm
D	= bore diameter in mm
p	= seal face pressure in psi
ΔP	= pressure gradient across seal face in psi
V	= rubbing velocity in ft/sec

COLLECTION AND COMPILATION OF DATA

Existing bearings and shaft seals of three small gas turbine engines (PT6A-27, JT12, and ST9) and six large engines (JT3D, JT8D, JT9D, TF30 P100, JTF20, and JTF22) were reviewed. In cases of multiple engine versions, efforts were made to utilize latest designs.

A survey of bearing and seal characteristics was made to ensure collection of essential bearing and seal data as quickly as possible. As a result, prints were accumulated for each engine bearing and seal. These prints or drawings contain essential design information for vendor coordination and company reference.

Also, several characteristics were found to be common to small and large engine bearings and seals. These characteristics often change with flight conditions. For this reason, sea level takeoff (SLTO) was selected as the basic flight point to analyze, because it is a common flight performance point shared by all engines.

The following data common to small and large engine bearings were accumulated for each engine bearing:

1. Operating Clearance or Contact Angle at SLTO

Bearings are designed to operate with a definite amount of looseness or diametral internal clearance. For roller bearings, this radial or diametral internal clearance is usually a nominal 0.0005 in. to 0.0015 in. Main shaft ball bearings are normally split-race, angular contact bearings because of extra capacity, easy assembly, and freedom to employ a one-piece cage. Ball bearings are usually designed to operate at a contact angle range of 15 deg to 30 deg depending on speed, load, thermal environment, and life requirements. Operating clearance or contact angle is one of the most important design characteristics of a bearing, since it influences contact stresses, deflections, load distribution, and fatigue life.

2. Methods of Lubrication and Cooling

Since bearings separate rotating and stationary structures, friction and wear from the relative motion of metallic surfaces must be minimized. Methods of lubrication and cooling are extremely important and prevent metal-to-metal contact by establishing an oil film and by removing heat generated.

There are three basic methods of lubricating and cooling bearings: (1) oil mist, (2) direct oil jet, and (3) under-race slots with optional oil holes at split race of ball bearings or at corner relief of roller bearings. For each bearing application, the method of lubricating and cooling must be optimized to ensure successful operation for extended periods of time. This optimization study must consider loads, speeds, sizes, environmental conditions, cost, and lubricant type.

3. Bearing Oil-Inlet Temperature at SLTO

Oil-inlet temperatures directly affect absolute values of race temperatures, because the removal of heat generated at the contact zone of the bearing is reduced as oil temperatures increase.

Lubricant properties are greatly affected by bearing temperatures. Temperatures influence oil viscosity, which is directly related to oil film thickness at the rolling element-raceway contact area. Oil film thickness must be greater than surface asperities, or surface distress will occur. Therefore, oil inlet temperatures have been controlled to provide sufficient oil film thickness. Oil inlet temperatures have been maintained between 180° F and 300° F.

4. Bearing Race Temperatures at SLTO

Race temperatures are extremely important for design purposes. The principal use is for calculating the change in bearing internal clearance to establish operating contact angle or internal clearance. Accuracy of analytically calculated race temperatures is, therefore, of utmost importance.

Although oil inlet temperatures are constant in the majority of the engines, race temperatures differ because of variations in bearing size, loads, speeds, and lubrication methods. Inlet oil temperature is the principal influence on the magnitude of race temperatures.

The lubrication properties of oil are greatly affected by bearing temperatures. Temperatures influence oil viscosity that is directly related to oil film thickness at the rolling element-raceway contact area. Oil film thickness, by necessity, must be greater than surface asperities, or surface distress will occur. Therefore, oil inlet temperatures must be controlled to provide sufficient oil film thickness. Race temperatures also affect the change in internal clearance of a bearing during operation; accuracy of analytically calculated race temperature is, therefore, of utmost importance. For this reason, analytical methods are constantly being updated to relate the effects of bearing loads, speed, size, and oil inlet temperatures.

Rig testing various size bearings under a wide range of loads, speeds, lubricants, and lubricant temperatures has provided inner and outer race temperature data. These data, coupled with a dimensionless heat transfer analysis, which considers friction, oil churning, and viscous drag, have established a prediction system for determining race temperatures. This prediction system is scalable to the extent that expected heat generation for small or large bearings is determined from previous small or large bearing rig testing.

5. Radial Loads (1 g and rotor response loads at SLTO)

Rotor, disc, and blade weights must be supported by bearings and passed on to the supporting structure. These loads are caused by gravity and are called "g" loads.

Although rotors are dynamically balanced before operation, a zero unbalance can never be achieved. Furthermore, discs slip on the shaft during operation and cause additional unbalance. The resulting radial loads caused by shaft unbalance are called rotor response loads and must be supported by bearings and housing structures.

Response and gravity loads must be anticipated during design to evaluate their effects on bearing life.

6 Maximum Maneuver Loads

When an airplane undergoes a maneuver condition, large radial loads result from gyroscopic moments. These radial loads are called maneuver loads. They must be transferred through the bearings to the supporting structure of the bearings. In such cases, bearings are required to structurally withstand resulting maneuver loads without fracture or permanent indentation.

Maneuver loads are functions of engine speed and shaft inertia, which are governed by engine design requirements. For example, commercial planes are often required to maneuver through a 1-rad/sec turn without engine failure; stiffer requirements, such as a 3-1/2-rad/sec maneuver, are sometimes imposed in military applications. In such cases, bearings are required to structurally withstand resulting maneuver loads without fracturing.

Small engine bearings have lower maneuver load requirements than large engine bearings. With this exception, no correlation between engine size (corrected airflow) and bearing maneuver load was found.

7. Preloaded Bearings

High-speed ball or roller bearings, which have small anticipated thrust or radial loads, respectively, are generally preloaded. Preloading is required to ensure a minimum contact load to prevent the bearing elements from sliding or skidding.

Method of preloading is constant regardless of engine size. A duplex-mounted ball bearing and an out-of-round outer race roller bearing are utilized to obtain preload in engines. The amount of preload is variable and depends on bearing size and engine duty cycle requirements which affect speeds and loads. The amount of preload cannot be directly scaled for this reason.

Analysis techniques are utilized to predict the amount of preload necessary to prevent skidding. The same analytical relationships are used for determining proper preload for engine bearings regardless of size. Techniques consider bearing size, loads, speeds, lubricant temperature, and roller bearing flexible structure.

8. Bearing Thrust Load at SLTO

Pressure gradients across compressor blades, turbine blades, and labyrinth seals result in axial shaft loads or ball bearing thrust loads. Definite pressure gradients are required throughout the engine for cooling purposes, engine thrust, and minimum shaft thrust load to prevent ball bearing skid.

Thrust loads affect bearing life and internal kinematics. For this reason, proper bearing thrust load is an important design consideration. Bearing thrust loads cannot be scaled, since minimum thrust load to prevent skid and maximum thrust load to obtain satisfactory life must be determined for each bearing application.

These data are presented in Tables I through IX.

The following standard design practices can be defined from these data:

- a. Roller bearings are designed with a nominal internal operating clearance of 0.0005 in. to 0.00015 in.
- b. Split-race, angular contact ball bearings are usually designed to operate at a contact range of 15 deg to 30 deg.
- c. Bearing oil-inlet temperatures have been maintained between 180° F and 300° F.
- d. Race temperatures are primarily dependent on oil inlet temperature.
- e. Maneuver loads are functions of engine speed and shaft inertia, which are governed by engine duty cycle requirements.
- f. Method of preloading bearings in engines is constant regardless of engine size. A duplex-mounted ball bearing and an out-of-round outer race roller bearing are utilized to obtain preload in an engine. Amount of preload is not constant but is dependent on size and duty cycle requirements.
- g. Sufficient thrust load must be applied to high-speed ball bearings to prevent skid.

Similarly, the following data common to small and large engine seals were accumulated for each engine seal:

1. Pressure Gradient at SLTO and Pressure Gradient Range

The chief purpose of shaft seals is to prevent the bearing compartment lubricant from leaking into the engine airpath. Air pressures surrounding a bearing compartment are designed to be greater than pressures inside the compartment. This prevents oil from being blown out of the compartment while complementing the sealing force of the seal. Pressure gradient at SLTO has been below 100 psi.

Pressure gradient range is an important seal design factor, since the pressure gradient must be large enough to prevent oil leaks and also small enough to eliminate excessive sealing force, which causes large seal wear.

2. Methods of Lubrication and Cooling

Compartment oil is normally utilized to remove frictional heat generated at the seal plate - seal face surface. At high rubbing velocities, tremendous wear may occur unless the seal rubbing surface is lubricated.

Three basic methods of lubricating and cooling seals are: (1) oil mist or oil jet directed at seal plate, (2) oil holes in seal plate for cooling and oil mist for lubrication, and (3) oil holes in seal plate for cooling and at the rubbing surface for lubrication. For each application, the methods of lubrication and cooling are optimized to ensure smooth seal operation for extended periods of time. Rubbing speeds, pressure gradient range, and thermal environment must be examined to provide proper cooling and lubrication.

3. Seal Air Temperature at SLTO

One of the principal environmental considerations in seal design is the temperature of the air surrounding the bearing compartment. Air temperature is usually greater than the bearing compartment temperatures and must be sealed out to prevent excessive oil temperatures. At the present time, air temperatures, where possible, are maintained below 1000° F.

4. Seal Spring Load

To ensure sealing during all flight conditions including low pressure gradient points, face pressure is maintained by a spring. (This spring load is specified in terms of load per inch of seal face mean or pitch diameter.) A constant spring load per inch of diameter has been established from past experience for most seal applications. This is independent of engine size.

These data are shown in Tables X through XVII.

The following standard design practices can be defined from these data:

1. Pressure gradient at SLTO has been maintained below 100 psi.
2. Seal air temperatures have been maintained below 1000° F, where possible.
3. Spring load per inch of diameter is constant, regardless of engine size.

This compilation of general data laid the foundations for selection of bearing and seal characteristics common to both large and small engines.

In all, 48 bearing and 42 seal positions in nine gas turbine engines were examined. Also, separate manufacturers or vendors for each bearing position were considered; this resulted in an examination of 92 bearings.

The accumulation of general bearing and seal data resulted in a selection from prints of characteristics common to both large and small engine bearings and seals. As a result, the following bearing characteristics were collected for each engine bearing:

1. Envelope dimensions
 - a. Inner diameter or bore diameter
 - b. Outer diameter
 - c. Width of inner raceway
 - d. Width of outer raceway
2. Bearing type
3. Element number or complement
4. Element size
 - a. Diameter
 - b. Length
 - c. Flat length
 - d. Crown radius

- e. Crown drop
- f. Gage point for crown drop measurement
- g. Corner radius
- 5. Pitch diameter
- 6. Ball bearing - inner and outer raceway curvatures
- 7. Cage type
- 8. Roller l/d (ratio of roller length to diameter)

Figures 1 through 3 illustrate the above characteristics.

Many of these characteristics are specified in Tables XVIII through XXVI.

Similarly, the following characteristics were obtained for each engine seal:

- 1. Seal type
- 2. Pitch diameter
- 3. Face width
- 4. Nose width
- 5. Pressure balance ratio
- 6. Secondary seal type
- 7. Method of spring loading

Many of these characteristics are presented in Tables XXVII through XXXIV.

This review resulted in the accumulation of 1656 characteristics for the 92 bearings and 294 characteristics for the 42 seals.

The following engine performance and rotor dynamic characteristics possibly related to bearing and seal design were gathered:

- 1. Corrected airflow into the engine and high compressor at SLTO
(Corrected airflow is defined mathematically as: Corrected Airflow = $\omega_a \sqrt{\theta} / \delta$, where ω_a is the physical inlet airflow in lb/sec (pps), θ is the ratio of the temperature at a specific engine location to the temperature on a standard day, and δ is the ratio of the pressure at a specific engine location to the pressure on a standard day.)
- 2. Rotor speed at SLTO

3. Shaft critical speeds
4. Damped bearings
5. Engine design life
6. Engine thrust with and without augmentation at SLTO
7. Engine weight with and without augments
8. Thrust specific fuel consumption (tsfc) with and without augmentation at SLTO

(tsfc is defined by: $tsfc = \dot{W}_F / T_F$, where $\dot{W}_F$ is the fuel flow in lb/hr and T_F is the net thrust in lbf.)
9. Engine thrust to weight ratio at SLTO
10. Maximum compressor blade tip speed

These engine performance and rotor dynamic characteristics are shown in Table XXXV.

After basic bearing and seal characteristics were obtained from prints, additional parameters that gage bearing and seal performance were calculated. These parameters were selected because of the possibility of defining standard design practices or scale factors.

It was felt that scale factors, if existent, would have to be functions of parameters that are common to bearing and seal designers. Concentrated efforts were applied to establish scale factors for common design parameters.

Simple computer programs were written to calculate the following design and performance characteristics common to both large and small engine bearings and seals:

1. Dynamic capacity is that constant radial load which a group of apparently identical bearings with stationary outer ring can endure for one million inner ring revolutions without fatigue.
2. Approximate bearing weight.
3. DN is the product of the bearing bore in millimeters times the maximum shaft speed in rpm; this parameter serves as a guide for limiting shaft speed or bearing bore. It is a measure of the relative motion of the bearing with respect to the engine axis.
4. Element rotational speed is the speed of the ball or roller about the element axis of rotation.

5. Element-to-cage sliding velocity is the velocity of the element with respect to the cage.
6. Cage-to-guiding surface sliding velocity is the velocity of the cage relative to the guiding raceway.
7. $D_m N$ is the product of the pitch diameter and shaft speed. Similar to DN , it is a measure of the motion of the pitch circle of the bearing relative to the engine axis.
8. d/D_m is the ratio of the element diameter to the pitch diameter. This is basically a differentiation of bearing series.
9. nd^2 or $nd\ell$ is the product of the number of elements or complement, element diameter, and the element length or diameter depending on bearing type. This is a relative measure of bearing capacity.
10. Roller ℓ/d is the ratio of the length to diameter of the element of a roller bearing. This is an intrinsic characteristic of each roller bearing. This parameter is related to capacity as well as optimized bearing dynamics.
11. Pitch-line velocity is the velocity of the cage and rolling elements relative to the bearing axis of rotation.
12. Element centrifugal load is the radial force created by the motion of the elements about the bearing axis of rotation.
13. Maximum element centrifugal load-induced stress is the maximum contact stress caused by element centrifugal load.
14. The rpm for constant centrifugal load-induced stress is the shaft speed required to produce a constant contact stress due to element centrifugal load.
15. Fatigue life is the number of hours at specific load and speed conditions that 90% of a group of bearings will complete before evidence of fatigue develops. This is an important design factor, since engine requirements usually dictate bearing life and, hence, affect bearing size.
16. Face sliding or rubbing velocity is the velocity of the seal face relative to the seal runner. This is a gauge of limiting seal speed and size.
17. ΔPV value is the product of the pressure gradient across the seal and the rubbing velocity. This is a measure of seal capability.
18. PV value is the product of the seal face pressure and seal rubbing velocity.

19. Face pressure due to spring load is the seal face pressure caused by spring load.
20. Total face pressure is the sum of the seal face pressures due to spring force and pressure gradients.
21. Spring force per inch of diameter is the ratio of the total spring force to the pitch diameter of the seal face.

These characteristics are specified in Tables XXXVI through XXXVIII.

Collected and calculated bearing and seal parameters totaled 3036 for the 92 bearings and 840 for the 42 seals.

COMPARISONS

An extensive study was made to establish possible relationships between engine size and selected bearing and seal characteristics. To relate engine size to bearing and seal design, the following performance characteristics were examined:

1. Engine thrust at sea level takeoff
2. Engine thrust-to-weight ratio at sea level takeoff
3. Thrust specific fuel consumption at sea level takeoff
4. Maximum compressor blade tip speed
5. Corrected engine airflow at sea level takeoff
6. Specific inlet airflow (ratio of total corrected inlet airflow to inlet area)

Except for corrected engine airflow, correlations were not obtained. This was attributed to the differences in duty cycle and engine augmentation requirements, which considerably affect engine thrust, thrust-to-weight ratio, and thrust specific fuel consumption. Maximum compressor blade tip speed for axial flow compressors and specific inlet airflow are nearly constant.

Total corrected airflow into the engine was compared with the following selected bearing characteristics: bore diameter, bearing DN, approximate bearing weight, $D_m N$, nd^2 or $nd \ell$, d/D_m , element centrifugal load, maximum stress caused by element centrifugal load, and rpm for constant centrifugal load induced stress.

Comparison of bore diameter vs total corrected airflow into the engine (Figure 4) showed that low rotor ball bearings increase in size with increased engine size or airflow.

A straight line relationship was obtained between total corrected airflow into the engine and low rotor ball bearing nd^2 , a measure of bearing capacity (Figure 5). This linear equation exhibited an increase in ball bearing nd^2 with engine size. These relationships were valid for all engines except one large engine (the JT9D) and the two small engines with centrifugal compressors (the PT6A-27, and ST9). Similarly, approximate low rotor ball bearing weight was found to increase with total corrected engine airflow.

The principal result of these comparisons was that low rotor ball bearings increase in size linearly with engine size.

Comparisons between corrected airflow into the high compressor and selected high rotor bearing characteristics were also made. The three small engines (PT6A-27, JT12, and ST9) were not included in the comparisons, since these engines either do not have high compressors or have centrifugal compressors.

The general result of the comparisons was an expected increase in high rotor roller bearing size, bore diameter, approximate roller bearing weight, and roller centrifugal load with increasing corrected airflow into the high compressor.

Figure 6 shows the increase in high rotor roller bearing bore diameter with corrected airflow into the high compressor. A linear relationship was obtained. Other comparisons failed to show significant correlations.

The total corrected airflow into the engine and into the high compressor was compared with the following selected low and high rotor seal characteristics: pitch diameter, pressure gradient, seal air temperature, face sliding velocity, PV value, and pressure gradient range.

These comparisons showed that seal pitch diameter has generally increased with increasing corrected airflow into the fan and high compressor. (See Figures 7 and 8.) Hence, seals, like bearings, were found to increase with engine size.

Seal rubbing velocity, a relative measure of seal operating severity, and PV value have increased in magnitude with improved seal technology and engine requirements. Other correlations were not obtained.

The following selected characteristics of large vs small engine bearings were analyzed:

1. Bore diameter vs shaft speed, pitch line velocity, and pitch diameter
2. Element rotational velocity vs pitch diameter
3. DN vs $D_m N$, method of cooling, and method of lubrication
4. Pitch diameter vs element diameter, nd^2 or $nd\ell$ maximum stress developed by centrifugal load, and rpm for constant centrifugal load induced stress
5. Element-to-cage sliding velocity vs pitch diameter
6. Cage-to-guiding surface sliding velocity vs pitch diameter and $d/D_m \cos \alpha$ (where α is mounted contact angle)
7. Shaft speed vs d/D_m , roller ℓ/d , method of cooling, and method of lubrication
8. $D_m N$ vs roller ℓ/d
9. d/D_m vs nd^2 or $nd\ell$
10. D_m vs d/D_m
11. nd^2 or $nd\ell$ vs maximum stress developed by centrifugal load and rpm for constant centrifugal load induced stress

12. Element diameter vs maximum stress developed by centrifugal load and rpm for constant centrifugal load induced stress

Correlations were found in some comparisons as listed and discussed below:

1. DN experience curve for main shaft bearings at sea level takeoff is shown in the comparison of bore diameter vs inner race speed (Figure 9).
2. Element rotational speed vs pitch diameter (Figures 10, 11 and 12) separated into three distinct bands: low rotor bearings, high rotor ball bearings, and high rotor roller bearings.

Element rotational speeds of some large engine bearings were equal to those of small engine bearings. For this reason, small and large engine bearings were indistinguishable, except by the magnitude of the bearing pitch diameter.

In each band, element rotational speed was found to generally increase as pitch diameter decreased. This was expected, since shaft speeds generally increase as engine size and bearing size decrease.

For constant pitch diameter, element rotational speed was greater for high rotor roller bearings than ball bearings.

3. All bearings were contained in a definite band in a comparison of pitch diameter vs bore diameter. (See Figure 13.)

A reference line was drawn through the points; an additional line was drawn at 45 deg to represent the theoretical case where pitch diameter would equal bore diameter. The distance between lines represented the bearing cross section thickness and shows a 15% greater increase than the bore diameter.

4. Comparison of pitch diameter with nd^2 and $nd\ell$ exhibited increased bearing capacity with increased pitch diameter. (See Figures 14 and 15.) This was expected, since a larger pitch diameter allows more space for an increase in the bearing complement, the element diameter, or both.
5. Comparison of $D_m N$ vs d/D_m separated into two bands, one for roller bearings and one for ball bearings. The majority of roller bearings, regardless of engine size or shaft location, were bounded between d/D_m of 0.075 and 0.11, as shown in Figure 16. Similarly, the majority of the ball bearings were bounded between d/D_m of 0.115 and 0.14, as shown in Figure 17.
6. Roller L/D ratio has been principally designed between 0.95 and 1.20. As shown in Figure 18, almost 50% of all rollers studied had an L/D ratio between 0.95 and 1.00.

7. Design limit on bearing cooling and lubrication by oil mist vs positive methods, such as direct jet or under race oil slots, was constant.

Other comparisons failed to show significant correlations.

The following selected characteristics of large vs small engine seals were compared:

1. Pressure balance ratio vs pitch diameter
2. Face pressure caused by spring load vs pitch diameter
3. Total face pressure vs pitch diameter
4. Spring load vs pitch diameter
5. Face pressure caused by spring load vs face sliding velocity
6. Face sliding velocity vs total face pressure, method of cooling, method of lubrication, and pressure gradient
7. Face width vs pitch diameter
8. Pressure gradient vs pitch diameter, method of cooling, and method of lubrication
9. Spring force/in. of diameter vs pressure gradient
10. Pitch diameter vs shaft speed and PV value
11. Shaft speed vs spring force/in. of diameter
12. Pressure gradient range vs method of cooling and method of lubrication

Results of the comparisons were:

1. Face rubbing velocity vs total face pressure and pressure gradient vs pitch diameter (Figures 19 and 20, respectively) showed a wide band of points with a tendency to increase. Due to the width of these bands, no exact correlations could be made.
2. Design limit on seal plate cooling and lubrication by oil mist, as opposed to positive methods, was constant.
3. Pressure balance ratio, seal face width, seal nose width, and spring force/in. of diameter were constant regardless of engine size. Other significant results were not obtained.

ROTOR DYNAMIC CHARACTERISTICS

In addition to defining standard design practices, large vs small engine rotor dynamic characteristics listed and discussed below were evaluated for possible relationships.

BEARINGS PER SHAFT

In general, long engines have three bearings per shaft and several intershaft bearings; shorter engines have either two or three bearings per shaft. The present trend in shaft dynamics is to have two bearings per shaft. More than two bearings can result in shaft alignment problems.

During engine design, the exact number of bearings required is determined by a thorough critical speed analysis.

ENGINE CRITICAL SPEEDS

All new engine rotor designs are analyzed with realistic support and case structures using critical speed analysis with strain energy consideration. The purpose of the analysis is to obtain shaft critical speeds and rotor response.

Critical speed analysis is dependent on shaft stiffness, bearing stiffness, bearing location, and number of bearings, as well as disc, shaft, and blade inertias. For this reason, past attempts to relate shaft critical speed or shaft sensitivity of one engine to another have failed. A possible relationship between shaft sensitivity and shaft speed to weight ratio may exist, but extensive vibration and rotor dynamic studies would be required to define this relationship.

New engines have a greater shaft slenderness (length to diameter) ratio compared to old engines. For this reason alone, critical speeds are not scalable.

DAMPED BEARINGS

When critical speeds occur within the flight envelope, bearing response loads can become large. To design out of the critical speed region, bearing supports are usually "softened." This reduces shaft critical speed below flight speed requirements. The shaft can then accelerate through the critical speed mode without vibration problems.

To provide softer supports, damped bearings are utilized. Methods of damping are constant. Roller bearings are oil-damped or floated on a thin film of oil. Ball bearings are designed with a "hairspring" support or a "hairspring" oil film combination. Expert structural and bearing design is required to establish manufacturing, deflection, stress, and raceway ovalization limitations.

The necessity for damped bearings has been principally created by the shaft sensitivity of advanced small, high-speed engines. This is because damped bearing requirements are related to shaft sensitivity caused by (1) rotating unbalance, (2) shaft speed to weight ratio, and (3) shaft strain energy. A comprehensive vibration analysis would be required to establish firm relationships.

INVESTIGATION OF SCALE FACTORS

Low rotor ball bearings were found to scale with total corrected airflow into the engine; similarly, high rotor roller bearings scaled with corrected airflow into the high compressor. Scale factors were found applicable to conventional engine designs with axial flow compressors.

Scale factors were established by obtaining ratios of selected bearing and seal characteristics vs ratios of engine airflow. Sea level takeoff was chosen as the operating condition because it is common to all engines. The purpose of the ratios was to graphically establish linear or polynomial relationships between selected bearing and seal characteristics of large and small engines. Scale factors could then be formulated as the slopes of resulting straight or bounding lines.

A simple computer program was written to calculate and tabulate the ratios of selected bearing and seal characteristics for the study engines at sea level takeoff. Ratios were obtained with respect to ST9 bearing and seal characteristics; but regardless of which engine was used as a basis, the ratios would have remained in the same relative positions.

The ST9 and PT6A-27 engines have power turbine and gas generator shafts instead of the usual low and high rotor shafts. Because of speed and size, the power turbine shafts were considered as low rotor shafts. For similar reasons, the gas generator shafts were considered as high rotor shafts.

To ratio bearing and seal characteristics, a ball and a roller bearing were needed for each shaft. The ST9 power turbine shaft has three bearings (single and duplex ball bearings and one roller bearing); the gas generator shaft has a ball and a roller bearing. The No. 2 duplex-mounted ball bearing (engine bearing order is established by progressive numbers from front of engine) was designed to provide engine maintainability, to alleviate critical speed problems, to support installation loads, and to locate the power drive shaft. These specialized purposes made scaling impractical. Hence, the No. 2 bearing was not utilized to obtain low rotor ball bearing ratios in the analysis.

Earlier studies tried to establish relationships between engine size and selected bearing and seal characteristics. Except for corrected airflow, correlations between bearing and seal selection and engine size were not obtained. In a study to establish scale factors between engine size and selected bearing and seal characteristics, only corrected airflow was considered. The total corrected airflow ratio was compared with the following ratios: bearing bore diameter, nd^2 or nd^3 , bearing weight, bearing capacity, d/D_m , DN , $D_m N$, pitch diameter, element diameter, pitch-line velocity, centrifugal load, element rotational speed, element-to-cage rubbing velocity, cage-to-land rubbing velocity, ratio of maximum stress developed by centrifugal load, and rpm ratio from constant centrifugal load induced stress.

Ratios of selected bearing characteristics ($D_m N$, pitch line, element rotational speed, element-to-cage rubbing velocity, and cage-to-land rubbing velocity) were found to generally decrease with increasing airflow ratios.

These comparisons substantiated expectations that bearing speeds generally decrease with increasing engine size or airflow.

Good correlations between total corrected airflow and bore diameter, nd^2 , and pitch diameter ratios were obtained for low rotor ball bearings. (See Figures 21, 22, and 23.)

The linear relationships coincided with previous results that low rotor ball bearing size has increased with increased engine size or corrected airflow; furthermore, scale factors were established between certain low rotor ball bearing characteristics and engine size. These scale factors are defined below:

$$\text{Bore diameter (mm)} = 0.11 (\text{total corrected airflow in lb/sec}) + 79.2 \quad (1)$$

$$nd^2 (\text{sq in.}) = 0.018 (\text{total corrected airflow in lb/sec}) + 6.09 \quad (2)$$

$$\text{Pitch diameter (in.)} = 0.0054 (\text{total corrected airflow in lb/sec}) + 3.99 \quad (3)$$

The average deviation for these equations is 3%.

Low rotor ball bearings of the JT9D engine and the two engines with centrifugal compressors, the PT6A-27 and the ST9, failed to satisfy the scale factor relationships.

Two bands, one for ball bearings and one for roller bearings, were obtained for d/D_m ratios regardless of the comparison. (See Figures 24 and 25.) These graphs coincide with previous results that d/D_m separates into distinct bands for the majority of the ball and roller bearings.

Similarly, relationships between the corrected airflow into the high compressor and ratios of selected high rotor bearing characteristics were investigated. The TF30 P100 engine was utilized as a basis to ratio selected high rotor bearing and seal characteristics. This was similar to utilization of the ST9 engine as a basis for establishing scale factors between total corrected airflow into the engine and selected bearing and seal characteristics. The TF30 P100 engine was chosen because of its lower value of corrected airflow into the high compressor vs other engines with high compressors. The three small engines (PT6A-27, JT12, and ST9) were disregarded in the analysis, since these engines either do not have high compressors or have centrifugal compressors.

Certain ratios (bore diameter, weight, nd^2 , pitch diameter, and element diameter) of high rotor roller bearing characteristics were found to increase with increasing corrected airflow into the high compressor. (See Figures 26 through 29.)

Results paralleled those obtained previously for low rotor ball bearings. Again, expectations that bearing size had increased with engine size were substantiated.

The straight lines of these comparisons established scale factors between certain high rotor roller bearing characteristics and engine size. These scale factors are defined below:

$$\text{Bore diameter (mm)} = 1.12 (\text{corrected airflow into high compressor in lb/sec}) + 92.3 \quad (4)$$

$$\text{nd } \ell \text{ (sq in.)} = 0.189 (\text{corrected airflow into high compressor in lb/sec}) + 1.23 \quad (5)$$

$$\text{Pitch diameter (in.)} = 0.049 (\text{corrected airflow into high compressor in lb/sec}) + 4.56 \quad (6)$$

$$\text{Element diameter (in.)} = 0.0043 (\text{corrected airflow into high compressor in lb/sec}) + 0.35 \quad (7)$$

Scaling equations are accurate within an average deviation of 6%.

An investigation was made to determine the possibility that the two small engines with centrifugal compressors might scale like large engines with axial compressors. The ST9 was chosen to compare with the large engines, and its centrifugal compressor was treated as a high compressor. ST9 bearings, however, failed to scale like the large engine bearings.

Using the ST9 as a basis, comparisons were made between the total corrected airflow into the engine and the following selected seal characteristic ratios: pitch diameter, pressure gradient, seal air temperature, seal rubbing velocity, seal PV value, pressure gradient range, spring force ratio, total face pressure, and face pressure caused by spring load ratio.

Comparisons showed that seal pitch diameter ratio increased with increasing total corrected airflow. This result confirmed initial expectations that seal size has increased with engine size. Scale factors were not obtained because upper and lower bounds for the data points could not be established. Other comparisons failed to show significant trends.

Similarly, comparisons between the corrected airflow into the high compressor and ratios of selected high rotor seal characteristics were made with the TF30 P100 as a basis.

Except for the expected trend for seal pitch diameter to increase with engine size, correlations were not obtained. Again, scale factors were impossible to obtain because of the difficulty in establishing upper and lower bounds.

The scalability study continued with an investigation to ascertain scale factors for selected characteristics of large vs small bearings and seals. Again, the ST9 bearings and seals were utilized as a basis to obtain ratios.

The following ratios of selected characteristics of large vs small engine bearings were analyzed:

1. Pitch diameter vs element rotational speed ratio, element diameter ratio, nd^2 or $nd\ell$ ratio, element-to-cage rubbing velocity ratio, cage-to-land rubbing velocity ratio, ratio of maximum stress developed by centrifugal load, and rpm ratio for constant centrifugal load induced stress
2. Bore diameter vs pitch line velocity ratio and pitch diameter ratio
3. d/D_m vs nd^2 or $nd\ell$ ratio
4. $D_m N$ vs d/D_m ratio
5. DN vs d/D_m ratio
6. nd^2 or $nd\ell$ vs ratio of maximum stress developed by centrifugal load and rpm ratio for constant centrifugal load induced stress
7. Element diameter vs ratio of maximum stress developed by centrifugal load and rpm ratio for constant centrifugal load induced stress

Correlation was found in some comparisons as listed and discussed below:

1. The graph of pitch diameter vs element diameter ratio exhibited expected increasing element size for increasing pitch diameter
2. Comparisons of pitch diameter vs nd^2 ratio for low rotor ball bearings or $nd\ell$ ratio for roller bearings showed expected increasing element number and size for increasing pitch diameter. (See Figures 30 and 31.)

Equations were derived to describe the relationships:

$$nd^2 \text{ (sq in.)} = 0.0196 (\text{pitch diameter})^3 + 0.1236 (\text{pitch diameter})^2 + 0.40 (\text{pitch diameter}) + 1.29, \text{ for low rotor ball bearings (where units for pitch diameter are in.)} \quad (8)$$

$$nd\ell \text{ (sq in.)} = 2.54 (\text{pitch diameter in in.}) - 5.71, \text{ for upper boundary} \quad (9)$$

$$nd\ell \text{ (sq in.)} = 2.09 (\text{pitch diameter in in.}) - 4.96, \text{ for lower boundary} \quad (10)$$

3. Comparisons of pitch diameter ratio vs bore diameter established definite scale factors. These factors can be utilized in determining the cross-section thickness between the bearing bore and pitch diameters or in comparing a new design to past experience.

Ball bearings and low rotor roller bearings were contained in a definite band. (See Figure 32.) The boundaries are defined by:

$$\text{Pitch diameter ratio} = 0.348 (\text{bore diameter}) + 0.27, \text{ for upper boundary} \quad (11)$$

$$\text{Pitch diameter ratio} = 0.348 (\text{bore diameter}) + 0.11, \text{ for lower boundary} \quad (12)$$

From these bounds, individual equations for low rotor ball bearings, high rotor ball bearings, and low rotor roller bearings were obtained by conversion factors.

High rotor roller bearings formed a straight line which was lower than the band obtained for other bearings (Figure 33). The straight line is defined by:

$$\text{Pitch diameter ratio} = 0.332 (\text{bore diameter}) + 0.10 \quad (13)$$

By conversion factors, the equation becomes

$$\text{Pitch diameter (in.)} = 1.13 (\text{bore diameter in in.}) + 0.35 \quad (14)$$

The average of these equations established the straight line obtained previously between bearing bore and pitch diameters (Figure 13). The equation is:

$$\text{Pitch diameter (mm)} = 1.15 (\text{bore diameter in mm}) + 8.9.$$

4. Pitch diameter vs element rotational speed ratio (Figures 34, 35, and 36) separated into three distinct bands: low rotor bearings, high rotor roller bearings, and high rotor ball bearings. Small and large engine bearings were distinguishable only by the magnitude of the pitch diameter. In general, the element rotational speed increased as the pitch diameter decreased. This was expected, since, as previously stated, shaft speeds have generally increased as engine and bearing sizes have decreased. Definite scale factors were not obtained because of the difficulty in establishing upper and lower bounds for these graphs.

In other comparisons, correlations were not obtained.

In addition, the following comparisons of ratios of selected characteristics of large vs small engine seals were made:

1. Pitch diameter vs spring force ratio, total force pressure ratio, face pressure caused by spring load ratio, pressure gradient range ratio, and seal PV value ratio
2. Ratio of face pressure due to spring load vs rubbing velocity ratio
3. Rubbing velocity ratio vs total face pressure ratio

Significant correlations were not obtained. Certain seal characteristics, such as pressure balance ratio, seal face width, seal nose width, and spring force/in. of diameter, were found to be nearly constant, regardless of engine size.

This concluded the 157 comparisons made to obtain scaling factors.

DISCUSSION OF SCALE FACTORS

Scale factors were found for low rotor ball bearings as a function of total corrected airflow into the engine. High rotor roller bearings were found to scale with corrected airflow into the high compressor. As anticipated, these results showed that bearing size has increased with engine size or airflow. However, the startling result of the scalability study was the remarkable linearity between the increase in bearing size with increased engine size.

Scale factors were found to be applicable to axial flow compressor engine designs, and not applicable to centrifugal compressor engine designs.

Questions arose as to why low rotor roller bearings and high rotor ball bearings did not scale. Considerable effort was required to finally uncover the answers.

Low rotor roller bearings are generally located at the front and rear of engines. The front roller bearing on conventionally designed engines, which do not have centrifugal compressors, has been sized so that a tool can be inserted inside the shaft. The tool is required to remove the tie bolt that connects the low turbine shaft to the low rotor.

At the rear of the engine, the roller bearing is sized to allow for an oil jet to the "bazooka" which "spirals" lubricant to intershaft bearings. In cases where there are no intershaft bearings, the bearing design is governed by two factors: (1) a straight-through shaft is designed to save manufacturing cost, and (2) to conserve weight, the rear of the shaft is made as small in diameter as possible.

High rotor ball bearings have been designed for two principal functions: to locate the main shaft accessory drive gear and to support high rotor thrust loads. Because of the variations in high rotor thrust loads coupled with engine life requirements, scalability of high rotor ball bearings is impractical.

The ultimate limitation on main-shaft bearing size is the airflow path, since neither bearings nor bearing compartments must obstruct the flow path.

The two small engines, the PT6A-27 and ST9, did not scale like the large engines and the JT12. Hence, investigations were made to explain the inapplicability of scale factors to small engines with centrifugal compressors.

The ST9 power turbine shaft roller bearing was designed to fit over the shaft optimized in size to satisfy critical speed requirements. As previously stated, the small 2-to-10-lb/sec airflow size engines rotate at considerably greater speeds than large engines. For this reason, bearing size in future small gas turbine engines will probably be governed by required shaft size to satisfy critical speed design criteria.

Thrust balancing the power turbine shaft of small engines is difficult because there is no compressor to counteract the turbine pressure loads. Because of this difficulty, low rotor ball bearings, which support power turbine shaft thrust loads, did not scale.

The gas generator shaft ball bearing is designed to locate the main shaft accessory drive gear and to support high rotor thrust loads. Bearing loads and engine life requirements usually define the bearing size.

Size of the gas generator shaft roller bearing is based on the shaft diameter required to satisfy critical speed design criteria and to provide clearance for power turbine shaft operation inside the gas generator shaft.

Hence, scale factors are only applicable to conventional engine designs, not to small gas turbine engines that have centrifugal compressors.

AREAS WHICH LIMIT THE UTILITY OF SCALE FACTORS

Areas exist that limit the utility of scaling factors. Scale factors obtained in the study are useful only as preliminary design guides and should be further restricted to engines without centrifugal compressors.

Rotor dynamic, performance, and design considerations listed below can limit scaling:

1. Outer race flanges
2. Manufacturing capabilities
3. Value engineering
4. Shaft torque
5. Weight reduction
6. Blade loss loads
7. Critical speed design criteria
8. Rotor response loads
9. Number of bearings per shaft
10. Fluid film damper
11. Airflow path
12. Preload design criteria
13. Maneuver loads
14. Duty cycle requirements
15. Gear and impeller locations
16. Life requirements
17. Shaft thrust loads

Because of factors such as fluid film dampers, bearings flanges, manufacture of a straight-through shaft to reduce cost, conservation of weight, and shaft torque, bearing size may be limited. Dampers reduce rotor response loads, thus reducing bearing size. However, the addition of a fluid film damper or of bearing flanges often dictates an increase in outer race stiffness or cross section.

Possible influence on bearing size can be exerted by bearing loads, such as blade loss loads, rotor response loads, preloads, and maneuvers loads, or by engine requirements, such as airflow path, critical speed design criteria, life, and number of bearings per shaft.

In additon, cooling and lubrication methods can be detrimental in determining bearing size. For instance, under-race oil holes sometimes result in larger than normal raceway thickness, preventing possible raceway fracture caused by heavy loads.

Similarly, corner-relief oil holes in roller bearings must be carefully analyzed to ensure that the raceway does not fracture and that oil holes will not "coke".

One of the latest recognized features in ball bearing cage design is the "elongated" ball pocket. This design concept provides for extreme ball excursion or the circumferential movement of a ball as it passes in and out of the load zone. In many cases, the extra ball pocket clearance means a reduction in the bearing complement to maintain sufficient cage web thickness for strength. The

reduction in ball complement will also reduce the bearing capacity or, effectively, nd^2 , if the ball diameter remains constant.

To reiterate, scale factors must be utilized with insight into the design concepts and limitations that can affect bearing design.

RECOMMENDED ADDITIONAL BEARING AND SEAL RESEARCH FOR ADVANCED SMALL ENGINES

There are several areas where bearing and seal technology is lacking or needs further development for advanced small engines. Where appropriate, tests to provide development of advanced technology are discussed.

BEARING MATERIAL IMPROVEMENT STUDY

Flanged bearings are demanded in modern gas turbine engines to reduce compartment or gearbox weight and to prevent outer race rotation within the housing. For this application, bearing materials would be required to have excellent structural properties to resist large bending moments and shear loads. In addition, excellent fatigue properties are needed to obtain long-life operation without surface or subsurface distress. Usual bearing materials provide adequate fatigue life. However, these materials are usually through-hardened steel and are quite notch sensitive. This high brittleness severely limits use in structural applications.

Metallurgists have developed new steels, but extensive tests are required to substantiate ultimate structural limits and, more importantly, to rate their mechanical capabilities, such as fatigue life and wear rate, as a function of oil film thickness to surface finish ratio.

To evaluate ultimate structural properties, bearing testing will be required. Essential structural designs that these tests must establish are: material rolling contact fatigue properties, maximum contact stress before plastic deformation and before fracture, maximum shear and maximum bending stress before fracture.

BALL BEARING CAGE STUDY

Several programs are needed to improve cage performance and predictability under adverse environments and operating conditions.

Flexible shafts create large bearing response loads that reduce ball bearing thrust to radial load ratio and cause large ball movement or excursion in the cage pocket. To counteract the resulting cage pocket wear, elongated pockets must be designed. Hence, analytical capabilities, which should include elastohydrodynamic effects, must be developed to predict ball excursions and the resulting ball loads when pocket clearances are inadequate. These analytical techniques must be correlated with test results by measuring the ball movements with the aid of a high-speed camera and the ball-cage web load with photoelastic methods.

CAGE CONFIGURATION AND VIBRATION STUDY

A program is needed to evaluate cage vibration and configurations. This program should include carefully controlled tests to establish tolerance requirements for cage pocket clearances, effects of cage vibration on various cage designs, and cage unbalance associated with cage speed, weight, journal width, clearance, and lubrication film thickness under journals.

ANALYTICAL BEARING PROGRAMS

Proven analytical methods combined with experience are the design tools for substantiating future bearing designs.

Present bearing analysis programs do not include bearing dynamic effects due to elastohydrodynamic forces. Future programs must include these forces that tests show affect bearing operation and durability.

Present elastohydrodynamic force equations do not include rheological or non-Newtonian effects. Further developments in this area are required. Resulting programs will require careful correlation with test results.

Principal areas where correlations must be established between analytical programs and experimental data include: (1) rolling element skid criteria, (2) rolling element-cage web load, (3) ball excursion, and (4) roller skew (the tendency of the roller to twist or turn from its neutral position).

ROLLER DYNAMICS STUDY

Roller end wear is a common problem with high-speed roller bearings. Theories, though unsuccessful, have been proposed to explain this phenomenon. An extensive test program will be required to fully explain the problem and confirm a solution.

Some parameters to study are: (1) sidewall height, (2) sidewall taper, (3) axial clearance between the roller end and sidewall, (4) relative velocity between the roller end and sidewall, (5) roller length variation, (6) roller unbalance, and (7) interaction effects with cages.

SEAL WEAR STUDY

The scalability study showed that shaft seals have increased with engine size and that pressure balance ratio, seal face and seal nose width, and spring force/in. of diameter have been constant. In addition, the type of secondary seal has usually been a piston ring because (1) they allow large axial travel caused by differential thermal growth, without restraining small motions of the primary seal while following runner irregularities, and (2) their cost is low.

Even though seal design has been constant, seal wear rate is unpredictable. For this reason, statistical seal wear studies, similar to previous bearing fatigue life studies, are needed. The effects on seal wear rates due to the following parameters must be closely established:

1. Seal air temperature
2. Face pressure
3. Rubbing velocity

4. Seal and runner materials
5. Pressure balance ratio
6. Seal size characteristics, such as pitch diameter, nose width, and face width
7. Lubrication or cooling methods

ANALYTICAL SEAL PROGRAMS STUDY

Analytical seal programs are needed to provide design guides for calculating (1) elastohydrodynamic effects at the seal face, (2) pressure profile at the seal face, and (3) more accurate seal leakage. Again, the analytical programs must be correlated with test or past seal performance data.

CONCLUSIONS

Twin-spool axial compressor engine designs have scalable low rotor ball bearings and high rotor roller bearings.

Valid scale factors exist for total corrected airflow vs several low rotor ball bearing characteristics and high rotor roller bearing characteristics. Remaining bearing characteristics were so dependent upon engine design and bearing location that scale factors were not practical.

There were no valid scale factors noted for seals. However, specific seal parameters such as pressure balance ratio, seal face width, seal nose width, and spring force per inch of diameter were found to be nearly constant.

Small gas turbine engines with centrifugal compressors do not scale like large twin-spool engines with axial compressors.

TABLE I. MAIN SHAFT BEARING GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR SMALL ENGINE NO. 1										
Bearing Location	Bearing Type	Nominal Operating Clearance or Contact Angle	Method of Lubrication	Method of Cooling	Oil-in Temperature (°F)	Bearing Race Temperatures (°F)		Thrust Load (lb _f)	Radial Loads (lb _f)	
						Inner	Outer	Static	Response	(X) Fatigue Life (hr)
1.	Roller	0.001 in.	four corner relief oil holes	under-race	300	338	353	-	5.6	300 6150
2.	Ball	25 deg	oil holes in split inner race	under-race	300	340	376	125	1.8	80 9750
3.	Ball	23 deg	oil holes in split inner race	under-race	300	319	347	1560	33.6	55 850
4.	Roller	0.001 in.	oil mist	under-race	300	333	344	-	21	60 6155
5.	Roller	27 deg	oil holes in split inner race	under-race	300	322	399	1750	21	* 1230
*Value could not be obtained. (X) Based on rotor response loads with life factor.										

TABLE II. MAIN SHAFT BEARING GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR SMALL ENGINE NO. 2											
Bearing Location	Bearing Type	Nominal Operating Clearance or Contact Angle	Method of Lubrication	Method of Cooling	Oil-in Temperature (°F)	Bearing-Race Temperatures (°F)		Thrust Load (lb _f)	Radial-Loads (lb _f)		ⓧ Maximum Maneuver Loads (lb _f)
						Inner	Outer		Static Load (1 g)	Rotor Response Loads	
1	Roller	0.0007 in.	jet	flood	195-210	325	300	-	40	*	432
2	Ball	29.5 deg	oil holes in inner race	under-race	195-210	300	325	1190	244	*	205
3	Roller	0.0007 in.	jet	flood	195-210	325	300	-	351	*	226
*Data not presently available ⓧ 1 rad/sec load											

TABLE III. MAIN SHAFT BEARING GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR SMALL ENGINE NO. 3												
Bearing Location	Bearing Type	Nominal Operating Clearance or Contact Angle	Method of Lubrication	Method of Cooling	Oil-in Temperature (°F)	Bearing Race Temperatures (°F)		Radial Loads (lbf)			Maximum Maneuver Loads (lbf)	Fatigue Life (hr)
						Inner	Outer	Thrust Load (lbf)	Static Load (l g)	Rotor Response Loads		
1	Ball	20 deg	oil slots in split inner race	lubricate also cools	200	300	250	450	10	✓ 70	290.5	1200
2	Roller	0.0015 in.	oil jet on each side aimed at cage inner ring clearance	lubricate also cools	200	425	375	-	20	✓ 650	290.5	+100,000
3	Roller	0.0015 in.	oil jet on each side aimed at cage inner ring clearance	lubricate also cools	200	400	350	-	14		262.5	+100,000
4	Ball	20 deg	oil slots in split inner race	lubricate also cools	200	330	280	450	2		262.5	1250
Legend	✓ 2nd stage compressor Blade loss 1.7 oz.in.at 30,000 rpm No structural damping					(X)	3-1/2 rad/sec information lost					**Roller bearings evaluated at 5 g loads; Ball bearings evaluated at mean effective thrust loads of 450 lb; No material improvement factors

TABLE IV. MAIN SHAFT BEARING GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR LARGE ENGINE NO. 1												
Bearing Location	Bearing Type	Nominal Operating Clearance or Contact Angle	Method of Lubrication	Method of Cooling	Oil-in Temperature (°F)	Bearing Race Temperatures (°F)		Thrust Load (lbf)	Radial Loads (lbf)			Maximum Maneuver Loads (lbf)
						Inner	Outer		Static (l g)	Rotor Response Loads	(X)	
1	Roller	*	jet flood	jet flood	190-200	*	*	-	299	*	*	2931
2	Ball	*	flood	flood	190-200	*	*	4500	209	*	*	2931
2-1/2	Ball	*	jet mist	jet mist	190-200	*	*	366	6	*	*	**
3	Roller	*	jet flood	jet flood	190-200	*	*	-	241	*	*	3544
4	Ball	*	flood	flood	190-200	*	*	8100	192	*	*	2458
4-1/2	Roller	*	jet flood	jet flood	190-200	*	*	-	179	*	*	1832
5	Roller	*	flood	flood	190-200	*	*	-	325	*	*	1086
6	Roller	*			190-200	*	*	-	253	*	*	1832
*Data not presently available **No calculated load available (X)1 rad/sec load												

TABLE V. MAIN SHAFT BEARING GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR LARGE ENGINE NO. 2											
Bearing Location	Bearing Type	Nominal Operating Clearance or Contact Angle	Method of Lubrication	Method of Cooling	Oil-in Temperature (°F)	Bearing Race Temperatures (°F)		Thrust Load (lbf)	Radial Loads (lbf)		(X) Maximum Maneuver Loads (lbf)
						Inner	Outer		Static	Rotor Response	
1	Roller	0.003 in.	oil mist	oil mist	240	250	300	-	120	*	2319
2	Ball	32 deg	oil holes in split inner race	oil holes in split inner race	240	300	325	2550	160	*	2319
3	Ball	15 to 20 deg	oil mist	under-race	240	350	350	400	200	*	2048
4	Ball	37 deg	oil holes in split inner race	oil holes in split inner race	240	350	375	2460	120	*	747
4-1/2	Roller	0.001 in.	flood oiled	flood oiled	240	400	400	-	120	*	954
5	Roller	0.001 in.	oil mist	under-race	240	350	375	-	250	*	1301
6	Roller	0.005 in.	oil mist	under-race	240	250	350	-	150	*	954
* Data not presently available											
(N) 1 rad/sec load											

TABLE VI. MAIN SHAFT BEARING GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR LARGE ENGINE NO. 3											
Bearing Location	Bearing Type	Nominal Operating Clearance or Contact Angle	Method of Lubrication	Method of Cooling	Oil-in Temperature (°F)	Bearing Race Temperatures (°F)		Thrust Load (lbf)	Radial Loads (lbf)		ⓧ Maximum Maneuver Loads (lbf)
						Inner	Outer		Static (1 g)	Rotor Response Loads	
1	Ball	31 deg	oil holes in split inner race	under- race	180-200	250	350	16,600	1300	*	6500
2	Ball	36.5 deg	oil mist	under- race	180-200	220	270	10,000	195	*	5650
3	Roller	0.0005- 0.0015 in.	oil mist	under- race	180-200	330	355	-	830	*	5650
4	Roller	0.0005- 0.0015 in.	oil mist	under- race	180-200	320	333	-	645	*	6500
* Data not presently available											

TABLE VII. P100 MAIN SHAFT BEARING GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR LARGE ENGINE NO. 4												
Bearing Location	Bearing Type	Nominal Operating Clearance or Contact Angle	Method of Lubrication	Method of Cooling	Oil-in Temperature (°F)	Bearing Race Temperatures (°F)		Thrust Load (lbf)	Radia Loads (lbf)		Rotor Response Loads	(X) Maximum Maneuver Loads (lbf)
						Inner	Outer		Static	Response		
1	Roller	*	mist	under-race	250	272	279	-	149.7	*		5842
2	Ball	*	oil holes in split inner race	under-race	250	259	275	2940	121.3	*		5842
3	Roller	0.0015 in.	mist	under-race	250	269	276	-	102.0	*		5691
4	Ball	*	oil holes in split inner race	under-race	250	264	290	7460	100.9	*		2401
4-1/2	Roller	*	flood	flood	250	256	258	-	40.0	*		3840
5	Roller	0.0021 in.	mist	under-race	250	275	283	-	227.6	*		3290
6	Roller	0.0020 in.	mist	under-race	250	262	266	-	133.5	*		3840
*Data not presently available												
(X) 3-1/2 rad/sec load												

TABLE VIII. MAIN SHAFT BEARING GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR LARGE ENGINE NO. 5											
Bearing Location	Bearing Type	Nominal Operating Clearance or Contact Angle	Method of Lubrication	Method of Cooling	Oil-in Temperature (°F)	Bearing Race Temperatures (°F)		Thrust Load (lbf)	Radial Loads (lbf)		Maximum Maneuver Loads (lbf)
						Inner	Outer		Static	Rotor Response	
1	Ball	*	oil holes in split inner race	under-race	250	284	350	1,577	298.2	*	12,556
2	Ball	*	oil holes in split inner race	under-race	250	286	350	11,829	176.8	*	14,221
3	Roller	*	jet	under-race	250	365	400	-	86.2	*	36,171
4	Roller	*	jet	under-race	250	365	400	-	303.2	*	50,393
5	Roller	*	flooded by twin jet	under-race	250	287	300	-	143.4	*	12,556
*Data not presently available (X) 1 rad/sec											

TABLE IX. MAIN SHAFT BEARING GENERAL CHARACTERISTICS
AT SEA LEVEL TAKEOFF FOR LARGE ENGINE NO. 6

Bearing Location	Nominal Operating Clearance or Contact Angle	Method of Lubrication	Method of Cooling	Oil-in Temperature (°F)	Bearing Race Temperatures (°F)		Thrust Load (lb _f)	Radial Loads (lb _f)		⊗ Maximum Maneuver Loads (lb _f)	** Fatigue Life (hr)
					Inner	Outer		(1 g)	Rotor Response		
1	0.0018 in.	four corner relief oil holes (also mist)	under - race	200	248	263	-	41	385	6700	51,000
2	31 deg	oil holes in split inner race	under - race	200	238	348	3500	120	700	6000	3240
3	22.4 deg	oil holes in split inner race	under - race	200	251	296	6000	140	500	5300	1300
4	0.003 in.	four corner relief oil holes (also mist)	under - race	200	304	328	-	230	800	5700	1544
5	0.002 in.	two corner relief oil holes (also mist)	under - outer - race oil slots	200	230	230	-	100	424	1100	16,285
** Based on rotor response loads with life factor ⊗ 3-1/2 rad/sec load					Bearings at locations 1, 4, & 5 are roller bearings; bearings at locations 2 & 3 are ball bearings.						

TABLE X. MAIN SHAFT SEALS - GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR SMALL ENGINE NO. 1					
Seal Location and Type	Pressure Gradient (psi)	Pressure Gradient Range (psi)	Seal Air Temperature (°F)	Method of Lubrication	Method of Cooling
No. 1 Compartment, Forward Dry Face Seal	0	0	90	Oil Mist	Oil Cooled Seal Plate
No. 1 Compartment, Aft Dry Face Seal	4	4	490	Oil Mist	Oil Cooled Seal Plate
No. 2 Compartment, Forward Dry Face Seal	39	39	742	Oil Mist	Oil Cooled Seal Plate
No. 2 Compartment, Aft Dry Face Seal	15	15	742	Oil Mist	Oil Cooled Seal Plate

TABLE XI. MAIN SHAFT SEALS - GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR SMALL ENGINE NO. 2						
Seal Location and Type	Pressure Gradient (psi)	Pressure Gradient Range (psi)	Seal Air Temperature (° F)	Method of Lubrication	Method of Cooling	
No. 1 Ring Seal	21	21	600	Oil Mist	Oil Mist	
No. 2 Dry Face Seal	25	25	600	Oil Mist	Oil Cooled Seal Plate	
No. 3 Dry Face Seal	53	53	590	Oil Mist	Oil Cooled Seal Plate	

TABLE XII. MAIN SHAFT SEALS - GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR LARGE ENGINE NO. 1					
Seal Location and Type	Method of Cooling	Method of Lubrication	SLTO Pressure Gradient (psi)	Pressure Gradient Range (psi)	SLTO Air Temperature (° F)
No. 1 Dry Face Seal	Oil Mist	Oil Mist	2	4	440
No. 2 Dry Face Seal	Oil Mist	Oil Mist	37	39	440
No. 3 Dry Face Seal	Oil Cooled Seal Plate	Oil Mist	52	55	700
No. 4 Dry Face Seal	Oil Mist	Oil Mist	99	99	840
No. 4 1/2 Triple Carbon Riding Ring Seal	Oil Flow Under Seal Plate	Oil Mist	94	94	840
No. 5 Dry Face Seal	Oil Jet Cooled Seal Plate	Oil Mist	94	94	840
No. 6 Ring Seal	Oil Mist	Oil Mist	12	14	550
No. 6 Back-to-Back Ring Seal	Oil Mist	Oil Mist	12	14	550

TABLE XIII. MAIN SHAFT SEALS - GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR LARGE ENGINE NO. 2					
Seal Location and Type	Method of Cooling	Method of Lubrication	SLTO Pressure Gradient (psi)	Pressure Gradient Range (psi)	SLTO Air Temperature (° F)
No. 4-1/2 Three-Stage Carbon Riding Ring Seal	Oil on Inside Diameter	Oil Mist	73	81	870
No. 5 Dry Face Seal	Oil Cooled Seal Plate	Oil Mist	73	81	870
No. 6 Ring Seal	Oil on Inside Diameter	Oil Mist	13	15	500
No. 6 Back-to-Back Ring Seal	Oil on Inside Diameter	Oil Mist	13	15	500

TABLE XIV. MAIN SHAFT SEALS - GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR LARGE ENGINE NO. 3					
Seal Location and Type	Method of Cooling	Method of Lubrication	SLTO Pressure Gradient (psi)	Pressure Gradient Range (psi)	SLTO Air Temperature (° F)
No. 1 Dry Face Seal	Oil Mist	Oil Mist	29	29	468
No. 1-1/2 Front and Rear Dry Face Seals	Oil Cooled Seal Plates	Oil Mist	50	50.3	727
No. 4 Ring Seal Back-to-Back	Oil Mist	Oil Mist	19	19	480

TABLE XV. MAIN SHAFT SEALS - GENERAL CHARACTERISTICS AT SEA LEVEL
TAKEOFF FOR LARGE ENGINE NO. 4

Seal Location and Type	Method of Cooling	Method of Lubrication	SLTO Pressure Gradient (psi)	Pressure Gradient Range (psi)	SLTO Air Temperature (° F)
No. 1 Dry Face	Oil Cooled Seal Plate	Oil Mist	25	39	435
No. 2 Dry Face	Oil Cooled Seal Plate	Oil Mist	64	96	596
No. 3 Dry Face	Oil Cooled Seal Plate	Oil Mist	63	89	678
No. 4 Wet Face	Oil Cooled Seal Plate	Oil Holes at Rubbing Face	58	84	913
No. 4-1/2 Triple Carbon Riding Ring Seal	Oil Cooled Seal Plate	Oil Mist	41	61	546
No. 5 Wet Face	Oil Cooled Seal Plate	Oil Holes at Rubbing Face	62	90	546
No. 6 Back-to-Back Ring Seal	Oil Cooled Seal Plate	Oil Mist	13	29	781

TABLE XVI. MAIN SHAFT SEALS - GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR LARGE ENGINE NO. 5					
Seal Location and Type	Method of Cooling	Method of Lubrication	SLTO Pressure Gradient (psi)	Pressure Gradient Range (psi)	SLTO Air Temperature (° F)
No. 1 Dry Face Seal	Oil Cooled Seal Plate	Oil Mist	49	55	523
No. 1-2 Front and Rear Dry Face Seals	Oil Cooled Seal Plate	Oil Mist	65	80	745
No. 2 Dry Face Seal	Oil Cooled Seal Plate	Oil Mist	49	68	523
No. 3 Wet Face Seal	Oil Cooled Seal Plate	Oil Holes at Seal Rubbing Surface	100	127	1150
No. 4 Wet Face Seal	Oil Cooled Seal Plate	Oil Holes at Seal Rubbing Surface	100	127	1150
No. 5 Back-to-Back Ring Seal	Oil Cooled Seal Plate	Oil Mist	49	68	1047

TABLE XVII. MAIN SHAFT SEALS - GENERAL CHARACTERISTICS AT SEA LEVEL TAKEOFF FOR LARGE ENGINE NO. 6					
Seal Location and Type	Method of Cooling	Method of Lubrication	SLTO Pressure Gradient (psi)	Pressure Gradient Range (psi)	SLTO Air Temperature (° F)
No. 1 Dry Face Seal	Oil Cooled Seal Plate	Oil Mist	12.7	29.2	353
No. 2 Front and Rear Dry Face Seals	Oil Cooled Seal Plate	Oil Mist	29.2 (Front)	58.8 (Front)	353 (Front)
			63.8 (Rear)	108.3 (Rear)	646 (Rear)
No. 3 Wet Face Seal (Front)	Oil Cooled Seal Plate	Oil Holes at Rubbing Face of Seal	63.8	108.3	646
No. 3 Wet Face Seal (Rear)	Oil Cooled Seal Plate	Oil Holes at Rubbing Face of Seal	53.8	95.7	483
No. 4 Comp. Front and Rear Wet Face Seals	Oil Cooled Seal Plate	Oil Holes at Rubbing Face of Seal	57.2	62.87	646
No. 5 Dry Face Seal	Oil Cooled Seal Plate	Oil Mist	48	*	683
* Data not available					

TABLE XVIII. SMALL ENG

Bearing Location and Type	Vendor	ID (in.)	ID (mm)	OD (in.)	Width		Pitch Diameter (in.)	N
					ID (in.)	OD (in.)		
No. 1 Roller Bearing	5	1.7802	45.3	2.7559	0.4744	0.4824	2.327	C
	4	1.7802	45.3	2.7559	0.4744	0.4824	2.325	P
No. 2 Ball Bearing	4	1.5748	40	2.460	1.084	0.944	2.0174	P
	9	1.5748	40	2.460	1.084	0.957	2.017	P
No. 3 Ball Bearing	3	1.9685	50	4.0855	1.050	0.7894	2.8092	P
	4	1.9685	50	4.0855	1.050	0.7894	2.7460	P
	1	1.9685	50	4.0855	1.050	0.7894	2.7760	P
No. 4 Roller Bearing	1	2.255	57.3	3.7402	0.7330	0.9600	3.0407	PV
	5	2.255	57.3	3.7402	0.7330	0.9600	3.001	PV
No. 5 Ball Bearing	3	2.3622	60	4.1339	0.8561	0.8631	3.24805	PV
	4	2.3622	60	4.1339	0.8561	0.8631	3.2480	PV
	9	2.3622	60	4.1339	0.8561	0.8661	3.2480	PV
	3	2.3622	60	4.1339	0.8561	0.8631	3.24805	PV
Upper T/S Ball Bearing	3	0.7874	20	1.4567	0.7874	0.3543	1.122	PV
Lower T/S Ball Bearing	3	0.5906	15	1.380	0.4331	0.530	0.9843	PV

13

ENGINE NO. 1 MAIN SHAFT BEARINGS

er	Ring Material	Element Material	Number of Elements	Element Diameter (in.)	Ball-Race Curvatures		Total Length (in.)	L/D Ratio	Cage Type
					Inner (%)	Outer (%)			
	CEVM 315	CEVM 315	22	0.2283	-	-	0.2800	1.23	One-Piece Machined
	PWA 725	PWA 725	20	0.25	-	-	0.25	1.00	One-Piece Machined
	PWA 725	PWA 725	18	0.25	52	52	-	-	One-Piece Machined
	PWA 725	PWA 725	18	0.2656	53	53	-	-	One-Piece Machined
	PWA 725	PWA 725	15	0.50	52				One-Piece Machined
	PWA 725	PWA 725	14	0.50	52				One-Piece Machined
	PWA 725	PWA 725	13	0.5625	52/ 52.18	58/ 52.35	-	-	One-Piece Machined
	PWA 725	PWA 725	18	0.3543	52/ 52.18	52/ 52.35	0.3465	0.98	One-Piece Machined
	PWA 725	PWA 725	20	0.3389	52/ 52.18	52/ 52.35	0.3465	1.16	One-Piece Machined
5	PWA 725	PWA 725	15	0.531	52/ 52.18	52/ 52.35	-	-	One-Piece Machined
	PWA 725	PWA 725	15	0.531	52/ 52.18	52/ 52.35	-	-	One-Piece Machined
	PWA 725	PWA 725	15	0.531	52/ 52.18	52/ 52.35	-	-	One-Piece Machined
5	PWA 725	PWA 725	15	0.531	52/ 52.18	52/ 52.35	-	-	One-Piece Machined
	PWA 725	PWA 725	10	0.1875	52	52	-	-	One-Piece Machined
	PWA 725	PWA 725	7	0.25	52	52	-	-	Two-Piece, Riveted

A

TABLE XIX. SMALL ENGINE NO. 2 MA

Bearing Location and Type	Vendor No.	ID (in.)	ID (mm)	OD (in.)	Width		Pitch Diameter (in.)	Ring Material	Elem Mate
					ID (in.)	OD (in.)			
No. 1 Roller Bearing	1	2.9528	75	4.1339	0.810	0.8268	3.563	AMS 6441 or	AMS 6440 6441
	5	2.9528	75	4.1339	0.810	0.8268	3.544	AMS 6294	AMS 6440 6441
No. 2 Ball Bearing	1	3.1496	80	5.1181	1.122	0.9055	4.272	PWA 723	PWA
No. 3 Roller Bearing	1	3.1496	80	4.3307	0.9449	0.6299	3.753	PWA 725	PWA

TABLE XX. SMALL ENGINE NO. 3

Bearing Location and Type	Vendor No.	ID (in.)	ID (mm)	OD (in.)	Width		Pitch Diameter (in.)	Ring Material	Elem Mate
					ID (in.)	OD (in.)			
No. 1 Ball Bearing	1	1.1811	30	2.8346	0.9055	0.748	2.047	PWA 723	PWA
Nos. 2, 3 Roller Bearing	1	1.5748	40	2.6672	0.5907	0.5906	2.126	PWA 725	PWA
No. 4 Ball Bearing	1	1.1811	30	2.8346	0.9055	0.748	2.047	PWA 723	PWA

B

ENGINE NO. 2 MAIN SHAFT BEARINGS								
Ring Material	Element Material	Number of Elements	Element Diameter (in.)	Ball-Race Curvatures		Total Length (in.)	L/D Ratio	Cage Type
				Inner (%)	Outer (%)			
IS 1 or	AMS 6440 or 6441	28	0.3150	-	-	0.4331	1.375	One-Piece Machined
IS 4	AMS 6440 or 6441	26	0.3145	-	-	0.3537	1.125	One-Piece Machined
PA 723	PWA 723	20	0.59375	51.75/ 52	51.75/ 52	-	-	One-Piece Machined
PA 725	PWA 725	30	0.3150			0.4252	1.35	One-Piece Machined

ENGINE NO. 3 MAIN SHAFT BEARINGS								
Ring Material	Element Material	Number of Elements	Element Diameter (in.)	Ball-Race Curvatures		Total Length (in.)	L/D Ratio	Cage Type
				Inner (%)	Outer (%)			
PA 723	PWA 723	10	0.53125	52	52	-	-	One-Piece (Rabbit Ear Style of Ball Retention)
PA 725	PWA 725	16	0.2953	-	-	0.3465	1.175	One-Piece Machined
PA 723	PWA 723	10	0.53125	52	52	-	-	One-Piece (Rabbit Ear Style of Ball Retention)

TABLE XXI. LARGE ENGINE NO. 1 MAIN SHAFT BE

Bearing Location and Type	Vendor	ID (in.)	ID (mm)	OD (in.)	Width		Pitch Diameter (in.)	Ring Material	Element Material	Number of Elements	Diam (in.)
					ID (in.)	OD (in.)					
No. 1 Roller Bearing	1	5.1181	130	7.0866	1.0236	0.8661	6.142	PWA 723	PWA 723	26	0.55
	5	5.1181	130	7.0866	1.0236	0.8661	6.1035	PWA 742	PWA 742	30	0.49
No. 2 Ball Bearing	2	5.1181	130	7.874	2.560	2.560	6.496	PWA 725	PWA 725	21	0.81
	3	5.1181	130	7.874	2.560	2.560	6.496	PWA 725	PWA 725	21	0.81
	4	5.1181	130	7.874	2.560	2.560	6.4734	PWA 725	PWA 725	21	0.81
	1	5.1181	130	7.874	2.560	2.560	6.496	PWA 725	PWA 725	21	0.81
No. 2-1/2 Ball Bearing	3	4.3307	110	5.9055	1.00	0.7874	5.11815	PWA 723	PWA 723	19	0.468
	2	4.3307	110	5.9055	1.00	0.7874	5.1180	PWA 723	PWA 723	19	0.5
No. 3 Roller Bearing	5	4.2520	108	5.6693	0.7874	0.9449	4.953	PWA 742	PWA 742	30	0.36
	1	4.2520	108	5.6693	0.7874	0.9449	4.961	PWA 725	PWA 725	34	0.354
	2	4.2520	108	5.6693	0.7874	0.9449	4.9528	PWA 725	PWA 725	32	0.363
No. 4 Ball Bearing	4	5.5118	140	8.6614	3.1496	3.1496	7.0610	PWA 723	PWA 723	20	0.937
	3	5.5118	140	8.6614	3.1496	3.1496	7.0866	PWA 723	PWA 723	20	0.937
	2	5.5118	140	8.6614	3.1496	3.1496	7.087	PWA 723	PWA 723	20	0.937
	1	5.5118	140	9.6614	3.1496	3.1496	7.087	PWA 723	PWA 723	19	1.000
No. 4-1/2 Ball Bearing	1	3.9500	101	5.200	0.6299	1.2598	4.575	PWA 725	PWA 725	36	0.315
	5	3.9500	101	5.200	0.6299	1.2598	4.5742	PWA 724	PWA 724	34	0.314
No. 5 Roller Bearing	1	5.9051	150	8.4646	1.3780	1.0236	7.17	PWA 725	PWA 725	28	0.669
	5	5.9051	150	8.4646	1.3780	1.0236	7.2783	PWA 725	PWA 725	28	0.669
No. 6 Roller Bearing	5	2.7559	70	4.3307	0.8661	1.1811	3.5445	AMS 6294	AMS 6440	24	0.363
	2	2.7559	70	4.3307	0.8661	1.1811	3.5493	AMS 6440	AMS 6274	24	0.363
	4	2.7559	70	4.3307	0.8661	1.1811	3.5433	AMS 6440	AMS 6440	24	0.393

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E XXI. LARGE ENGINE NO. 1 MAIN SHAFT BEARINGS

Pitch Diameter (in.)	Ring Material	Element Material	Number of Elements	Diameter (in.)	Ball-Race Curvature		Total Length (in.)	L/D Ratio	Cage Type
					Inner	Outer			
6.142	PWA 723	PWA 723	26	0.5512	-	-	0.5512	1.00	One-Piece Machined
6.1035	PWA 742	PWA 742	30	0.4985	-	-	0.5337	1.07	One-Piece Machined
6.496	PWA 725	PWA 725	21	0.8125	0.52	0.516	-	-	One-Piece
6.496	PWA 725	PWA 725	21	0.8125	0.514	0.514	-	-	One-Piece
6.4734	PWA 725	PWA 725	21	0.8125	0.515	0.515	-	-	One-Piece
6.496	PWA 725	PWA 725	21	0.8125	0.515/ 0.5175	0.515/ 0.5175	-	-	One-Piece
5.11815	PWA 723	PWA 723	19	0.4688	0.515	0.515	-	-	Two-Piece, Riveted
5.1180	PWA 723	PWA 723	19	0.5	0.516	0.53	-	-	Two-Piece, Riveted
4.953	PWA 742	PWA 742	30	0.3629	-	-	0.3937	1.08	One-Piece Machined
4.961	PWA 725	PWA 725	34	0.3543	-	-	0.3465	0.98	One-Piece Machined
4.9528	PWA 725	PWA 725	32	0.3637	-	-	0.3543	0.975	One-Piece Machined
7.0610	PWA 723	PWA 723	20	0.9375	0.52	0.52	-	-	One-Piece Machined
7.0866	PWA 723	PWA 723	20	0.9375	0.521	0.521	-	-	One-Piece Machined
7.087	PWA 723	PWA 723	20	0.9375	0.52	0.52	-	-	One-Piece Machined
7.087	PWA 723	PWA 723	19	1.000	0.515/ 0.5175	0.52/ 0.5225	-	-	One-Piece Machined
4.575	PWA 725	PWA 725	36	0.3150	-	-	0.3071	0.975	One-Piece Machined
4.5742	PWA 724	PWA 724	34	0.3145	-	-	0.3902	1.24	One-Piece Machined
7.17	PWA 725	PWA 725	28	0.6693	-	-	0.6614	0.99	One-Piece Machined
7.2783	PWA 725	PWA 725	28	0.6693	-	-	0.6693	1.00	One-Piece Machined
3.5445	AMS 6294	AMS 6440	24	0.3633	-	-	0.4587	1.26	One-Piece Machined
3.5493	AMS 6440	AMS 6274	24	0.3637	-	-	0.4587	1.26	One-Piece Machined
3.5433	AMS 6440	AMS 6440	24	0.3937	-	-	0.4587	1.00	One-Piece Machined

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TABLE XXII. LARGE ENGINE NO. 2 MAIN

Bearing Location and Type	Vendor No.	ID (in.)	ID (mm)	OD (in.)	Width		Pitch Diameter (in.)	Ring Material	Element Material	Number of Elements
					ID (in.)	OD (in.)				
No. 1 Roller Bearing	1	3.7402	95	5.550	1.0074	2.061	4.488	AMS 6440	AMS 6440	28
	5	3.7402	95	5.550	1.0074	2.061	4.551	AMS 6294	AMS 6440	28
No. 2 Ball Bearing	1	3.937	100	6.49605	2.560	2.560	5.295	PWA 725	PWA 725	18
	3	3.937	100	6.49605	2.560	2.560	5.21655	PWA 725	PWA 725	18
	4	3.937	100	6.49605	2.560	2.560	5.2165	PWA 725	PWA 725	18
No. 3 Ball Bearing	4	4.508	115	6.8897	1.1024	1.0908	5.6727	PWA 725	PWA 725	10
	3	4.508	115	6.8897	1.1024	1.0908	5.7087	PWA 725	PWA 725	15
No. 4 Ball Bearing	1	4.9213	125	7.4803	2.560	2.560	6.280	PWA 725	PWA 725	21
	3	4.9213	125	7.4803	2.560	2.560	6.2008	PWA 725	PWA 725	21
	4	4.9213	125	7.4803	2.560	2.560	6.2008	PWA 725	PWA 725	21
No. 4-1/2 Roller Bearing	5	3.1496	80	4.2516	0.6300	0.8650	3.6412	PWA 742	PWA 742	32
No. 5 Roller Bearing	5	5.1181	130	7.0893	1.4961	0.9843	6.102	PWA 742	PWA 742	28
No. 6 Roller Bearing	5	3.3465	85	5.041	0.8755	1.5	4.1355	PWA 742	PWA 742	28
	1	3.3465	85	5.041	0.8755	1.5	4.134	PWA 725	PWA 725	26

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XXII. LARGE ENGINE NO. 2 MAIN SHAFT BEARINGS

Bolt Number (in.)	Ring Material	Element Material	Number of Elements	Element Diameter (in.)	Ball-Race Curvatures		Total Length (in.)	L/D Ratio	Cage Type
					Inner	Outer			
88	AMS 6440	AMS 6440	26	0.4331	-	-	0.5118	1.18	One-Piece Machined
51	AMS 6294	AMS 6440	28	0.3827	-	-	0.4587	1.2	One-Piece Machined
95	PWA 725	PWA 725	18	0.8125	0.5175/ 0.52	0.5175/ 0.52	-	-	One-Piece Machined
1655	PWA 725	PWA 725	18	0.8125	0.52	0.515	-	-	One-Piece Machined
165	PWA 725	PWA 725	18	0.8125	0.52	0.52	-	-	One-Piece Machined
727	PWA 725	PWA 725	16	0.6250	0.51	0.52	-	-	Two-Piece, Riveted
087	PWA 725	PWA 725	15	0.6250	0.52	0.52	-	-	Two-Piece, Riveted
80	PWA 725	PWA 725	21	0.8125	0.515/ 0.5175	0.52/ 0.5225	-	-	One-Piece Machined
008	PWA 725	PWA 725	21	0.8125	0.52	0.515	-	-	One-Piece Machined
008	PWA 725	PWA 725	21	0.8125	0.52	0.52	-	-	One-Piece Machined
412	PWA 742	PWA 742	32	0.2490	-	-	0.3537	1.42	One-Piece Machined
02	PWA 742	PWA 742	28	0.4980	-	-	0.5737	1.15	One-Piece Machined
355	PWA 742	PWA 742	28	0.3643	-	-	0.4587	1.26	One-Piece Machined
34	PWA 725	PWA 725	26	0.3937	-	-	0.3858	0.98	One-Piece Machined

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TABLE XXIII. LARGE ENGINE NO. 3 MAIN S

Bearing Location and Type	Vendor No.	ID (in.)	ID (mm)	OD (in.)	Width		Pitch Diameter (in.)	Ring Material	Element Material	N Ele
					ID (in.)	OD (in.)				
No. 1 Ball Bearing	3	8.2648	210	13.7795	2.4409	2.2047	11.200	PWA 725	PWA 725	
No. 2 Ball Bearing	4	8.6614	220	12.6	1.8065	1.811	10.6299	PWA 725	PWA 725	
	3	8.6614	220	12.6	1.8065	1.811	10.6299	PWA 725	PWA 725	
No. 3 Roller Bearing	1	9.2520	235	12.2047	1.620	1.820	10.72	PWA 725	PWA 725	
	1	9.2520	235	12.2047	1.620	1.820	10.72	PWA 725	PWA 725	
No. 4 Roller Bearing	4	6.4961	165	9.0551	1.6142	1.1811	7.7800	PWA 723	PWA 723	
	4	6.4961	165	9.0551	1.6142	1.1811	7.78	PWA 725	PWA 725	
	2	6.4961	165	9.0551	1.6142	1.1811	7.7627	PWA 725	PWA 725	

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II. LARGE ENGINE NO. 3 MAIN SHAFT BEARINGS									
Pitch Diameter (in.)	Ring Material	Element Material	Number of Elements	Element Diameter (in.)	Base-Line Curvatures		Total Length (in.)	L/D Ratio	Cage Type
11.200	PWA 725	PWA 725	20	1.5625	0.525	0.525	-	-	One-Piece Machined
10.6299	PWA 725	PWA 725	25	1.125	0.52	0.52	-	-	One-Piece Machined
10.6299	PWA 725	PWA 725	25	1.125	0.5225	0.5225	-	-	One-Piece Machined
10.72	PWA 725	PWA 725	32	0.9055	-	-	0.8976	0.99	One-Piece Machined
10.72	PWA 725	PWA 725	32	0.9055	-	-	0.8976	0.99	One-Piece Machined
7.7800	PWA 723	PWA 723	28	0.7087	-	-	0.7087	1.00	One-Piece Machined
7.78	PWA 725	PWA 725	28	0.7087	-	-	0.7087	1.00	One-Piece Machined
7.7627	PWA 725	PWA 725	26	0.7411	-	-	0.7600	1.02	One-Piece Machined

TABLE XXIV. LARGE ENGINE NO. 4 M

Bearing Location and Type	Vendor No.	ID (in.)	ID (mm)	OD (in.)	Width		Pitch Diameter (in.)	Ring Material	Element Material	Nu El
					ID (in.)	OD (in.)				
No. 1 Roller Bearing	1	3.7402	95	5.4336	1.0074	1.2300	4.528	PWA 725	PWA 725	
	2	3.7402		5.4336	1.0074	1.2300	4.528	PWA 725	PWA 725	
No. 2 Ball Bearing	4	4.33070	110	6.2992	0.9449	0.947	5.314	PWA 725	PWA 725	
	3	4.33070		6.2992	0.9449	0.947	5.2999	PWA 725	PWA 725	
No. 3 Roller Bearing	1	3.9360	100	5.5118	0.6625	0.760	4.723	PWA 725	PWA 725	
	2	3.9360	100	5.5118	0.6625	0.760	4.723	PWA 725	PWA 725	
	4	3.9360	100	5.5118	0.6625	0.760	4.723	PWA 725	PWA 725	
No. 4 Ball Bearing	3	4.4488	113	7.087	1.281	1.1811	5.6904	PWA 725	PWA 725	
	2	4.4488	113	7.087	1.281	1.1811	5.787	PWA 725	PWA 725	
	1	4.4488	113	7.087	1.281	1.1811	5.827	PWA 725	PWA 725	
No. 4-1/2 Roller Bearing	4	3.1050	79	4.3116	0.7874	1.0236	3.701	PWA 725	PWA 725	
	1	3.1050	79	4.3116	0.7874	1.0236	3.701	PWA 725	PWA 725	
	5	3.1050	79	4.3116	0.7874	1.0236	3.701	PWA 725	PWA 725	
No. 5 Roller Bearing	1	4.8939	124.5	6.7461	1.063	0.9449	5.820	PWA 725	PWA 725	
	5	4.8939	124.5	6.7461	1.063	0.9449	5.9339	PWA 725	PWA 725	
	4	4.8939	124.5	6.7461	1.063	0.9449	5.950	PWA 725	PWA 725	
No. 6 Roller Bearing	2	2.5591	65	4.2523	0.9487	1.4176	3.372	PWA 725	PWA 725	
	4	2.5591	65	4.2523	0.9487	1.4176	3.353	PWA 725	PWA 725	
	5	2.5591	65	4.2543	0.9487	1.4176	3.382	PWA 725	PWA 725	

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LE XXIV. LARGE ENGINE NO. 4 MAIN SHAFT BEARINGS

Pitch Diameter (in.)	Ring Material	Element Material	Number of Elements	Element Diameter (in.)	Ball-Race Curvatures		Total Length (in.)	L/D Ratio	Cage Type
					Inner	Outer			
4.528	PWA 725	PWA 725	26	0.3337	-	-	0.3858	1.16	One-Piece Machined
4.528	PWA 725	PWA 725	24	0.3871	-	-	0.420	1.09	One-Piece Machined
5.314	PWA 725	PWA 725	22	0.625	0.52	0.52	-	-	One-Piece Machined
5.2999	PWA 725	PWA 725	22	0.625	0.52	0.515	-	-	One-Piece Machined
4.723	PWA 725	PWA 725	30	0.3543	-	-	0.3465	0.98	One-Piece Machined
4.723	PWA 725	PWA 725	32	0.3350	-	-	0.360	1.07	One-Piece Machined
4.723	PWA 725	PWA 725	30	0.3543	-	-	0.3543	1.00	One-Piece Machined
5.6904	PWA 725	PWA 725	20	0.750	0.52	0.52	-	-	One-Piece Machined
5.787	PWA 725	PWA 725	20	0.750	0.53	0.52	-	-	One-Piece Machined
5.827	PWA 725	PWA 725	20	0.750	0.5187/ 0.5213	0.5187/ 0.5213	-	-	One-Piece Machined
3.701	PWA 725	PWA 725	32	0.2756	-	-	0.3307	1.20	One-Piece Machined
3.701	PWA 725	PWA 725	32	0.2953	-	-	0.3465	1.17	One-Piece Machined
3.701	PWA 725	PWA 725	30	0.2799			0.3537	1.26	One-Piece Machined
5.820	PWA 725	PWA 725	30	0.4724	-	-	0.4646	0.98	One-Piece Machined
5.9339	PWA 725	PWA 725	30	0.4980	-	-	0.5737	1.15	One-Piece Machined
5.950	PWA 725	PWA 725	30	0.4724	-	-	0.4724	1.00	One-Piece Machined
3.372	PWA 725	PWA 725	20	0.3148	-	-	0.350	1.11	One-Piece Machined
3.353	PWA 725	PWA 725	24	0.3150	-	-	0.3150	1.00	One-Piece Machined
3.382	PWA 725	PWA 725	24	0.3543	-	-	0.3543	1.00	One-Piece Machined

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TABLE XXV. LARGE ENGINE NO. 5 MA

Bearing Location and Type	Vendor No.	ID (in.)	ID (mm)	OD (in.)	Width		Pitch Diameter (in.)	Ring Material	Element Material
					ID (in.)	OD (in.)			
No. 1 Ball Bearing	3	4.9213	125	7.4803	1.280	1.280	6.0008	PWA 725	PWA 725
No. 2 Ball Bearing	6	5.7087	145	8.2677	1.280	1.280	6.8900	PWA 725	PWA 725
No. 3 Roller Bearing	6	6.8898	175	9.0551	1.250	1.420	8.015	PWA 725	PWA 725
No. 4 Roller Bearing	6	6.6929	170	9.0551	1.300	1.440	8.00	PWA 725	PWA 725
No. 5 Roller Bearing	5	2.5591	65	3.937	0.700	1.100	3.25	PWA 725	PWA 725
(1)	7,8	2.5591	65	3.937	0.700	1.100	3.25	PWA 725	PWA 725

(1) Outer Race Rotation

B

LARGE ENGINE NO. 5 MAIN SHAFT BEARINGS

Ring Material	Element Material	Number of Elements	Element Diameter (in.)	Ball-Race Curvatures		Total Length (in.)	L/D Ratio	Cage Type
				Inner	Outer			
PWA 725	PWA 725	20	0.8125	0.515	0.52			One-Piece Machined
PWA 725	PWA 725	23	0.8125	0.515	0.515			One-Piece Machined
PWA 725	PWA 725	32	0.6323	-	-	0.7237	1.14	One-Piece Machined
PWA 725	PWA 725	32	0.5910	-	-	0.6610	1.12	One-Piece Machined
PWA 725	PWA 725	22	0.3634	-	-	0.4587	1.26	One-Piece Machined
PWA 725	PWA 725	20	0.354	-	-	0.354	1.00	One-Piece Machined

TABLE XXVI. LARGE ENGINE NO. 6 MAIN SHAFT BEARINGS

Bearing Location and Type	Vendor No.	ID (in.)	ID (mm)	OD (in.)	Width		Pitch Diameter (in.)	Ring Material	Element Material	Number of Elements	Element Diameter (in.)
					ID (in.)	OD (in.)					
No. 1 Roller Bearing	5	3.9370	100	5.8781	1.1417	1.500	4.76	PWA 725	PWA 725	20	0.5512
	4	3.970	100	5.8781	1.1417	1.500	4.76	PWA 725	PWA 725	-	-
	7	3.970	100	5.8781	1.1417	1.500	4.76	PWA 725	PWA 725	-	-
No. 2 Ball Bearing	3	4.3307	110	6.6929	1.408	1.1417	5.5118	PWA 725	PWA 725	18	0.750
	4	4.3307	110	6.6929	1.408	1.1417	5.5118	PWA 725	PWA 725	18	0.750
	2	4.3307	110	6.6929	1.408	1.1417	5.5118	PWA 725	PWA 725	18	0.750
	9	4.3307	110	6.6929	1.408	1.1417	5.5118	PWA 725	PWA 725	18	0.750
No. 3 Ball Bearing	3	6.1024	155	8.8583	1.686	1.4173	7.4804	PWA 725	PWA 725	20	0.90625
	4	6.1024	155	8.8583	1.686	1.4173	7.4804	PWA 725	PWA 725	20	0.90625
	2	6.1024	155	8.8583	1.686	1.4173	7.4804	PWA 725	PWA 725	20	0.90625
No. 4 Roller Bearing	4	6.4961	165	8.8583	1.2583	1.3780	7.75	PWA 725	PWA 725	32	0.6299
	5	6.4961	165	8.8583	1.2583	1.3780	7.75	PWA 725	PWA 725	32	0.6299
No. 5 Roller Bearing	4	3.1496	80	4.9213	2.0079	1.6535	4.055	PWA 725	PWA 725	22	0.4331
	2	3.1496	80	4.9213	2.0079	1.6535	4.055	PWA 725	PWA 725	22	0.4331
	7	3.1496	80	4.9213	2.0079	1.6535	4.055	PWA 725	PWA 725	22	0.4331

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XXVI. LARGE ENGINE NO. 6 MAIN SHAFT BEARINGS

Pitch Diameter (in.)	Ring Material	Element Material	Number of Elements	Element Diameter (in.)	Ball-Race Curvatures		Total Length (in.)	L/D Ratio	Cage Type
					Inner (%)	Outer (%)			
4.76	PWA 725	PWA 725	20	0.5512	-	-	0.5906	1.07	One-Piece Machined Rollers Separable from Cage
4.76	PWA 725	PWA 725	-	-	-	-	-	-	
4.76	PWA 725	PWA 725	-	-	-	-	-	-	
5.5118	PWA 725	PWA 725	18	0.750	52.5	52	-	-	One-Piece Machined
5.5118	PWA 725	PWA 725	18	0.750	52.5	52	-	-	One-Piece Machined
5.5118	PWA 725	PWA 725	18	0.750	52.5	52	-	-	One-Piece Machined
5.5118	PWA 725	PWA 725	18	0.750	52.5	52	-	-	One-Piece Machined
7.4804	PWA 725	PWA 725	20	0.90625	52	52	-	-	One-Piece Machined
7.4804	PWA 725	PWA 725	20	0.90625	52	52	-	-	One-Piece Machined
7.4804	PWA 725	PWA 725	20	0.90625	52	52	-	-	One-Piece Machined
7.75	PWA 725	PWA 725	32	0.6299	-	-	0.6299	1.00	One-Piece Machined Roller Separable from Cage
7.75	PWA 725	PWA 725	32	0.6299	-	-	0.6299	1.00	
4.055	PWA 725	PWA 725	22	0.4331	-	-	0.4331	1.00	One-Piece Machined Rollers Separable from Cage
4.055	PWA 725	PWA 725	22	0.4331	-	-	0.4331	1.00	
4.055	PWA 725	PWA 725	22	0.4331	-	-	0.4331	1.00	

TABLE XXVII. SMALL ENGINE NO. 1 MAIN SHAFT SEALS						
Seal Location and Type	Secondary Seal Type	Method Of Spring Loading	Nose Width (in.)	Face Width (in.)	Pitch Diameter (in.)	Pressure Balance Ratio (%)
No. 1 Compartment Forward Dry Face Seal (CDJ-83)	Piston Ring	Wave Washer	0.030/ 0.020	0.150	2.634	55
No. 1 Compartment Aft Dry Face Seal	Piston Ring	Bellows Spring	0.035/ 0.030	0.148	2.555	55
No. 2 Compartment Forward Dry Face Seal	Piston Ring	Bellows Spring	0.035/ 0.030	0.150	2.929	81
No. 2 Compartment Aft Dry Face Seal	Piston Ring	Bellows	0.035/ 0.030	0.150	3.414	55

TABLE XXVIII. SMALL ENGINE NO. 2 MAIN SHAFT SEALS						
Seal Location and Type	Secondary Seal Type	Method Of Spring Loading	Nose Width (in.)	Face Width (in.)	Pitch Diameter (in.)	Pressure Balance Ratio (%)
No. 1 Ring Seal	None	None	0.040	0.037	3.811	-
No. 2 Dry Face Seal	Piston Ring	Springs	0.080	0.150	3.702	67
No. 3 Dry Face Seal	Piston Ring	Springs	0.060	0.150	3.702	67

TABLE XXIX. LARGE ENGINE NO. 1 MAIN SHAFT SEALS

Seal Location and Type	Secondary Seal Type	Method Of Spring Loading	Nose Width (in.)	Face Width (in.)	Pitch Diameter (in.)	Pressure Balance Ratio (%)
No. 1 Dry Face Seal	Piston Ring	Springs	0.095/ 0.085	0.150	6.31	63.3
No. 2 Dry Face Seal	Piston Ring	Springs	0.095/ 0.085	0.150	6.36	63.3
No. 3 Dry Face Seal	Piston Ring	Springs	0.075/ 0.065	0.150	6.96	63.3
No. 4 Dry Face Seal	Piston Ring	Springs	0.090/ 0.080	0.150	6.76	63.3
No. 4 1/2 Triple Carbon Riding Ring Seal	None	Wave Washer	-	-	-	-
No. 5 Dry Face Seal	Piston Ring	Springs	0.085/ 0.075	0.156	7.018	63.3
No. 6 Ring Seal	None	None	-	-	-	-
No. 6 Back-to-Back Ring Seal	None	Wave Washer	-	-	-	-

TABLE XXX. LARGE ENGINE NO. 2 MAIN SHAFT SEALS						
Seal Location and Type	Secondary Seal Type	Method Of Spring Loading	Nose Width (in.)	Face Width (in.)	Pitch Diameter (in.)	Pressure Balance Ratio (%)
No. 4 1/2 Three Stage Carbon Riding Ring Seal	None	Wave Washer	-	-	-	-
No. 5 Dry Face Seal	Piston Ring	Springs	0.085/ 0.075	0.200	6.127	66
No. 6 Ring Seals	None	None	-	-	-	-
No. 6 Back-to-Back Ring Seal	None	Wave Washer	-	-	-	-

TABLE XXXI. LARGE ENGINE NO. 3 MAIN SHAFT SEALS						
Seal Location and Type	Secondary Seal Type	Method Of Spring Loading	Nose Width (in.)	Face Width (in.)	Pitch Diameter (in.)	Pressure Balance Ratio (%)
No. 1 Dry Face Seal	Piston Seal Ring	Springs	0.105 0.095	0.150	10.215	64.7
No. 1 1/2 Front and Rear Dry Face Seal	Piston Seal Ring	Springs	0.105/ 0.095	0.150	9.815	65
No. 4 Ring Seal Back-to-Back	None	Wave Washer	-	-	-	-

TABLE XXXII. LARGE ENGINE NO. 4 MAIN SHAFT SEALS

Seal Location and Type	Secondary Seal Type	Method Of Spring Loading	Nose Width (in.)	Face Width (in.)	Pitch Diameter (in.)	Pressure Balance Ratio (%)
No. 1 Dry Face	Piston Ring	Springs	0.120/ 0.100	0.200	4.576	66
No. 2 Dry Face	Piston Ring	Springs	0.130/ 0.110	0.150	5.4977	66
No. 3 Dry Face	Piston Ring	Springs	0.130/ 0.110	0.150	4.868	66
No. 4 Wet Face	Piston Ring	Springs	0.085/ 0.065	0.200	5.300	68
No. 4 1/2 Triple Carbon Riding Ring Seal	Ring Seal	Wave Washer	-	-	-	-
No. 5 Wet Face	Piston Ring	Springs	0.070/ 0.050	0.200	6.200	67.5
No. 6 Back-to-Back Ring Seal	-	Wave Washer	-	-	-	-

TABLE XXXIII. LARGE ENGINE NO. 5 MAIN SHAFT SEALS

Seal Location and Type	Secondary Seal Type	Method Of Spring Loading	Nose Width (in.)	Face Width (in.)	Pitch Diameter (in.)	Pressure Balance Ratio (%)
No. 1 Dry Face Seal	Piston Seal Ring	Springs	0.080/ 0.070	0.150	6.753	65
No. 1-2 Front and Rear Dry Face Seal	Piston Seal Ring	Springs	0.080/ 0.070	0.150	6.25	66.8
No. 2 Dry Face Seal	Piston Seal Ring	Springs	0.080/ 0.070	0.150	6.753	65.2
No. 3 Wet Face Seal	Piston Seal Ring	Springs	0.120/ 0.100	0.200	8.16	67.5
No. 4 Wet Face Seal	Piston Seal Ring	Springs	0.120/ 0.100	0.200	8.16	67.5
No. 5 Back-to-Back Ring Seal	None	Wave Washer	-	-	-	-

TABLE XXXIV. LARGE ENGINE NO. 6 MAIN SHAFT SEALS						
Seal Location and Type	Secondary Seal Type	Method Of Spring Loading	Nose Width (in.)	Face Width (in.)	Pitch Diameter (in.)	Pressure Balance Ratio (%)
No. 1 Dry Face Seal	Piston Ring	Spring	0.210/ 0.190	0.200	5.382	67
No. 2 Front and Rear Dry Face Seals	Piston Ring	Springs	0.130/ 0.120	0.200	5.12	65
No. 3 Wet Face Seal (Front)	Piston Ring	Springs	0.130/ 0.120	0.200	5.12	65
No. 3 Wet Face Seal (Rear)	Piston Ring	Springs	0.130/ 0.120	0.200	7.08	85
No. 4 Comp. Front and Rear Wet Face Seals	Piston Ring	Springs	0.120/ 0.100	0.225	7.514	70
No. 5 Dry Face Seal	Piston Ring	Springs	0.140/ 0.120	0.200	6.286	67

TABLE XXXV. SMALL AND LARGE ENGINE PERFORMANCE

Engine	SLTO Corrected Airflow Into Engine (pps)	SLTO Corrected Airflow Into High Compressor (pps)	Low Rotor Speed at SLTO (rpm)	High Rotor Speed at SLTO (rpm)	SLTO Engine Thrust With Augmentation (lb _f)	SLTO Engine Thrust Without Augmentation (lb _f)
Small Engine 1	8.36	NA*	16,300	36,000	NA	NA
Small Engine 2	52.5	NA	33,000	37,500	NA	3,300
Small Engine 3	6.4	NA	16,000	NA	NA	NA
Large Engine 1	461	55.5	6,560	9,730	NA	18,000
Large Engine 2	315	48	8,800	12,250	NA	14,000
Large Engine 3	1480	127.1	3,742	8,084	NA	43,500
Large Engine 4	255.8	28.7	10,528	14,760	25,100	14,500
Large Engine 5	393	62.8	8,000	12,150	33,400	18,100
Large Engine 6	224	54.9	10,130	13,200	28,131	16,400

*NA - Not applicable or available

B

ENGINE PERFORMANCE AND ROTOR DYNAMIC CHARACTERISTICS

Engine Parameters						
Engine Thrust Augmentation (p_f)	SLTO Engine Thrust Without Augmentation (lb_f)	SLTO Engine Thrust to Weight Ratio With Augmentation	SLTO Engine Thrust to Weight Ratio Without Augmentation	SLTO Thrust Specific Fuel Consumption tsfc With Augmentation ($lb/hr/lb$)	SLTO Thrust Specific Fuel Consumption tsfc Without Augmentation ($lb/hr/lb$)	Maximum Compressor Blade Tip Speed (f/s)
A	NA	NA	NA	NA	NA	NA
A	3,300	NA	7.06	NA	0.995	1200
A	NA	NA	NA	NA	NA	1735
A	18,000	NA	4.24	NA	0.535	1425
A	14,000	NA	4.52	NA	0.565	1400
A	43,500	NA	5.14	NA	0.365	1430
,100	14,560	6.31	3.66	2.45	0.686	1520
,400	18,100	7.45	4.03	2.06	0.500	1460
,131	16,415	8.22	6.1	2.1	0.642	1450

TABLE XXXVI. CALCULATED BEARING CHARACTERISTICS

MAINSHAFT BEARING CHARACTERISTICS

ROW	CNS	ALOM	RAI	CAP	EFF.	IFMC	ROLL	CAP	APOR	MT.	DN	ROW TITLE
1	1.000000	00	0.0		3.700000	-01	1.235544	04	1.587245	00	1.207500	06
2	1.000000	00	0.0		2.104000	-01	0.776315	03	1.580033	00	1.207500	06
3	0.643076	-01	1.137790	04	0.0		0.0		3.453418	00	1.368000	06
4	1.000000	00	0.0		3.800000	-01	1.280015	04	1.340074	00	1.298000	06
5	1.000000	00	0.0		2.150000	-01	4.013000	03	7.812735	-01	6.333000	05
6	0.643076	-01	3.300076	03	0.0		0.0		7.812735	-01	6.333000	05
7	0.643076	-01	3.000000	03	0.0		0.0		7.026701	-01	6.333000	05
8	0.643076	-01	4.315177	03	0.0		0.0		2.340023	00	1.800000	06
9	0.643076	-01	3.153430	03	0.0		0.0		2.340023	00	1.800000	06
10	1.000000	00	0.0		3.550000	-01	0.713430	03	1.534474	00	1.800000	06
11	1.000000	00	0.0		2.480000	-01	0.709055	03	1.534474	00	2.067000	06
12	0.643076	-01	7.586013	03	0.0		0.0		2.100015	00	9.428000	05
13	0.643076	-01	7.084013	03	0.0		0.0		2.100015	00	9.428000	05
14	0.643076	-01	7.686013	03	0.0		0.0		2.100015	00	9.428000	05
15	1.000000	00	0.0		4.000000	-01	2.513574	04	4.000000	00	8.928000	05
16	1.000000	00	0.0		4.000000	-01	2.513574	04	4.000000	00	8.928000	05
17	0.643076	-01	3.280013	04	0.0		0.0		2.073721	01	8.528000	05
18	0.643076	-01	3.280013	04	0.0		0.0		2.073721	01	8.528000	05
19	0.643076	-01	3.280013	04	0.0		0.0		2.073721	01	8.528000	05
20	0.643076	-01	3.280013	04	0.0		0.0		2.073721	01	8.528000	05
21	0.643076	-01	3.280013	04	0.0		0.0		2.073721	01	8.528000	05
22	0.643076	-01	3.280013	04	0.0		0.0		2.073721	01	8.528000	05
23	1.000000	00	0.0		3.440000	-01	1.351360	04	2.507040	00	7.084000	05
24	1.000000	00	0.0		3.100000	-01	1.207423	04	2.514895	00	7.084000	05
25	1.000000	00	0.0		3.020000	-01	1.207423	04	2.514895	00	7.084000	05
26	0.643076	-01	4.153015	04	0.0		0.0		3.611570	00	7.084000	05
27	0.643076	-01	4.153015	04	0.0		0.0		3.611570	00	7.084000	05
28	0.643076	-01	4.153015	04	0.0		0.0		3.611570	00	7.084000	05
29	0.643076	-01	4.153015	04	0.0		0.0		3.611570	00	7.084000	05
30	0.643076	-01	4.153015	04	0.0		0.0		3.611570	00	7.084000	05
31	1.000000	00	0.0		2.710000	-01	1.039440	04	2.026918	00	6.525000	05
32	1.000000	00	0.0		3.470000	-01	1.276443	04	2.026918	00	6.525000	05
33	1.000000	00	0.0		5.700000	-01	1.858770	04	3.054212	00	1.450250	06
34	1.000000	00	0.0		5.700000	-01	1.858770	04	3.054212	00	1.450250	06
35	1.000000	00	0.0		4.000000	-01	1.383700	04	3.054212	00	1.450250	06
36	1.000000	00	0.0		4.000000	-01	1.383700	04	3.054212	00	1.450250	06
37	1.000000	00	0.0		4.000000	-01	1.383700	04	3.054212	00	1.450250	06
38	1.000000	00	0.0		4.000000	-01	1.383700	04	3.054212	00	1.450250	06
39	1.000000	00	0.0		4.000000	-01	1.383700	04	3.054212	00	1.450250	06
40	0.643076	-01	3.441845	06	0.0		0.0		1.510172	01	8.900000	05
41	0.643076	-01	3.441845	06	0.0		0.0		1.510172	01	8.900000	05
42	0.643076	-01	3.441845	06	0.0		0.0		1.510172	01	8.900000	05
43	0.643076	-01	3.441845	06	0.0		0.0		1.510172	01	8.900000	05
44	0.643076	-01	3.441845	06	0.0		0.0		1.510172	01	8.900000	05
45	0.643076	-01	3.441845	06	0.0		0.0		1.510172	01	8.900000	05
46	0.643076	-01	3.441845	06	0.0		0.0		1.510172	01	8.900000	05
47	0.643076	-01	3.441845	06	0.0		0.0		1.510172	01	8.900000	05
48	1.000000	00	0.0		3.180000	-01	8.870710	03	1.203426	00	7.040000	05
49	1.000000	00	0.0		5.000000	-01	2.473015	04	5.054403	00	1.592500	06
50	1.000000	00	0.0		4.220000	-01	1.537454	04	3.451345	00	7.480000	05
51	1.000000	00	0.0		3.600000	-01	1.304544	04	3.451345	00	7.480000	05

TABLE XXXVI. CALCULATED BEARING CHARACTERISTICS (CONTINUED)

ROW	FLRTSD	FLCGVL	CAGE RUB VEL ON OUTER RACE	CAGE RUB VEL ON INNER RACE	D/E	ND**2	ROW TITLE
1	9.000781E 04	7.427472E 03	0.0	7.704519E 03	9.873234E-02	0.0	SMALL ENG. NO. 2
2	8.000844E 04	7.410131E 03	0.0	7.711157E 03	9.874144E-02	0.0	SMALL ENG. NO. 2
3	8.700555E 04	8.840150E 03	0.0	9.537922E 03	1.780747E-01	7.049592E 00	SMALL ENG. NO. 2
4	9.573181E 04	7.853490E 03	0.0	7.926660E 03	9.303242E-02	0.0	SMALL ENG. NO. 1
5	7.401843E 04	4.003422E 03	0.0	5.154137E 03	1.075248E-01	0.0	SMALL ENG. NO. 1
6	4.403750E 04	6.250340E 03	0.0	4.419203E 03	1.239219E-01	1.250000E 00	SMALL ENG. NO. 1
7	4.101045E 04	4.242113E 03	0.0	4.448904E 03	1.318807E-01	1.260779E 00	SMALL ENG. NO. 1
8	9.407881E 04	1.574737E 04	0.0	1.348315E 04	1.500000E 00	3.750000E 00	SMALL ENG. NO. 1
9	7.901248E 04	1.579004E 04	0.0	1.476427E 04	1.046440E-01	0.0	SMALL ENG. NO. 1
10	1.577360E 05	1.306154E 04	0.0	1.571336E 04	1.120290E-01	0.0	SMALL ENG. NO. 1
11	4.879457E 04	4.783211E 03	0.0	7.247727E 03	1.534827E-01	4.229413E 00	SMALL ENG. NO. 1
12	4.879457E 04	4.783211E 03	0.0	7.247727E 03	1.534827E-01	4.229413E 00	SMALL ENG. NO. 1
13	4.879457E 04	4.783211E 03	0.0	7.247727E 03	1.534827E-01	4.229413E 00	SMALL ENG. NO. 1
14	4.879457E 04	4.783211E 03	0.0	7.247727E 03	1.534827E-01	4.229413E 00	SMALL ENG. NO. 1
15	7.401407E 04	5.107305E 03	0.0	6.909000E 03	9.032506E-02	0.0	LARGE ENG. NO. 1
16	1.308424E 04	5.204518E 03	-5.730137E 03	0.0	3.148012E-02	0.0	LARGE ENG. NO. 1
17	7.588485E 04	5.504453E 03	0.0	5.036180E 03	1.348328E 01	1.348328E 01	LARGE ENG. NO. 1
18	7.588485E 04	5.504453E 03	0.0	5.036180E 03	1.348328E 01	1.348328E 01	LARGE ENG. NO. 1
19	7.588485E 04	5.504453E 03	0.0	5.036180E 03	1.348328E 01	1.348328E 01	LARGE ENG. NO. 1
20	7.588485E 04	5.504453E 03	0.0	5.036180E 03	1.348328E 01	1.348328E 01	LARGE ENG. NO. 1
21	7.588485E 04	5.504453E 03	0.0	5.036180E 03	1.348328E 01	1.348328E 01	LARGE ENG. NO. 1
22	1.412267E 04	7.112443E 03	0.0	-2.223084E 03	9.749240E-02	4.175694E 00	LARGE ENG. NO. 1
23	1.013441E 04	1.818114E 03	0.0	-7.141145E 03	7.315442E-02	4.750000E 00	LARGE ENG. NO. 1
24	1.000405E 04	1.818114E 03	0.0	-1.804384E 03	7.315442E-02	0.0	LARGE ENG. NO. 1
25	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1
26	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1
27	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1
28	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1
29	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1
30	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1
31	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1
32	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1
33	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1
34	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1
35	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1
36	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1
37	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1
38	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1
39	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1
40	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1
41	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1
42	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1
43	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1
44	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1
45	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1
46	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1
47	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1
48	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1
49	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1
50	1.412084E 04	8.367431E 03	0.0	9.512357E 03	7.317717E-02	0.0	LARGE ENG. NO. 1

TABLE XXXVI. CALCULATED BEARING CHARACTERISTICS (CONTINUED)

ROW	NDL	ROLL/D	PITCH LINE VELOCITY	CAGE SPD	BALL CF.	ROLL CF.	ROW TITLE
1	3.910041E 00	1.374000E 00	6.817773E 03	7.335703E 03	0.0	2.589343E 01	SMALL ENG. NO. 2
2	2.822270E 00	1.174441E 00	6.804137E 03	7.335420E 03	0.0	2.104325E 01	SMALL ENG. NO. 2
3	0.0	0.0	7.840935E 03	7.035070E 03	3.304144E 01	0.0	SMALL ENG. NO. 2
4	4.018198E 00	1.340841E 00	7.745527E 03	7.374340E 03	0.0	2.715867E 01	SMALL ENG. NO. 1
5	1.580000E 00	1.000000E 00	4.427733E 03	7.273654E 03	0.0	6.062020E 00	SMALL ENG. NO. 1
6	0.0	0.0	3.871000E 03	7.234660E 03	3.440172E 00	0.0	SMALL ENG. NO. 1
7	0.0	0.0	3.700000E 03	7.177335E 03	3.003505E 00	0.0	SMALL ENG. NO. 1
8	0.0	0.0	1.777135E 04	1.468105E 04	1.420275E 02	0.0	SMALL ENG. NO. 1
9	0.0	0.0	1.104017E 04	1.505302E 04	1.672617E 02	0.0	SMALL ENG. NO. 1
10	2.207475E 00	0.770848E -01	1.428514E 04	1.611437E 04	0.0	1.704414E 02	SMALL ENG. NO. 1
11	2.448407E 00	1.161600E 00	1.254437E 04	1.505728E 04	0.0	1.091201E 02	SMALL ENG. NO. 1
12	0.0	0.0	5.020771E 03	6.062334E 03	4.957422E 01	0.0	SMALL ENG. NO. 1
13	0.0	0.0	5.020771E 03	6.062334E 03	4.057115E 01	0.0	SMALL ENG. NO. 1
14	0.0	0.0	5.020771E 03	6.062334E 03	0.0	2.589571E 01	LARGE ENG. NO. 1
15	7.800145E 00	1.000000E 00	4.745925E 03	2.893732E 03	0.0	2.315919E 01	LARGE ENG. NO. 1
16	7.081489E 00	1.070411E 00	4.817084E 03	3.013049E 03	0.0	0.0	LARGE ENG. NO. 1
17	0.0	0.0	4.065945E 03	2.909184E 03	4.106370E 01	0.0	LARGE ENG. NO. 1
18	0.0	0.0	4.745925E 03	2.909184E 03	4.106370E 01	0.0	LARGE ENG. NO. 1
19	0.0	0.0	4.065945E 03	2.909184E 03	4.106370E 01	0.0	LARGE ENG. NO. 1
20	0.0	0.0	4.065945E 03	2.909184E 03	4.106370E 01	0.0	LARGE ENG. NO. 1
21	0.0	0.0	1.103155E 04	8.277321E 03	7.400363E 01	0.0	LARGE ENG. NO. 1
22	0.0	0.0	1.103155E 04	8.277321E 03	7.400363E 01	0.0	LARGE ENG. NO. 1
23	4.784700E 00	1.084871E 00	1.040000E 04	9.070455E 03	0.0	5.243713E 01	LARGE ENG. NO. 1
24	4.174000E 00	3.705848E -01	1.047727E 04	8.049073E 03	0.0	4.428795E 01	LARGE ENG. NO. 1
25	4.174000E 00	0.7415. -1E-01	1.047727E 04	8.049073E 03	0.0	4.776195E 01	LARGE ENG. NO. 1
26	0.0	0.0	7.015172E 03	4.281781E 03	0.0	0.0	LARGE ENG. NO. 1
27	0.0	0.0	7.015172E 03	4.281781E 03	2.742883E 02	0.0	LARGE ENG. NO. 1
28	0.0	0.0	7.015172E 03	4.281781E 03	2.742883E 02	0.0	LARGE ENG. NO. 1
29	0.0	0.0	7.015172E 03	4.281781E 03	2.742883E 02	0.0	LARGE ENG. NO. 1
30	0.0	0.0	7.015172E 03	4.281781E 03	2.742883E 02	0.0	LARGE ENG. NO. 1
31	3.482513E 00	5.742200E -01	9.474703E 03	8.254746E 03	0.0	2.594484E 01	LARGE ENG. NO. 1
32	4.174000E 00	1.040000E 00	8.049073E 03	8.254746E 03	0.0	3.792540E 01	LARGE ENG. NO. 1
33	1.754200E 01	0.431844E -01	8.049073E 03	8.254746E 03	0.0	1.304178E 02	LARGE ENG. NO. 1
34	3.000400E 00	1.040000E 00	2.730677E 03	2.943605E 03	0.0	1.323802E 02	LARGE ENG. NO. 1
35	4.003000E 00	1.261204E 00	2.730677E 03	2.943605E 03	0.0	5.863024E 00	LARGE ENG. NO. 1
36	3.710001E 00	1.000000E 00	2.730677E 03	2.943605E 03	0.0	5.874467E 00	LARGE ENG. NO. 1
37	4.743174E 00	1.017171E 00	2.730677E 03	2.943605E 03	0.0	5.797160E 00	LARGE ENG. NO. 1
38	4.315248E 00	1.195598E 00	4.851744E 03	3.083742E 03	0.0	2.738828E 01	LARGE ENG. NO. 1
39	0.0	0.0	4.000000E 03	4.000000E 03	0.0	1.504433E 01	LARGE ENG. NO. 2
40	0.0	0.0	5.212018E 03	3.755551E 03	3.447709E 01	0.0	LARGE ENG. NO. 2
41	0.0	0.0	5.120551E 03	3.755551E 03	3.300110E 01	0.0	LARGE ENG. NO. 2
42	0.0	0.0	5.120551E 03	3.755551E 03	3.300110E 01	0.0	LARGE ENG. NO. 2
43	0.0	0.0	8.114227E 03	3.756004E 03	3.300110E 01	0.0	LARGE ENG. NO. 2
44	0.0	0.0	8.114227E 03	3.756004E 03	3.300110E 01	0.0	LARGE ENG. NO. 2
45	0.0	0.0	8.114227E 03	3.756004E 03	3.300110E 01	0.0	LARGE ENG. NO. 2
46	0.0	0.0	8.114227E 03	3.756004E 03	3.300110E 01	0.0	LARGE ENG. NO. 2
47	0.0	0.0	8.114227E 03	3.756004E 03	3.300110E 01	0.0	LARGE ENG. NO. 2
48	2.318270E 00	1.427482E 00	1.000703E 04	1.044100E 04	0.0	2.597840E 01	LARGE ENG. NO. 2
49	7.306470E 00	1.157077E 00	4.086141E 03	5.455121E 03	0.0	4.555594E 01	LARGE ENG. NO. 2
50	4.578000E 00	1.501777E 00	4.086141E 03	5.455121E 03	0.0	1.209824E 01	LARGE ENG. NO. 2
51	3.240173E 00	0.700330E -01	4.377203E 03	3.084533E 03	0.0	1.257209E 01	LARGE ENG. NO. 2

TABLE XXXVI. CALCULATED BEARING CHARACTERISTICS (CONTINUED)

ROW	PITCH DIA (IN.) X SHAFT SPD	E IN MM	PITCH DIA (MM) X SHAFT SPD	E IN MM	ID IN MM	ROW TITLE
1	5.715400F 04	0.0	1.451170E 06	0.0	7.500000E 01	SMALL ENG. NO. 2
2	5.745800F 04	0.0	1.443284E 06	0.0	7.500000E 01	SMALL ENG. NO. 2
3	5.877000F 04	0.0	1.746094E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
4	5.963300F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
5	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
6	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
7	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
8	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
9	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
10	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
11	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
12	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
13	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
14	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
15	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
16	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
17	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
18	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
19	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
20	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
21	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
22	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
23	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
24	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
25	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
26	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
27	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
28	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
29	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
30	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
31	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
32	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
33	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
34	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
35	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
36	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
37	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
38	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
39	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
40	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
41	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
42	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
43	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
44	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
45	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
46	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
47	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
48	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
49	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2
50	5.997000F 04	0.0	1.534754E 06	0.0	8.500000E 01	SMALL ENG. NO. 2

TABLE XXXVI. CALCULATED BEARING CHARACTERISTICS (CONTINUED)

ROW	E IN IN.	ROW TITLE
1	3.540000E 00	SMALL ENG. NO. 2
2	3.540000E 00	SMALL ENG. NO. 2
3	4.271000E 00	SMALL ENG. NO. 2
4	3.752000E 00	SMALL ENG. NO. 1
5	3.325000E 00	SMALL ENG. NO. 1
6	2.017400E 00	SMALL ENG. NO. 1
7	2.014000E 00	SMALL ENG. NO. 1
8	2.745000E 00	SMALL ENG. NO. 1
9	2.902100E 00	SMALL ENG. NO. 1
10	3.395400E 00	SMALL ENG. NO. 1
11	3.700000E 00	SMALL ENG. NO. 1
12	3.249000E 00	SMALL ENG. NO. 1
13	3.249000E 00	SMALL ENG. NO. 1
14	3.247000E 00	SMALL ENG. NO. 1
15	4.107200E 00	SMALL ENG. NO. 1
16	4.107200E 00	LARGE ENG. NO. 1
17	4.405000E 00	LARGE ENG. NO. 1
18	4.405000E 00	LARGE ENG. NO. 1
19	4.471000E 00	LARGE ENG. NO. 1
20	4.405000E 00	LARGE ENG. NO. 1
21	5.119000E 00	LARGE ENG. NO. 1
22	5.119000E 00	LARGE ENG. NO. 1
23	4.767400E 00	LARGE ENG. NO. 1
24	4.047400E 00	LARGE ENG. NO. 1
25	4.767400E 00	LARGE ENG. NO. 1
26	7.061000E 00	LARGE ENG. NO. 1
27	7.304000E 00	LARGE ENG. NO. 1
28	7.067000E 00	LARGE ENG. NO. 1
29	7.067000E 00	LARGE ENG. NO. 1
30	4.570000E 00	LARGE ENG. NO. 1
31	4.570000E 00	LARGE ENG. NO. 1
32	7.184700E 00	LARGE ENG. NO. 1
33	7.184700E 00	LARGE ENG. NO. 1
34	3.543000E 00	LARGE ENG. NO. 1
35	3.543000E 00	LARGE ENG. NO. 1
36	3.543000E 00	LARGE ENG. NO. 1
37	4.445000E 00	LARGE ENG. NO. 1
38	4.445000E 00	LARGE ENG. NO. 1
39	4.706000E 00	LARGE ENG. NO. 2
40	5.214500E 00	LARGE ENG. NO. 2
41	5.214500E 00	LARGE ENG. NO. 2
42	5.172700E 00	LARGE ENG. NO. 2
43	5.172700E 00	LARGE ENG. NO. 2
44	4.200000E 00	LARGE ENG. NO. 2
45	4.203000E 00	LARGE ENG. NO. 2
46	4.203000E 00	LARGE ENG. NO. 2
47	3.700000E 00	LARGE ENG. NO. 2
48	4.101000E 00	LARGE ENG. NO. 2
49	4.103700E 00	LARGE ENG. NO. 2
50	4.103700E 00	LARGE ENG. NO. 2

TABLE XXXVI. CALCULATED BEARING CHARACTERISTICS (CONTINUED)

*** CASH DENGRAH NITMUT ***

MAINSHAFT BEARING CHARACTERISTICS

ROW	CNC AIDM	RAIL CAP	SEE LENG	ROLL CAP	APPR WT.	DN	ROW TITLE
51	0.304074E-01	0.000000E+00	0.0	0.0	5.070613E 01	7.958200E 05	LARGE ENG. NO. 3
52	0.304074E-01	0.000000E+00	0.0	0.0	3.362105E 01	1.778480E 06	LARGE ENG. NO. 3
53	0.304074E-01	0.000000E+00	0.0	0.0	3.362105E 01	1.778480E 06	LARGE ENG. NO. 3
54	1.000000E 00	0.0	0.0	0.0	7.4897450E 04	1.859740E 06	LARGE ENG. NO. 3
55	1.000000E 00	0.0	0.0	0.0	4.402724E 04	6.174300E 05	LARGE ENG. NO. 3
56	1.000000E 00	0.0	0.0	0.0	1.110118E 01	1.000160E 06	LARGE ENG. NO. 3
57	1.000000E 00	0.0	0.0	0.0	1.707209E 00	1.000160E 06	LARGE ENG. NO. 3
58	1.000000E 00	0.0	0.0	0.0	3.707209E 00	1.000160E 06	LARGE ENG. NO. 3
59	0.043074E-01	1.284310E 04	0.0	0.0	4.665850E 00	1.150000E 06	LARGE ENG. NO. 3
60	0.043074E-01	1.284310E 04	0.0	0.0	4.665850E 00	1.150000E 06	LARGE ENG. NO. 3
61	1.000000E 00	0.0	0.0	0.0	2.496840E 00	1.476000E 06	LARGE ENG. NO. 3
62	1.000000E 00	0.0	0.0	0.0	2.496840E 00	1.476000E 06	LARGE ENG. NO. 3
63	1.000000E 00	0.0	0.0	0.0	2.507442E 00	1.476000E 06	LARGE ENG. NO. 3
64	0.043074E-01	1.700000E 04	0.0	0.0	7.000041E 00	1.467880E 06	LARGE ENG. NO. 3
65	0.043074E-01	1.700000E 04	0.0	0.0	7.000041E 00	1.467880E 06	LARGE ENG. NO. 3
66	0.043074E-01	1.700000E 04	0.0	0.0	7.000041E 00	1.467880E 06	LARGE ENG. NO. 3
67	1.000000E 00	0.0	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3
68	1.000000E 00	0.0	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3
69	1.000000E 00	0.0	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3
70	1.000000E 00	0.0	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3
71	1.000000E 00	0.0	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3
72	1.000000E 00	0.0	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3
73	1.000000E 00	0.0	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3
74	1.000000E 00	0.0	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3
75	0.043074E-01	1.700000E 04	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3
76	0.043074E-01	1.700000E 04	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3
77	1.000000E 00	0.0	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3
78	1.000000E 00	0.0	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3
79	1.000000E 00	0.0	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3
80	1.000000E 00	0.0	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3
81	1.000000E 00	0.0	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3
82	0.043074E-01	1.700000E 04	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3
83	0.043074E-01	1.700000E 04	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3
84	1.000000E 00	0.0	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3
85	1.000000E 00	0.0	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3
86	1.000000E 00	0.0	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3
87	1.000000E 00	0.0	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3
88	1.000000E 00	0.0	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3
89	0.043074E-01	1.700000E 04	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3
90	0.043074E-01	1.700000E 04	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3
91	1.000000E 00	0.0	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3
92	1.000000E 00	0.0	0.0	0.0	1.700000E 00	1.467880E 06	LARGE ENG. NO. 3

TABLE XXXVI. CALCULATED BEARING CHARACTERISTICS (CONTINUED)

ROW	FLRTSD	EL-CG.VL	CAGE HUB VEL. ON OUTER RACE	CAGE RUB VEL. ON INNER RACE	D/E	ND**2	ROW TITLE
51	1.31903E 04	5.70170E 03	0.0	5.96566E 03	1.305000E-01	4.882813E 01	LARGE ENG. NO. 3
52	2.78167E 04	1.11372E 04	0.0	1.14130E 04	1.058335E-01	3.164063E 01	LARGE ENG. NO. 3
53	3.781427E 04	1.11372E 04	0.0	1.167407E 04	1.058335E-01	3.164063E 01	LARGE ENG. NO. 3
54	4.781427E 04	1.11372E 04	0.0	1.164694E 04	9.440524E-02	0.0	LARGE ENG. NO. 3
55	5.781427E 04	1.11372E 04	0.0	1.164694E 04	2.109253E-02	0.0	LARGE ENG. NO. 3
56	6.781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
57	7.781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
58	8.781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
59	9.781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
60	1.0781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
61	1.1781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
62	1.2781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
63	1.3781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
64	1.4781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
65	1.5781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
66	1.6781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
67	1.7781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
68	1.8781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
69	1.9781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
70	2.0781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
71	2.1781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
72	2.2781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
73	2.3781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
74	2.4781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
75	2.5781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
76	2.6781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
77	2.7781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
78	2.8781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
79	2.9781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
80	3.0781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
81	3.1781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
82	3.2781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
83	3.3781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
84	3.4781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
85	3.5781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
86	3.6781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
87	3.7781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
88	3.8781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
89	3.9781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
90	4.0781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
91	4.1781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3
92	4.2781427E 04	1.11372E 04	0.0	1.164694E 04	2.52704E-02	0.0	LARGE ENG. NO. 3

TABLE XXXVI. CALCULATED BEARING CHARACTERISTICS (CONTINUED)

ROW	NDL	ROLL/D	PITCH LINE VEL.	CAGE SPD	BALL CF.	ROLL CF.	ROW TITLE
51	0.0	0.0	4.766871F 02	1.635770F 02	2.374365E 02	0.0	LARGE ENG. NO. 3
52	0.0	0.0	1.013002F 02	3.643019E 03	4.216687E 02	0.0	LARGE ENG. NO. 3
53	0.0	0.0	3.017082F 04	3.640019E 03	4.216687E 02	0.0	LARGE ENG. NO. 3
54	2.600885E 01	2.012755E-01	1.070611F 04	3.700843E 03	0.0	2.310723E 02	LARGE ENG. NO. 3
55	1.604314F 01	1.000000E 00	3.643714F 03	1.700566E 03	0.0	2.525035F 01	LARGE ENG. NO. 3
56	1.646413E 01	1.004502E 00	3.647846F 03	1.697774E 03	0.0	2.935034E 01	LARGE ENG. NO. 3
57	3.046173E 00	5.703309F-01	5.609533E 03	4.806305E 03	0.0	1.872431E 01	LARGE ENG. NO. 4
58	3.001024F 00	1.094003F 00	5.720416F 03	4.814060E 03	0.0	2.098400F 01	LARGE ENG. NO. 4
59	0.0	0.0	4.567672F 03	4.702887E 03	5.033485E 01	0.0	LARGE ENG. NO. 4
60	0.0	0.0	4.521242E 03	4.701395E 03	4.013458E 01	0.0	LARGE ENG. NO. 4
61	3.687046E 00	9.770848E-01	8.460601F 03	4.826381E 03	0.0	3.019348E 01	LARGE ENG. NO. 4
62	3.850109F 00	1.076676F 00	8.477080E 03	4.846530E 03	0.0	2.829461E 01	LARGE ENG. NO. 4
63	3.745831E 00	1.000000E 00	9.646061F 03	6.826381E 03	0.0	3.087317E 01	LARGE ENG. NO. 4
64	0.0	0.0	9.646107F 03	6.809441E 03	2.131581E 02	0.0	LARGE ENG. NO. 4
65	0.0	0.0	7.867565E 03	6.513156E 03	2.177699E 02	0.0	LARGE ENG. NO. 4
66	0.0	0.0	7.964940E 03	6.519109E 03	2.106761E 02	0.0	LARGE ENG. NO. 4
67	3.014508F 00	1.100977E 00	1.780271F 04	1.280184E 04	0.0	4.805141E 01	LARGE ENG. NO. 4
68	3.074784F 00	1.173383F 00	1.761633E 04	1.281787E 04	0.0	5.790390E 01	LARGE ENG. NO. 4
69	3.070014F 00	1.761655E 00	1.760609E 04	1.280402E 04	0.0	5.302980F 01	LARGE ENG. NO. 4
70	4.584310E 00	3.834804E-01	1.033700F 04	6.789772E 03	0.0	8.751750F 01	LARGE ENG. NO. 4
71	4.504811E 00	1.000000E 00	1.058317E 04	6.706061E 03	0.0	9.132175E 01	LARGE ENG. NO. 4
72	3.038500E 00	1.111816E 00	4.213175E 03	4.773566E 03	0.0	8.402285F 00	LARGE ENG. NO. 4
73	2.381109F 00	1.000000E 00	4.184711F 03	4.742440E 03	0.0	7.519238F 00	LARGE ENG. NO. 4
74	3.017483F 00	1.000000E 00	4.172516F 03	4.712530E 03	0.0	1.053575F 01	LARGE ENG. NO. 4
75	0.0	0.0	5.722330F 03	3.526080E 03	9.487783F 01	0.0	LARGE ENG. NO. 5
76	0.0	0.0	7.784976F 03	3.525727E 03	2.287614E 02	0.0	LARGE ENG. NO. 5
77	1.664305E 01	1.144551E 00	1.174140F 04	5.505747E 03	0.0	2.590209E 02	LARGE ENG. NO. 5
78	1.750883F 01	1.118443F 00	1.178352E 04	5.676207E 03	0.0	1.944022F 02	LARGE ENG. NO. 5
79	3.643713E 00	1.762746E 00	3.781368E 03	4.467258E 03	0.0	1.228103E 01	LARGE ENG. NO. 5
80	3.504310E 00	1.000000E 00	3.776107F 03	4.435431F 03	0.0	8.947137E 00	LARGE ENG. NO. 5
81	5.510771E 00	1.071480F 00	5.580018E 03	4.478480E 03	0.0	5.403174E 01	LARGE ENG. NO. 5
82	0.0	0.0	6.456246E 03	4.476236E 03	2.787942E 01	0.0	LARGE ENG. NO. 6
83	0.0	0.0	1.167745E 04	5.869742E 03	4.071142E 02	0.0	LARGE ENG. NO. 6
84	1.540477E 01	1.070700E 00	1.230247F 04	4.063566E 03	0.0	2.461646E 02	LARGE ENG. NO. 6
85	1.267677F 01	1.000000E 00	1.230247F 04	4.063566E 03	0.0	2.461646E 02	LARGE ENG. NO. 6
86	4.176667E 00	1.000000E 00	5.351780F 03	5.605263E 03	0.0	3.265318E 01	LARGE ENG. NO. 6
87	4.779581E 00	1.000000E 00	5.961744F 03	5.615816E 03	0.0	3.455475F 01	LARGE ENG. NO. 6
88	4.174647F 00	1.000000E 00	5.961780F 03	5.615816E 03	0.0	3.265318E 01	LARGE ENG. NO. 6
89	0.0	0.0	6.686909F 03	1.267706E 04	1.003382E 02	0.0	SMALL ENG. NO. 3
90	1.437170E 00	1.173383F 00	7.988046F 03	1.420816E 04	0.0	4.090134E 01	SMALL ENG. NO. 3
91	1.437147E 00	1.173383F 00	7.988046F 03	1.414546E 04	0.0	5.281680F 01	SMALL ENG. NO. 3
92	0.0	0.0	7.508855E 03	1.417050E 04	1.205689E 02	0.0	SMALL ENG. NO. 3

TABLE XXXVI. CALCULATED BEARING CHARACTERISTICS (CONTINUED)

ROW	C IN IN.	ROW TITLE
51	1.120000F 01	LARGE ENG. NO. 3
52	1.063000E 01	LARGE ENG. NO. 3
53	1.063000F 01	LARGE ENG. NO. 3
54	1.072000F 01	LARGE ENG. NO. 3
55	7.780000F 00	LARGE ENG. NO. 3
56	7.780000F 00	LARGE ENG. NO. 3
57	4.528000F 00	LARGE ENG. NO. 3
58	4.517000F 00	LARGE ENG. NO. 3
59	5.313000F 00	LARGE ENG. NO. 4
60	5.700000E 00	LARGE ENG. NO. 4
61	4.713000F 00	LARGE ENG. NO. 4
62	4.713000F 00	LARGE ENG. NO. 4
63	4.713000F 00	LARGE ENG. NO. 4
64	5.601000F 00	LARGE ENG. NO. 4
65	5.787000F 00	LARGE ENG. NO. 4
66	5.857000F 00	LARGE ENG. NO. 4
67	3.700000F 00	LARGE ENG. NO. 4
68	3.700000E 00	LARGE ENG. NO. 4
69	3.700000F 00	LARGE ENG. NO. 4
70	5.820000E 00	LARGE ENG. NO. 4
71	5.050000F 00	LARGE ENG. NO. 4
72	3.372000E 00	LARGE ENG. NO. 4
73	3.353000E 00	LARGE ENG. NO. 4
74	3.382000F 00	LARGE ENG. NO. 4
75	4.703000F 00	LARGE ENG. NO. 5
76	4.890000E 00	LARGE ENG. NO. 5
77	9.716000E 00	LARGE ENG. NO. 5
78	9.000000E 00	LARGE ENG. NO. 5
79	3.350000E 00	LARGE ENG. NO. 6
80	3.350000F 00	LARGE ENG. NO. 6
81	4.757000E 00	LARGE ENG. NO. 6
82	5.511000F 00	LARGE ENG. NO. 6
83	7.680000F 00	LARGE ENG. NO. 6
84	7.750000F 00	LARGE ENG. NO. 6
85	7.750000F 00	LARGE ENG. NO. 6
86	4.054000E 00	LARGE ENG. NO. 6
87	4.054000F 00	LARGE ENG. NO. 6
88	4.054000F 00	LARGE ENG. NO. 6
89	2.067000E 00	SMALL ENG. NO. 3
90	2.125000E 00	SMALL ENG. NO. 3
91	2.125000E 00	SMALL ENG. NO. 3
92	2.067000E 00	SMALL ENG. NO. 3

TABLE XXXVII. CALCULATED MAIN SHAFT CARBON SEAL CHARACTERISTICS

MAIN SHAFT SEAL CHARACTERISTICS

ROW	CLIN VFI	RV VALUE	NOES,END	SP DBECS	FACE DBS	ROW TITLE
1	2.40040E 03	6.50100E 03	8.72744E 00	8.38334E 00	1.33873E 01	SMALL ENG. NO. 2
2	2.40040E 03	1.37823E 04	1.571831E 01	8.39334E 00	1.73033E 01	SMALL ENG. NO. 2
3	1.87331E 02	0.0	0.0	4.23747E 00	4.23747E 00	SMALL ENG. NO. 1
4	4.01330E 03	1.40524E 03	2.37507E 01	4.30147E 00	4.40147E 00	SMALL ENG. NO. 1
5	4.00870E 03	1.70634E 04	1.46873E 01	4.26547E 00	1.63354E 01	SMALL ENG. NO. 1
6	2.43017E 03	2.43017E 03	1.70634E 04	4.26547E 00	4.00870E 00	SMALL ENG. NO. 1
7	1.80410E 03	2.43017E 03	7.00054E 01	4.04347E 00	5.20863E 00	SMALL ENG. NO. 1
8	1.80410E 03	4.73544E 03	1.47454E 01	4.57047E 00	1.14404E 01	LARGE ENG. NO. 1
9	7.06340E 03	1.63737E 04	2.24877E 01	5.97507E 00	1.24010E 01	LARGE ENG. NO. 1
10	7.06340E 03	2.84771E 04	4.10644E 01	4.15772E 00	1.93107E 01	LARGE ENG. NO. 1
11	2.08107E 03	2.80317E 04	4.20004E 01	4.40888E 00	1.87005E 01	LARGE ENG. NO. 1
12	2.77807E 03	2.70644E 04	4.60444E 01	4.67473E 00	1.63557E 01	LARGE ENG. NO. 2
13	1.44784E 03	4.87401E 03	2.05708E 01	2.00835E 00	7.17134E 00	LARGE ENG. NO. 3
14	1.40357E 03	8.01278E 03	3.46801E 01	5.18804E 00	1.24889E 01	LARGE ENG. NO. 3
15	3.44704E 03	1.73107E 04	3.46801E 01	5.18804E 00	1.24889E 01	LARGE ENG. NO. 3
16	1.07084E 03	5.75570E 03	1.15074E 01	7.84567E 00	1.18755E 01	LARGE ENG. NO. 4
17	4.25404E 03	1.41331E 04	2.64901E 01	8.26378E 00	1.94037E 01	LARGE ENG. NO. 4
18	2.13174E 03	1.07617E 04	2.31734E 01	1.04621E 01	2.05420E 01	LARGE ENG. NO. 4
19	3.41344E 03	1.07074E 04	3.47451E 01	4.72050E 00	1.91405E 01	LARGE ENG. NO. 4
20	2.00704E 03	2.67544E 04	4.22470E 01	3.54760E 00	1.43076E 01	LARGE ENG. NO. 4
21	2.87744E 03	1.15080E 04	2.33874E 01	4.07784E 00	1.23778E 01	LARGE ENG. NO. 5
22	2.13174E 03	1.41808E 04	3.21420E 01	4.70050E 00	1.77105E 01	LARGE ENG. NO. 5
23	2.13174E 03	2.15770E 04	3.21420E 01	4.70050E 00	1.77105E 01	LARGE ENG. NO. 5
24	2.80044E 03	1.75620E 04	2.37014E 01	4.28480E 00	1.37328E 01	LARGE ENG. NO. 5
25	4.12801E 03	4.32508E 04	8.97230E 01	5.65420E 00	2.31842E 01	LARGE ENG. NO. 5
26	4.12801E 03	4.32508E 04	8.97230E 01	5.65420E 00	2.31842E 01	LARGE ENG. NO. 5
27	2.13174E 03	2.07114E 04	7.00002E 00	3.48800E 00	5.70740E 00	LARGE ENG. NO. 6
28	2.43017E 03	4.40414E 04	1.40063E 01	4.41408E 00	4.70405E 00	LARGE ENG. NO. 6
29	2.43017E 03	1.46384E 04	3.07863E 01	4.27787E 00	1.40674E 01	LARGE ENG. NO. 6
30	2.46011E 03	1.88160E 04	3.07863E 01	4.27787E 00	1.40674E 01	LARGE ENG. NO. 6
31	4.07770E 03	2.10385E 04	3.68004E 01	4.18117E 00	1.22511E 01	LARGE ENG. NO. 6
32	4.10774E 03	2.47557E 04	4.07417E 01	4.32402E 00	1.77660E 01	LARGE ENG. NO. 6
33	2.77844E 03	1.33344E 04	3.22387E 01	4.34751E 00	1.38375E 01	LARGE ENG. NO. 6

TABLE XXXVIII. CALCULATED RING SEAL CHARACTERISTICS

RING SEAL CHARACTERISTICS

ROW	RUB VEL	PV VALUE	AC AREA	AD AREA	PRESS. FORCE BACK TO BACK	ROW TITLE
1	2.498279E 02	5.466831E 03	2.896007E-01	5.079141E-02	0.0	SMALL ENG. NO. 2
2	1.705761E 02	1.480403E 04	7.390543E-01	3.928815E-01	0.0	LARGE ENG. NO. 1
3	1.752048E 02	1.252645E 04	5.082959E-01	1.952340E-01	0.0	LARGE ENG. NO. 2
4	1.753600E 02	2.729679E 03	5.452097E-01	1.449969E-01	0.0	LARGE ENG. NO. 2
5	1.753600E 02	2.729679E 03	5.452097E-01	1.449969E-01	2.714411E 00	LARGE ENG. NO. 2
6	1.313712E 02	2.476052E 03	1.314415E 00	7.915779E-01	0.0	LARGE ENG. NO. 3
7	2.254237E 02	9.242371E 03	5.904741E-01	3.133512E-01	0.0	LARGE ENG. NO. 4
8	1.561329E 02	7.133724E 03	3.928747E-01	5.882444E-01	5.097431E 00	LARGE ENG. NO. 4
9	2.091508E 02	1.024893E 04	6.033964E-01	5.323676E-01	2.042210E 01	LARGE ENG. NO. 5

ROW	NET FORCE BACK TO BACK	PRESS. FORCE TRIPLE	NET FORCE TRIPLE	NET FORCE SINGLE	FACE WIDTH	ROW TITLE
1	0.0	0.0	0.0	4.317499E 00	2.600017E-02	SMALL ENG. NO. 2
2	0.0	2.442954E 01	5.482954E 01	0.0	4.800070E-02	LARGE ENG. NO. 1
3	0.0	1.089274E 01	2.039273E 01	0.0	4.199982E-02	LARGE ENG. NO. 2
4	0.0	0.0	0.0	5.429923E 00	3.800011E-02	LARGE ENG. NO. 2
5	4.714411E 00	0.0	0.0	0.0	3.800011E-02	LARGE ENG. NO. 2
6	0.0	0.0	0.0	2.752881E 01	5.200000E-02	LARGE ENG. NO. 3
7	0.0	9.317370E 00	2.031737E 01	0.0	4.600000E-02	LARGE ENG. NO. 4
8	1.259743E 01	0.0	0.0	0.0	3.500032E-02	LARGE ENG. NO. 4
9	3.842210E 01	0.0	0.0	0.0	3.200006E-02	LARGE ENG. NO. 5

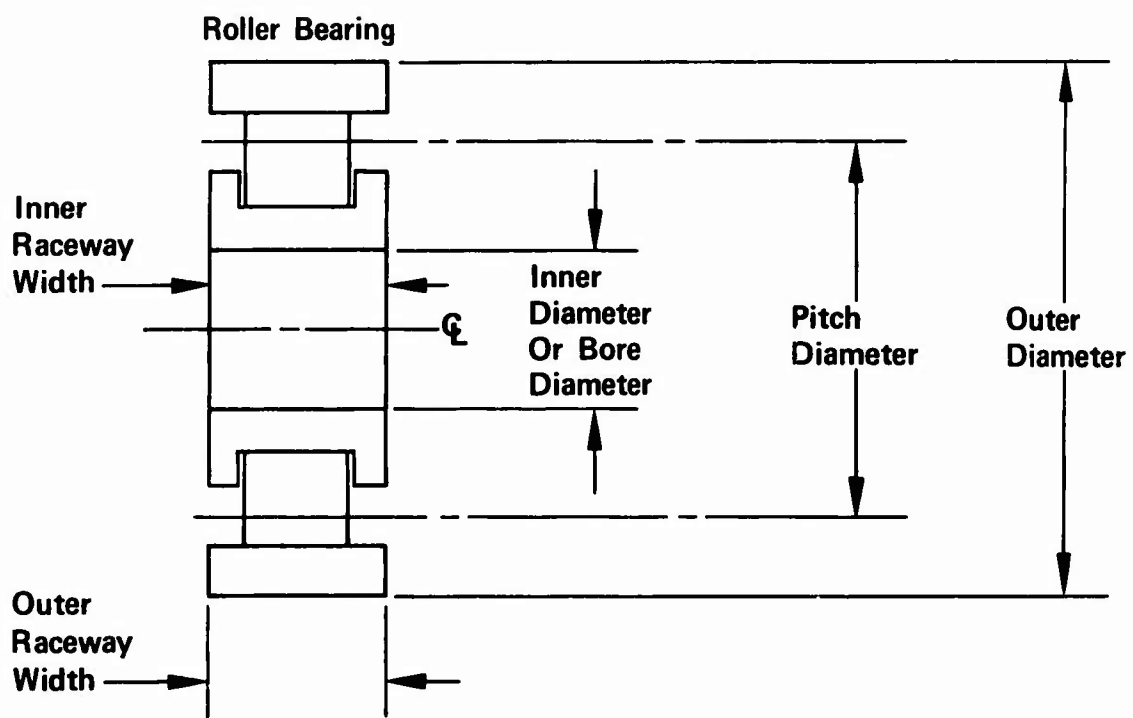


Figure 1. External Roller Bearing Geometry.

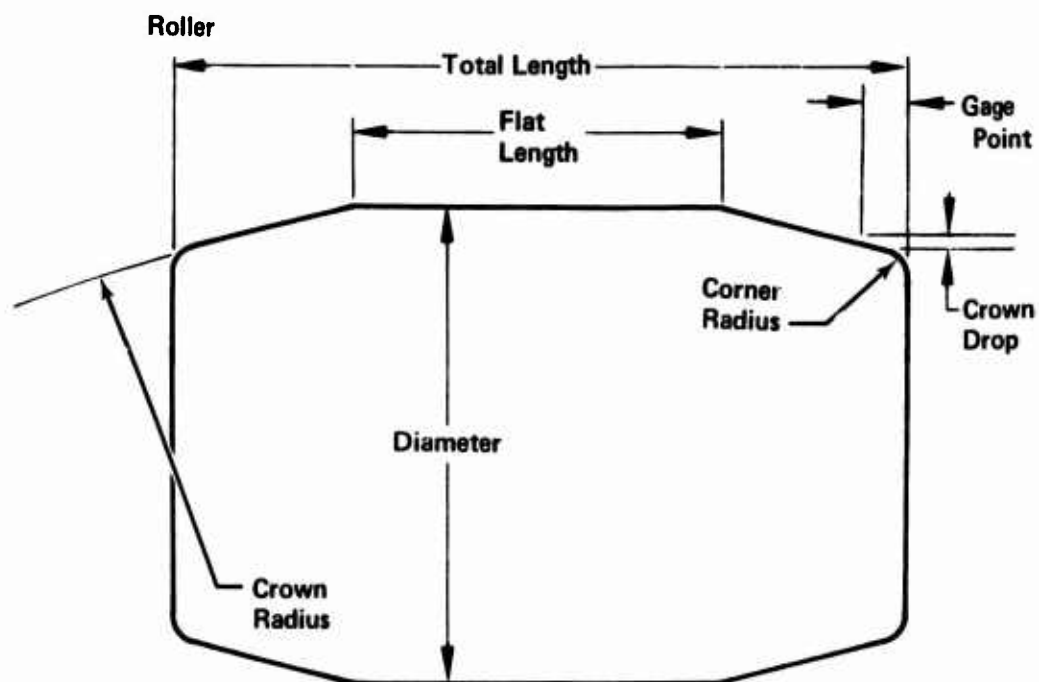


Figure 2. Roller Element Geometry.

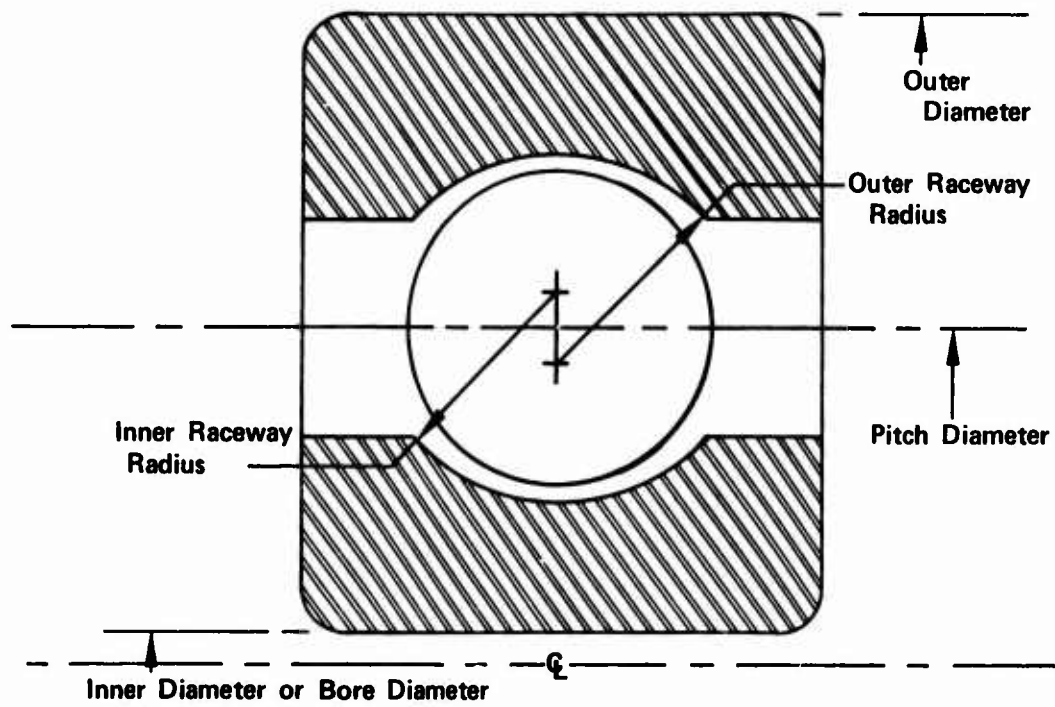


Figure 3. Ball Bearing Geometry.

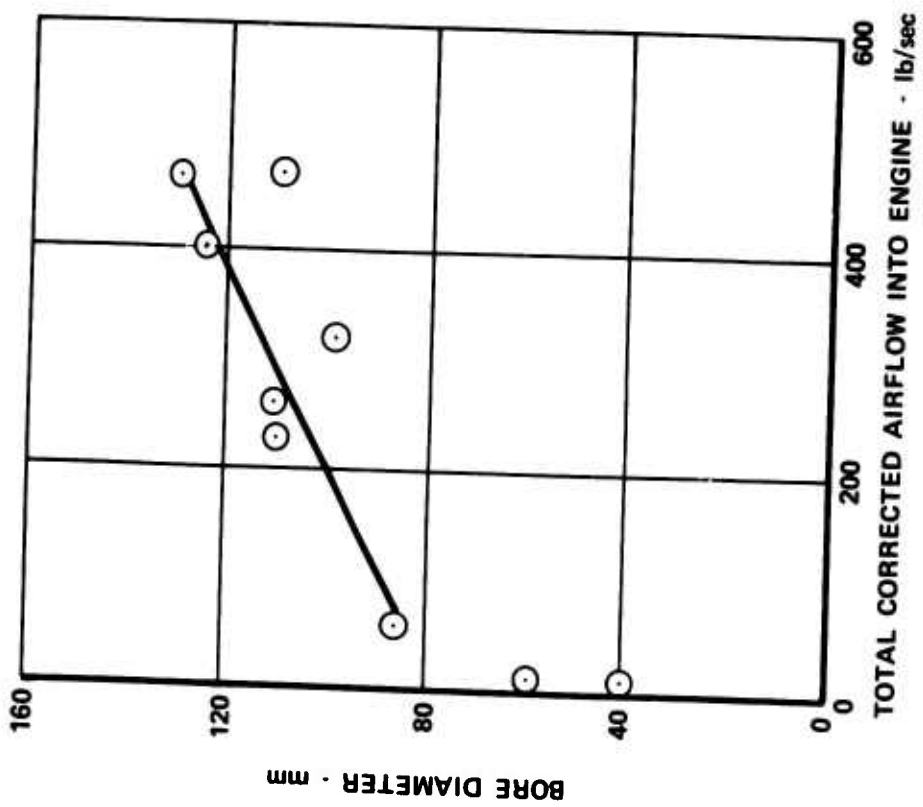


Figure 4. Low Rotor Ball Bearings at Sea Level Takeoff; Bore Diameter vs Total Corrected Airflow Into Engine.

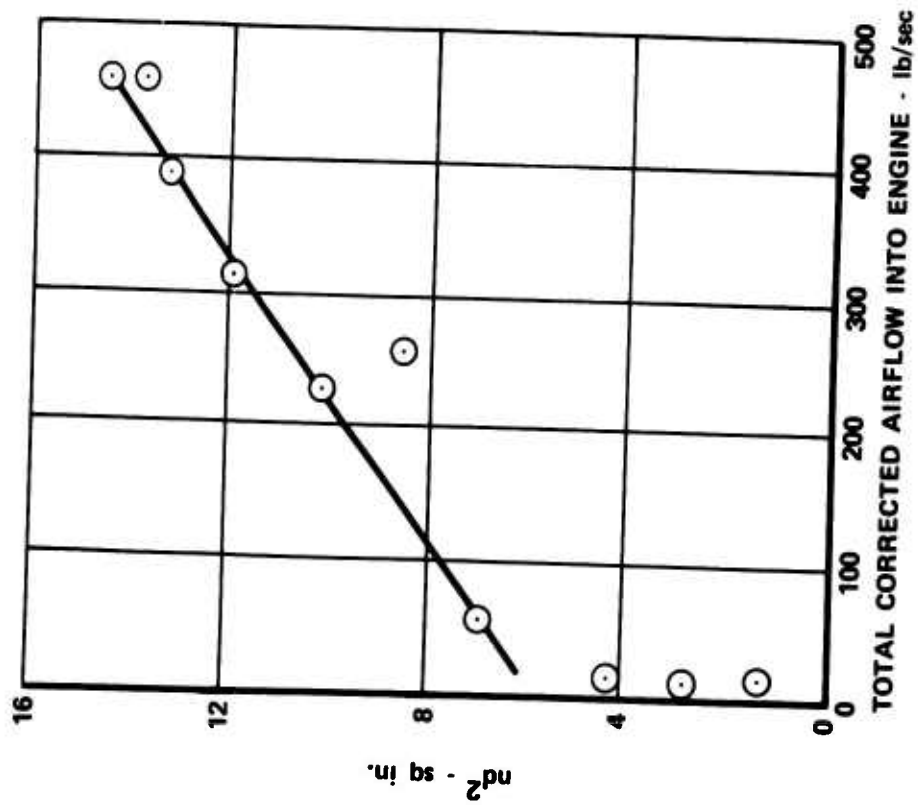


Figure 5. Low Rotor Ball Bearings at Sea Level Takeoff; nd^2 vs Total Corrected Airflow Into Engine.

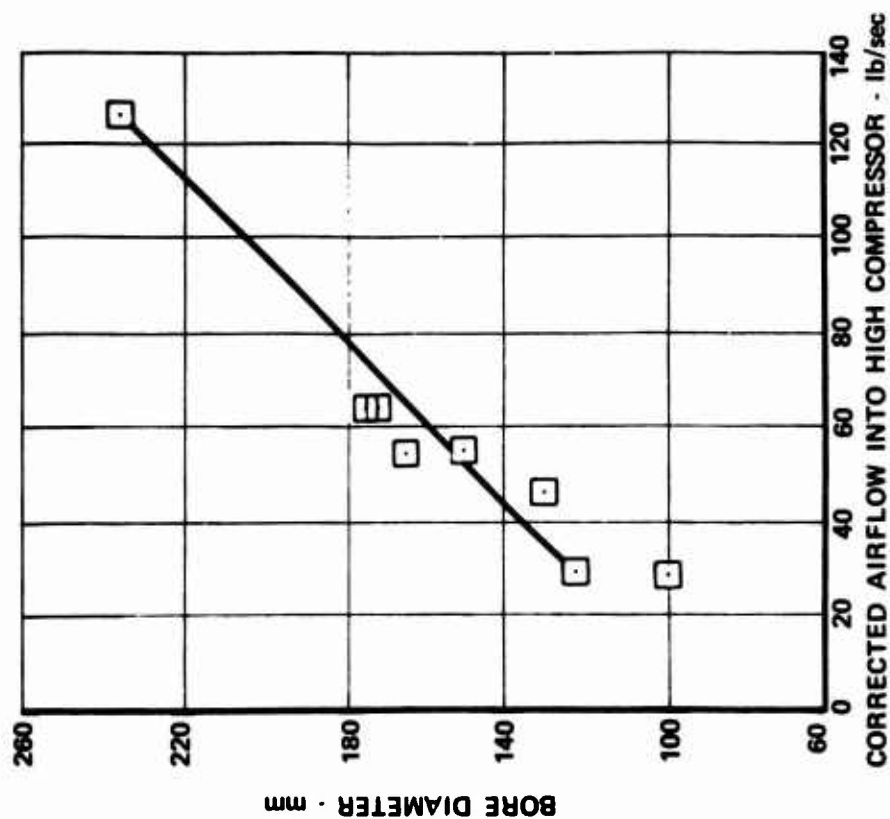


Figure 6. High Rotor Roller Bearings at Sea Level Takeoff; Bearing Bore Diameter vs Corrected Airflow Into High Compressor.

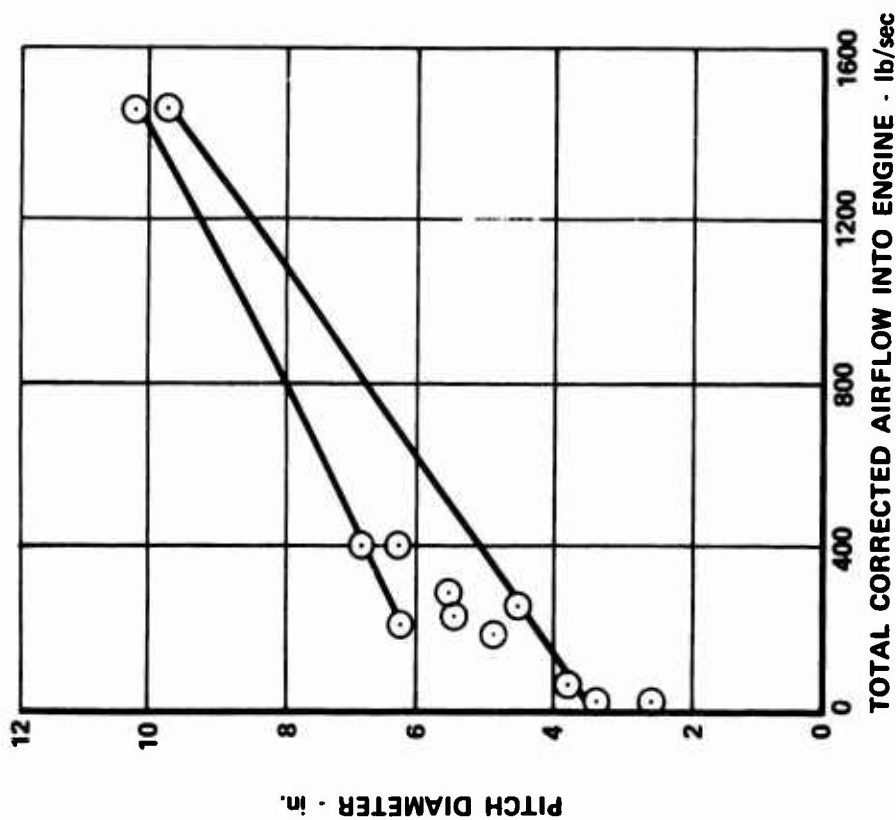


Figure 7. Low Rotor Seals at Sea Level Takeoff; Seal Pitch Diameter vs Total Corrected Airflow Into Engine.

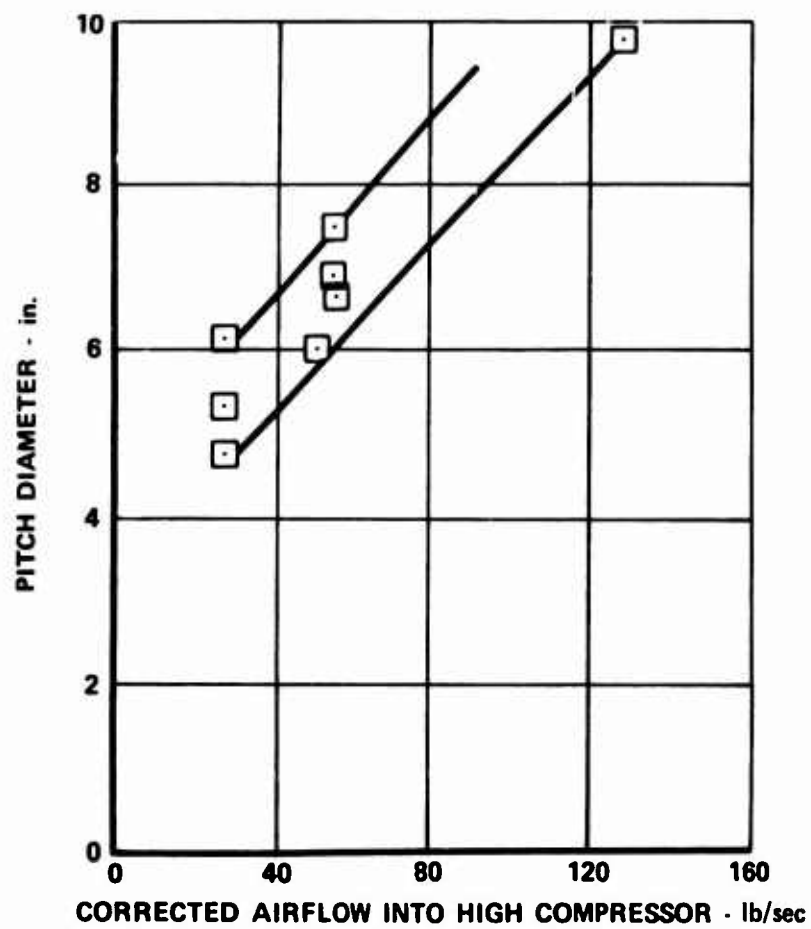


Figure 8. High Rotor Seals at Sea Level Takeoff; Seal Pitch Diameter vs Corrected Airflow Into High Compressor.

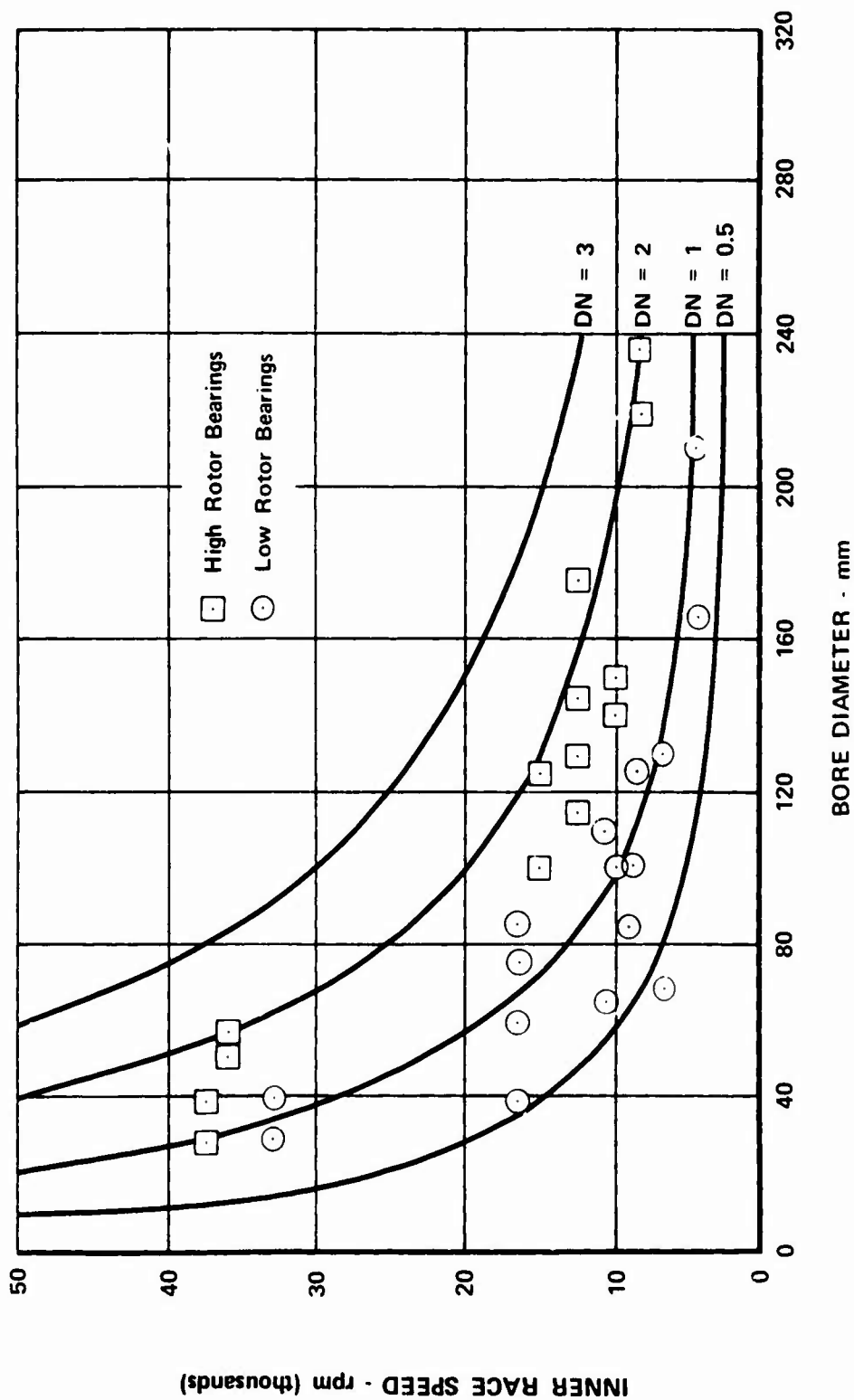


Figure 9. High and Low Rotor Bearings at Sea Level Takeoff; Inner Race Speed vs Bore Diameter.

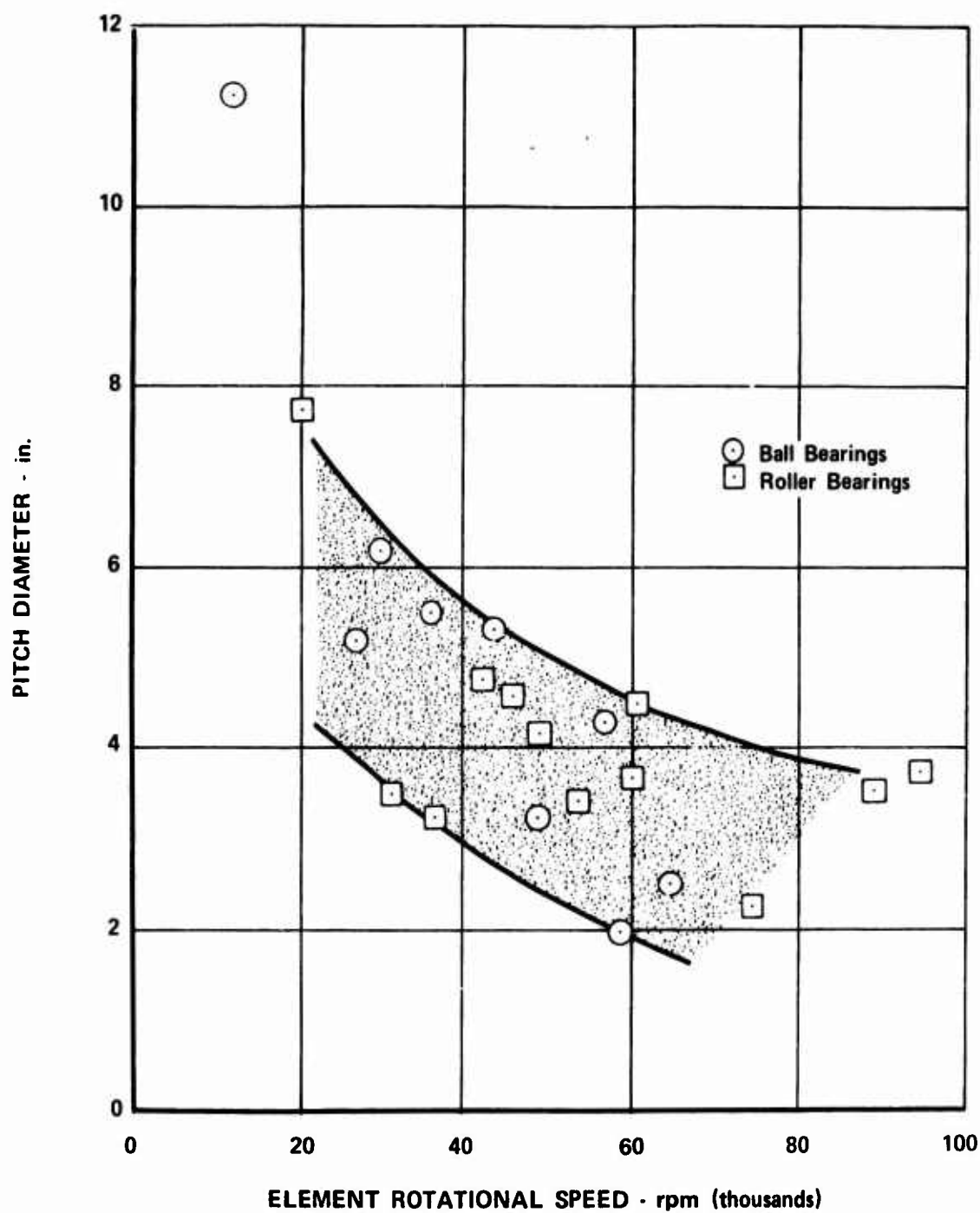


Figure 10. Low Rotor Bearings at Sea Level Takeoff; Pitch Diameter vs Element Rotational Speed.

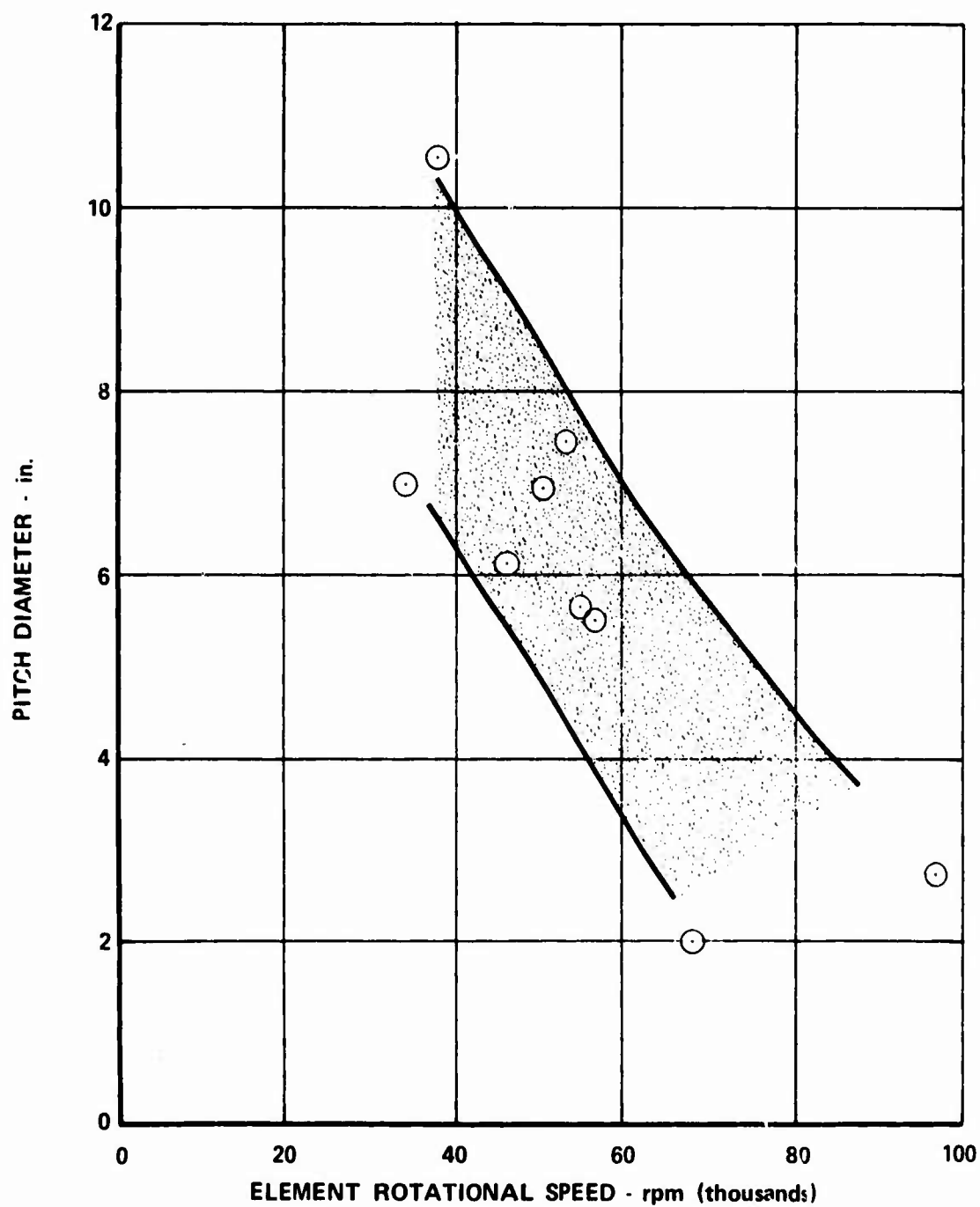


Figure 11. High Rotor Ball Bearings at Sea Level Takeoff; Pitch Diameter vs Element Rotational Speed.

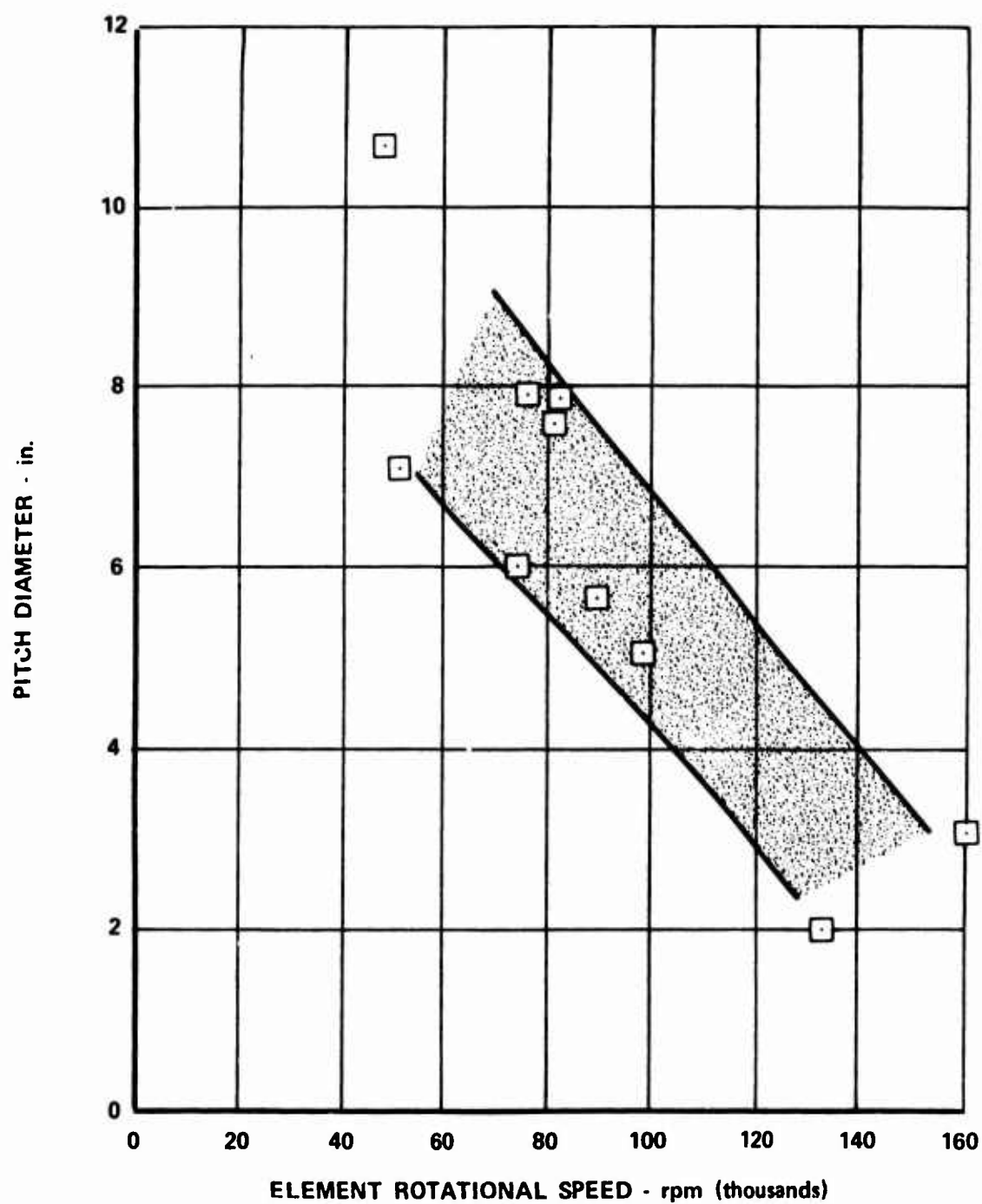


Figure 12. High Rotor Roller Bearings at Sea Level Takeoff; Pitch Diameter vs Element Rotational Speed.

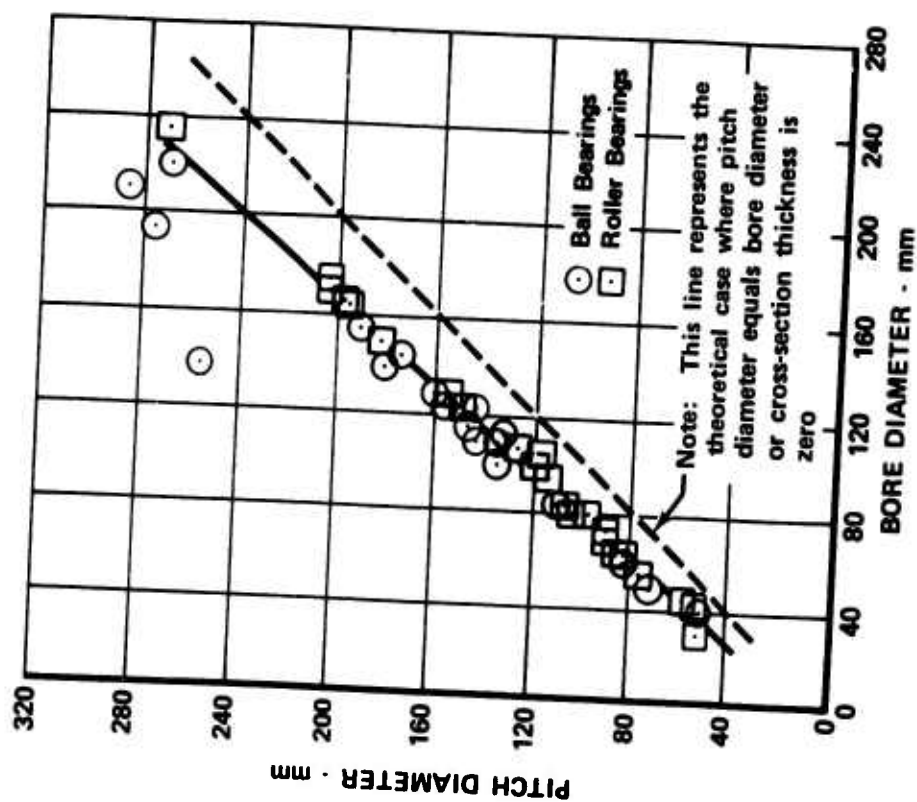


Figure 13. High and Low Rotor Bearings; Pitch Diameter vs Bore Diameter.

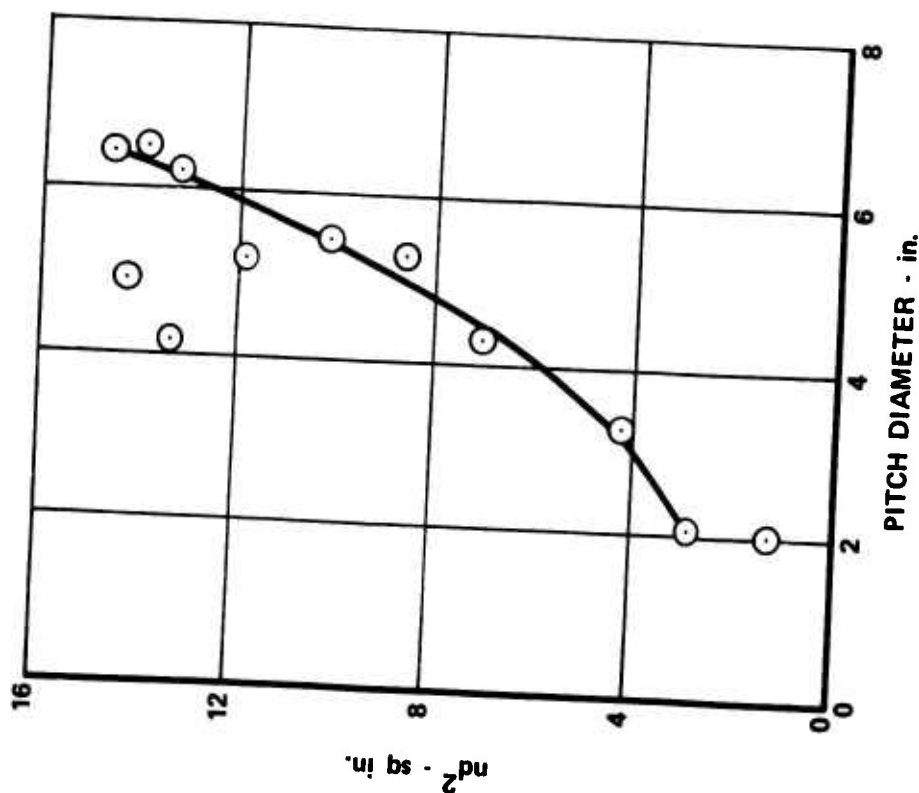


Figure 14. Low Rotor Ball Bearings; nd2 vs Pitch Diameter.

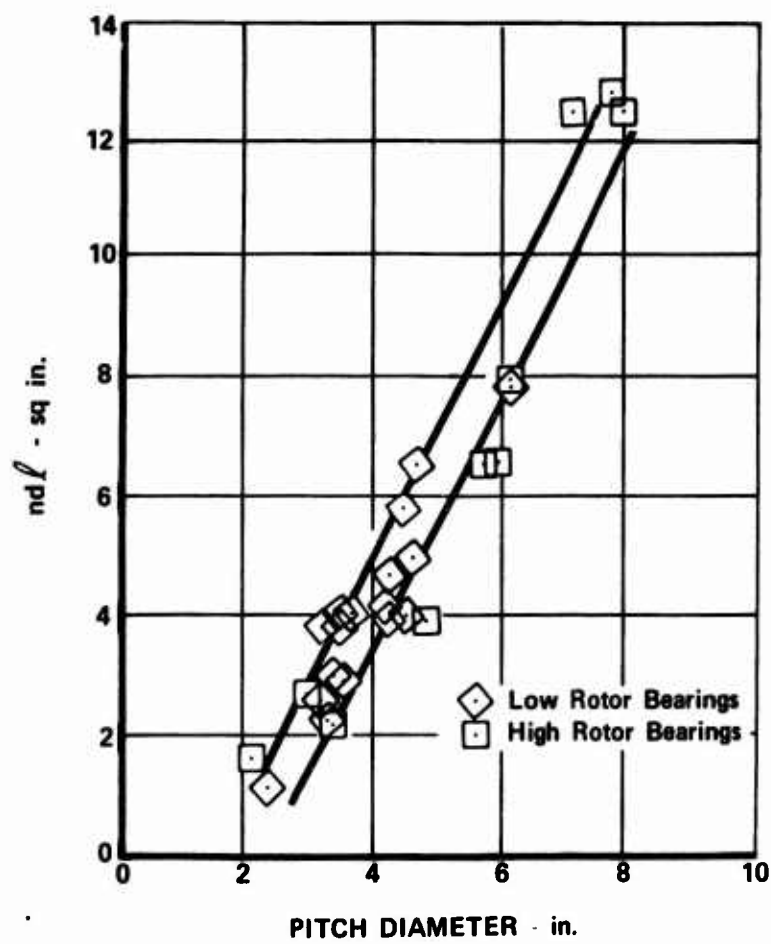


Figure 15. High and Low Rotor Roller Bearings; $nd\ell$ vs Pitch Diameter.

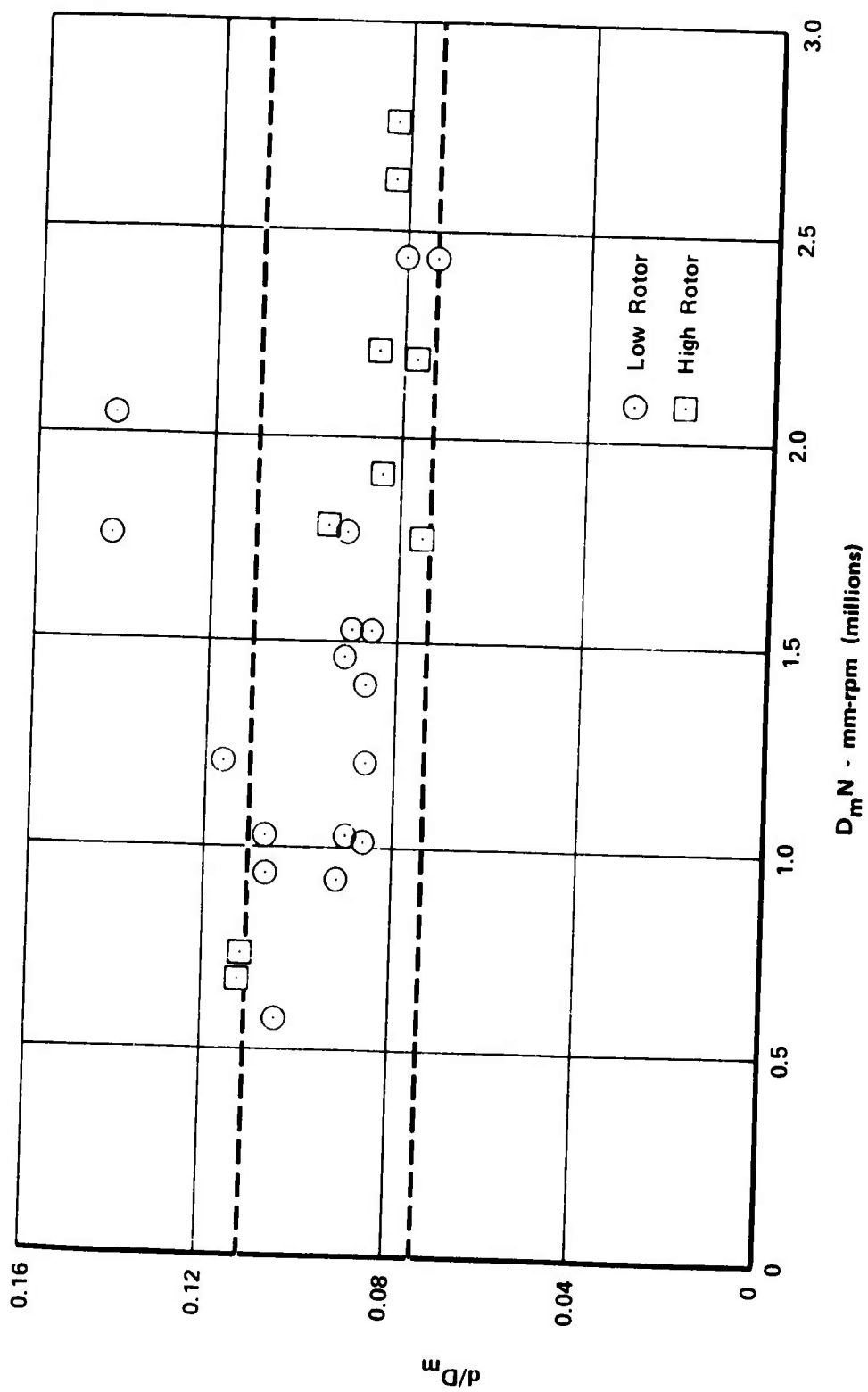


Figure 16. High and Low Rotor Roller Bearings at Sea Level Takeoff; Roller Diameter/Pitch Diameter vs Product of Pitch Diameter and Shaft Speed.

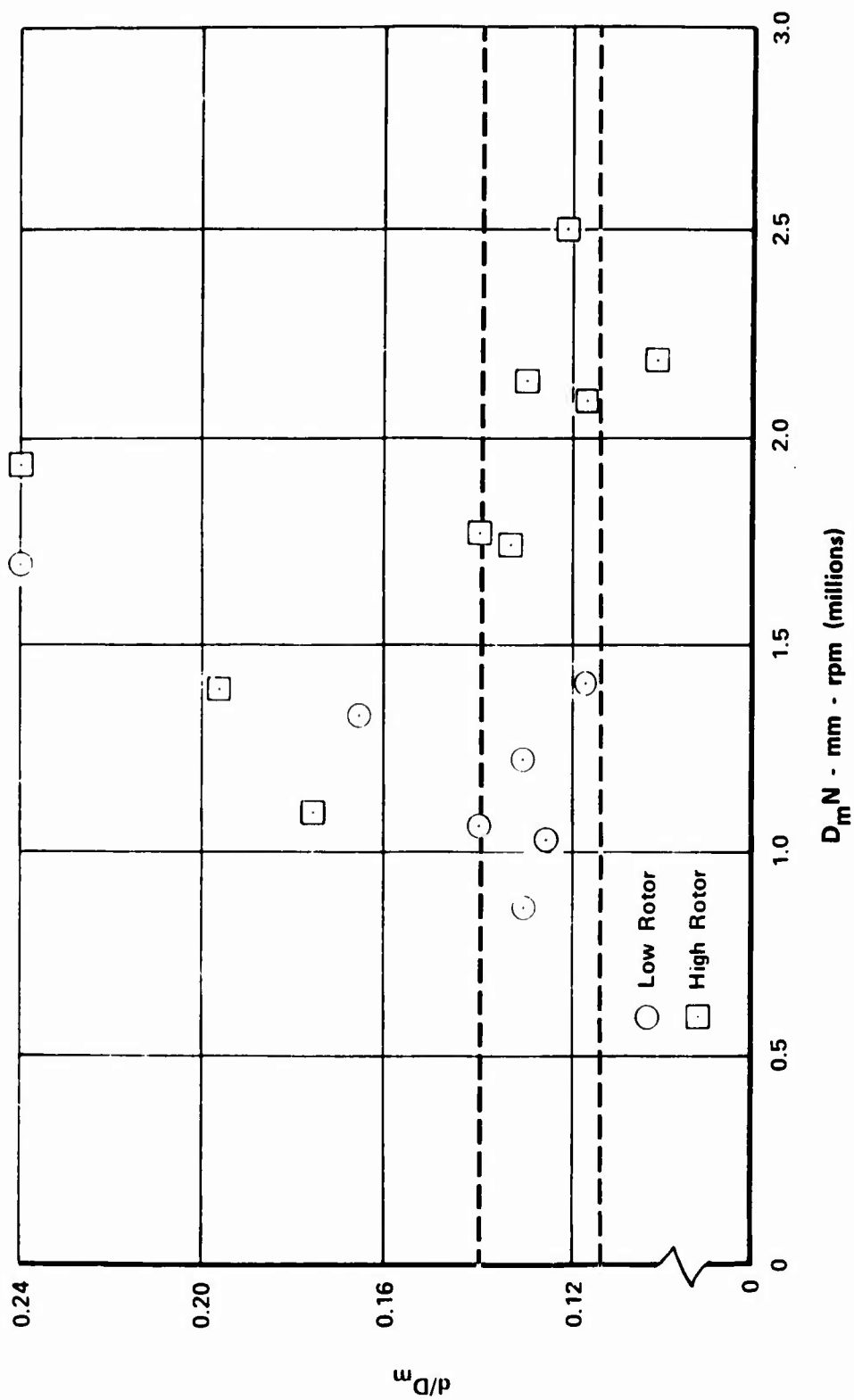


Figure 17. High and Low Rotor Ball Bearings at Sea Level Takeoff; Ball Diameter/Pitch Diameter vs Product of Pitch Diameter and Shaft Speed.

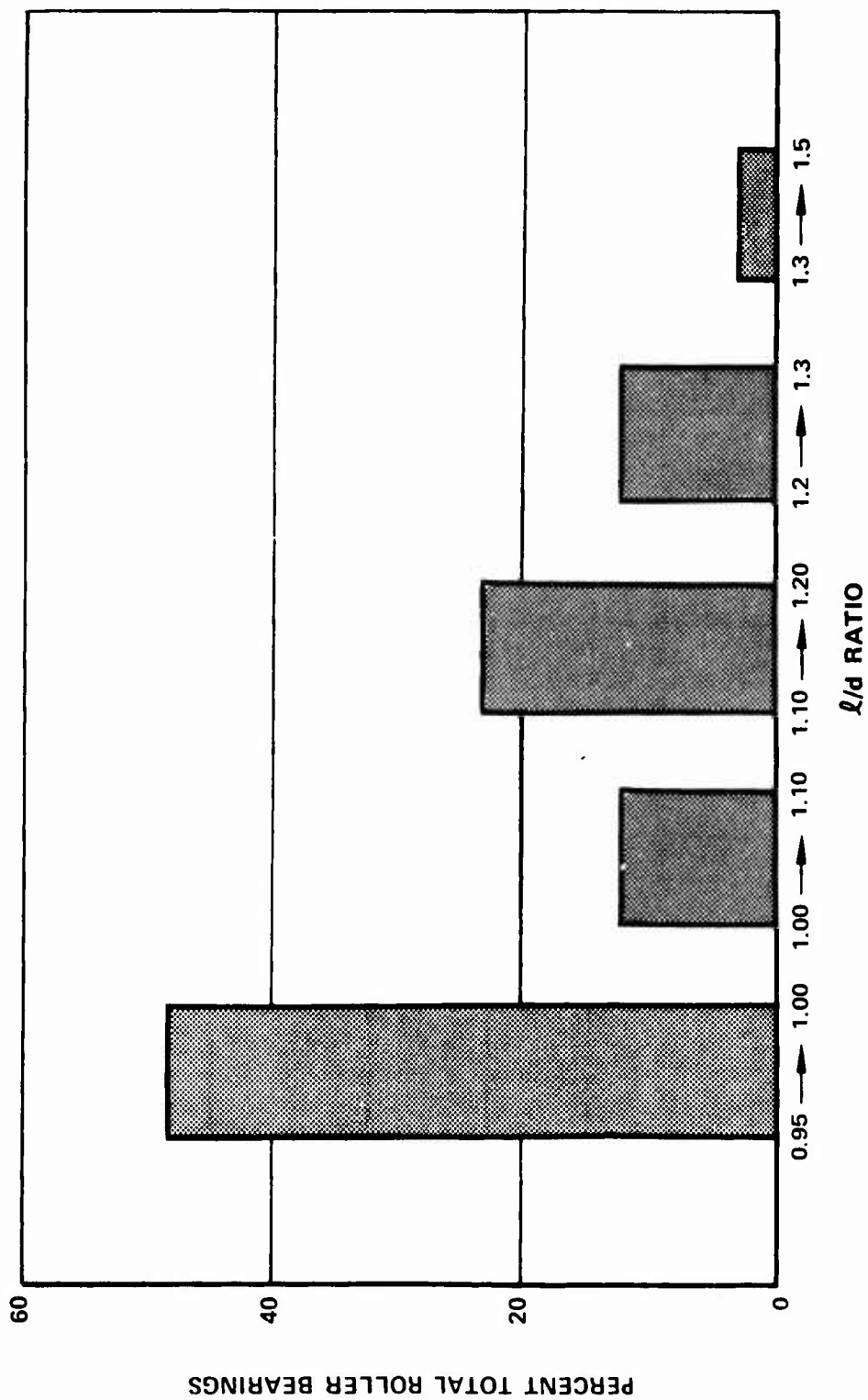


Figure 18. High and Low Rotor Roller Bearings; Percent Total Roller Bearings vs L/D Ratio.

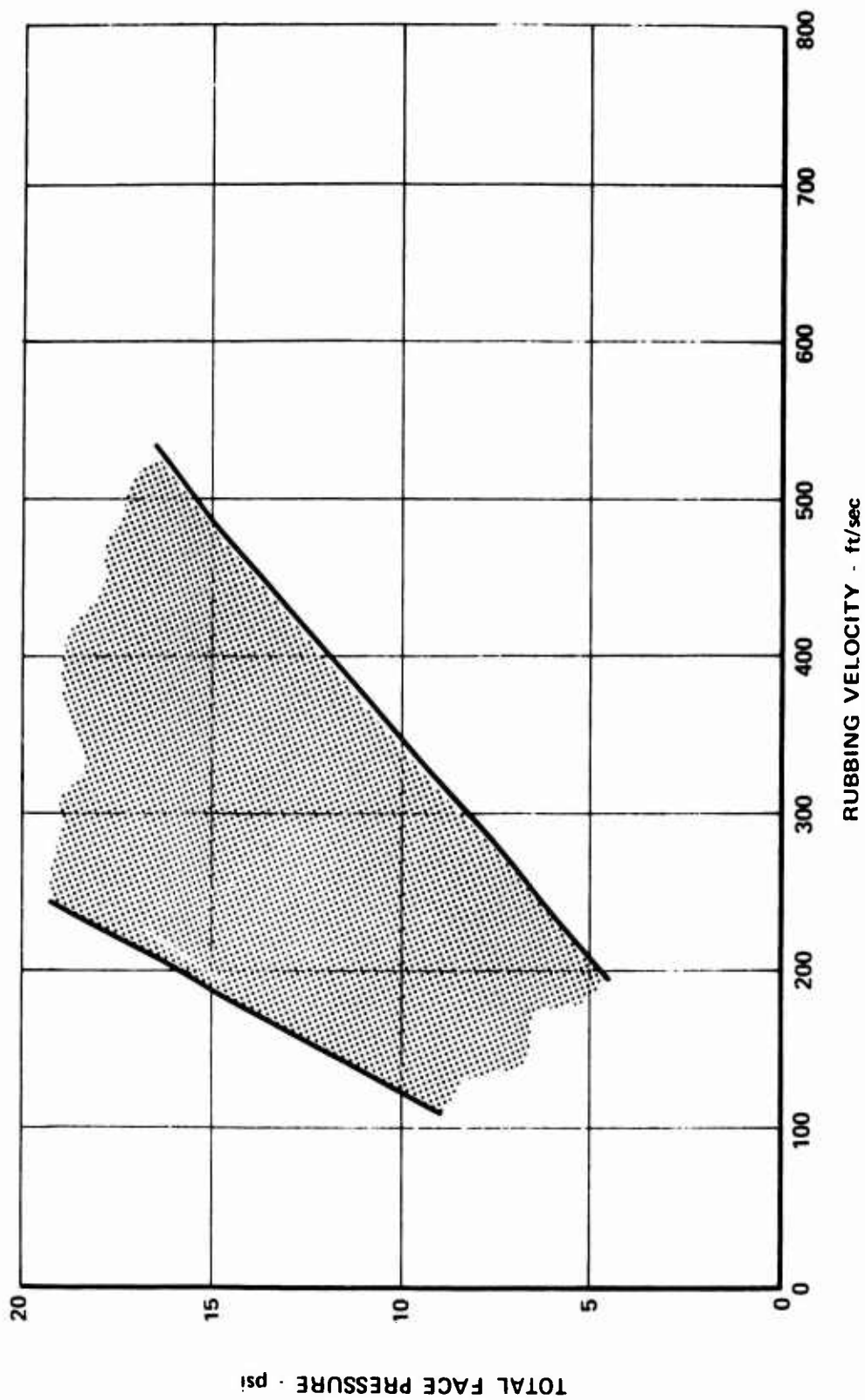


Figure 19. High and Low Rotor Seals at Sea Level Takeoff; Total Face Pressure vs Rubbing Velocity.

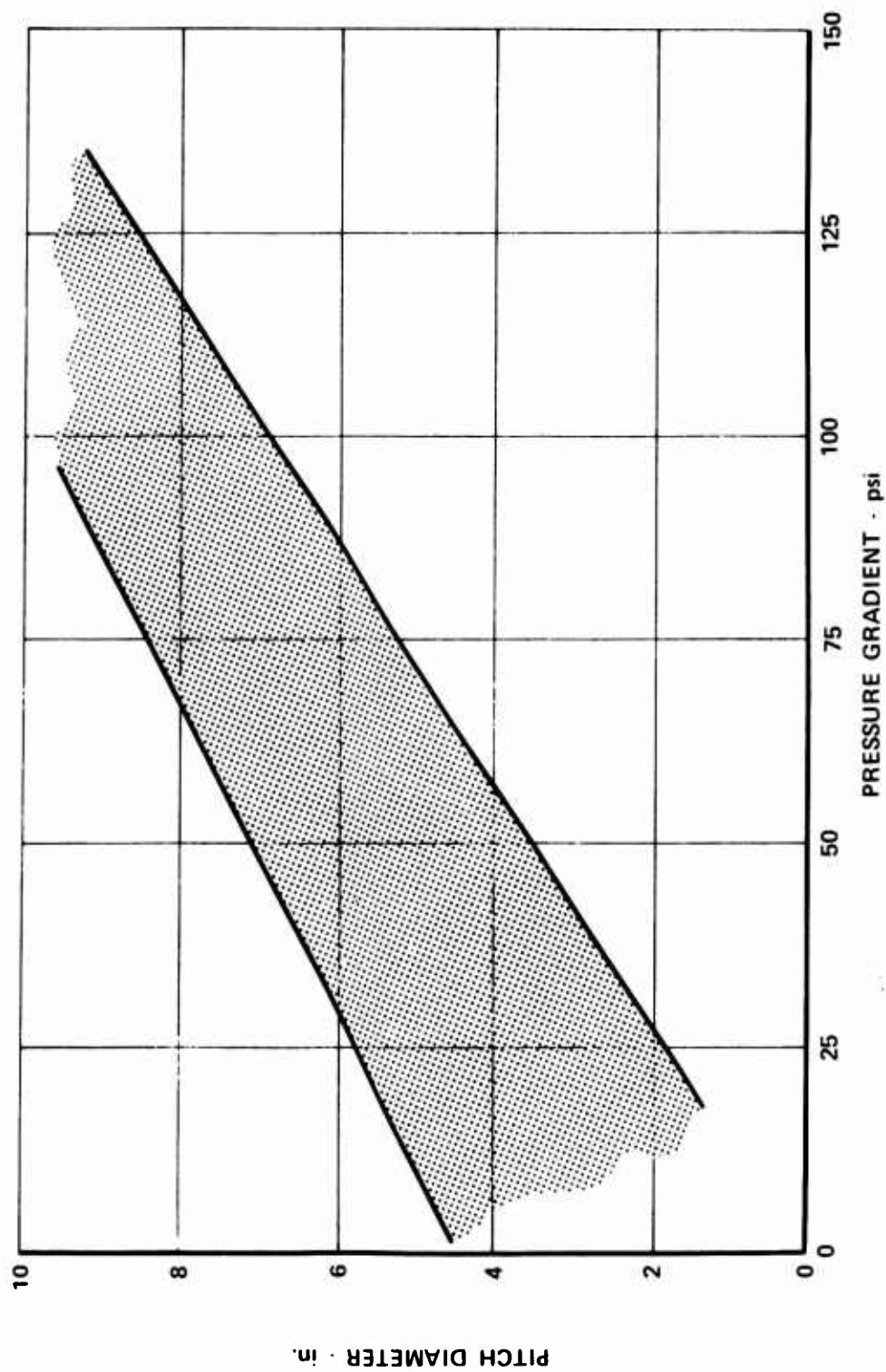


Figure 20. High and Low Rotor Seals at Sea Level Takeoff; Pitch Diameter vs Pressure Gradient.

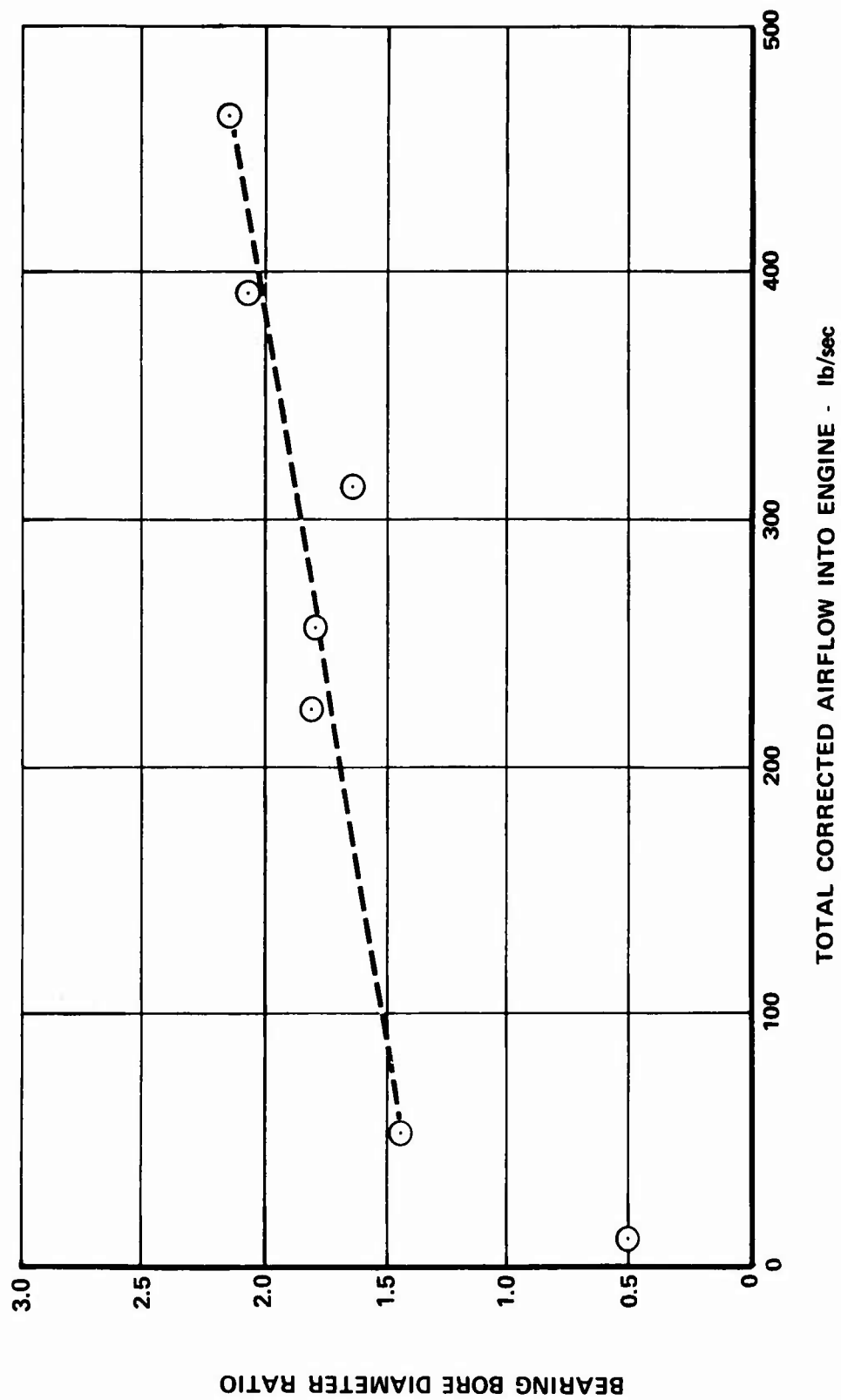


Figure 21. Low Rotor Ball Bearings at Sea Level Takeoff; Bearing Bore Diameter Ratio vs Total Corrected Airflow Into Engine.

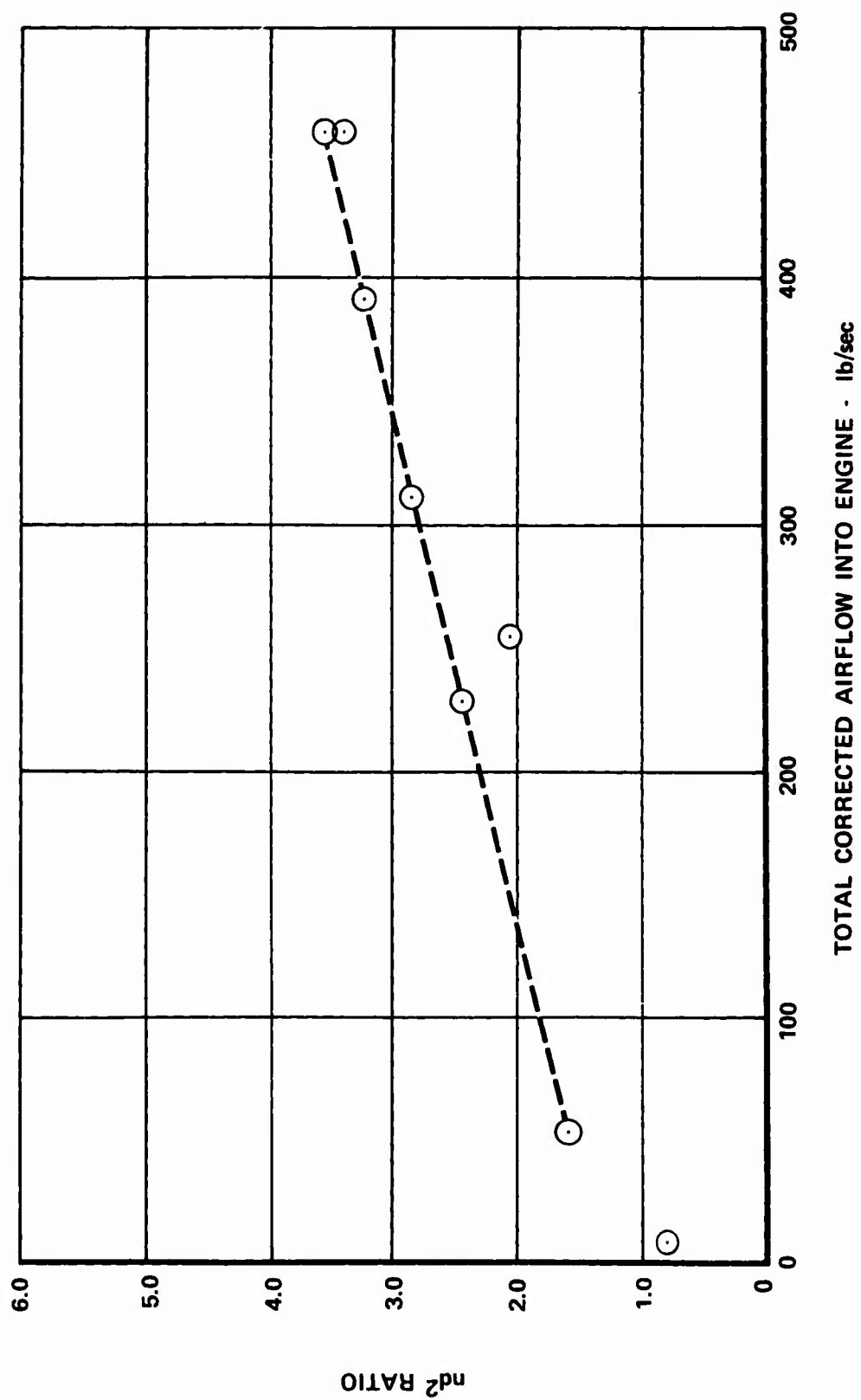


Figure 22. Low Rotor Ball Bearings at Sea Level Takeoff; nd^2 Ratio vs Total Corrected Airflow Into Engine.

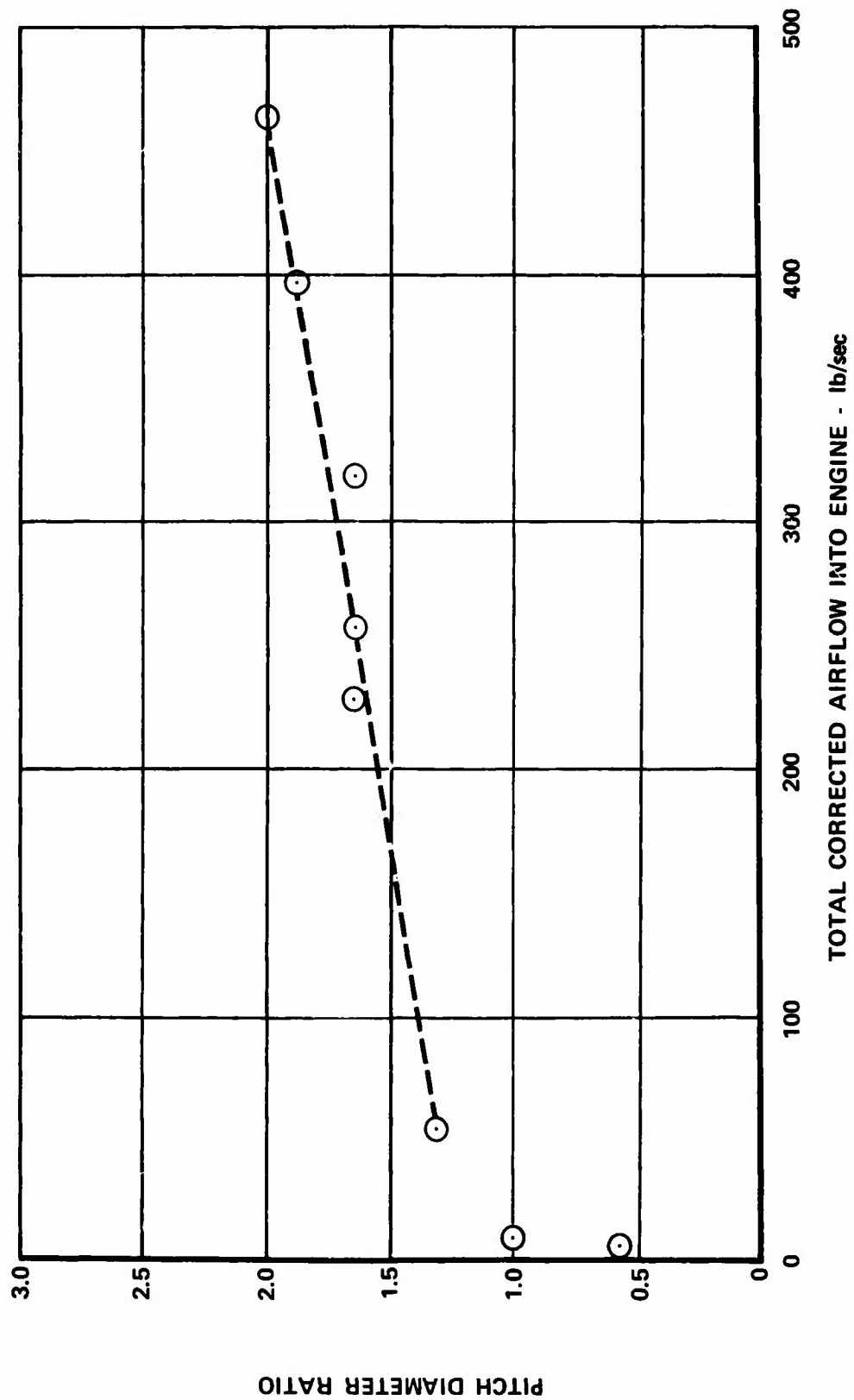


Figure 23. Low Rotor Ball Bearings at Sea Level Takeoff; Pitch Diameter Ratio vs Total Corrected Airflow Into Engine.

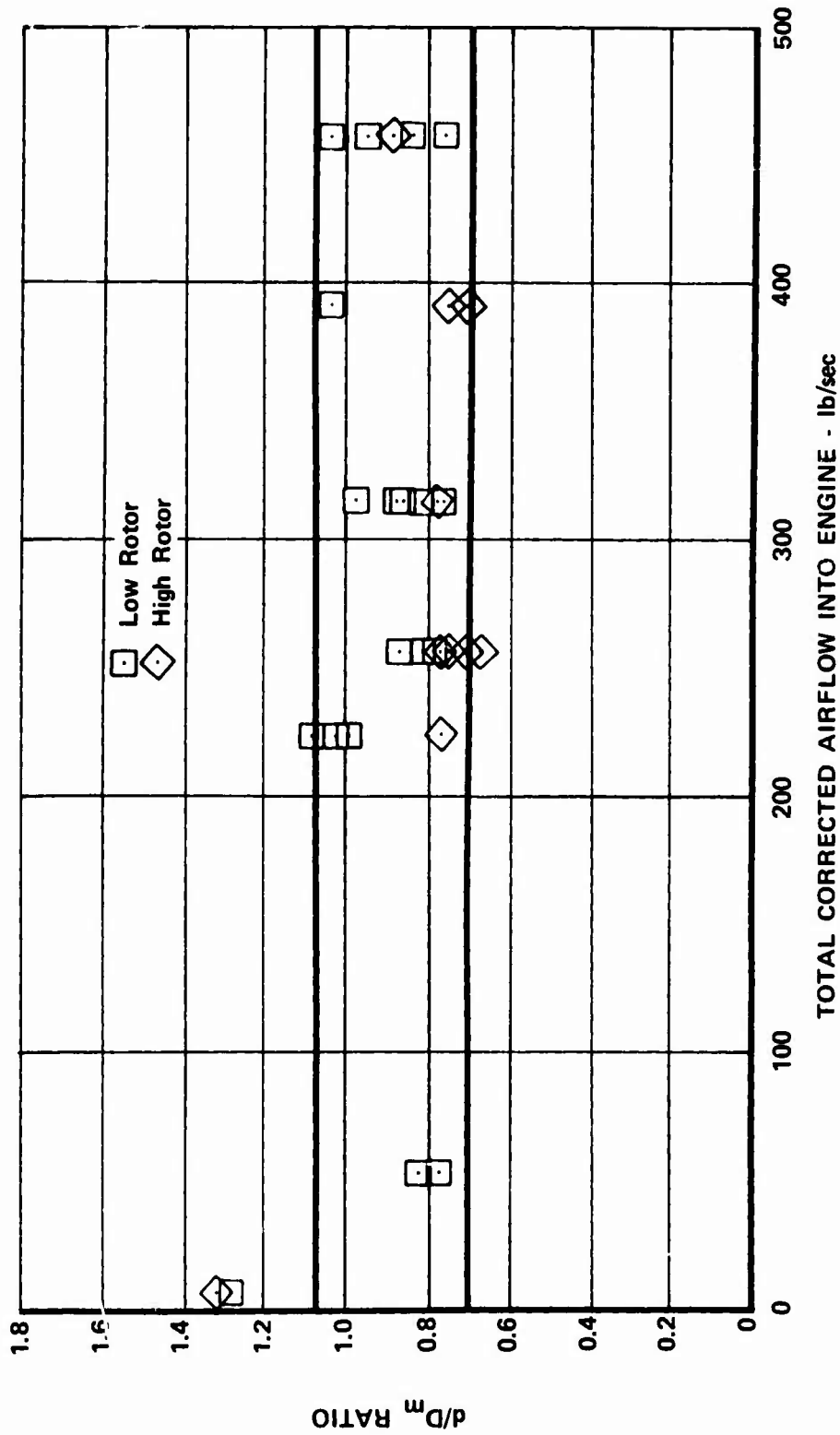


Figure 24. High and Low Rotor Roller Bearings at Sea Level Takeoff; d/D_m Ratio vs Total Corrected Airflow Into Engine.

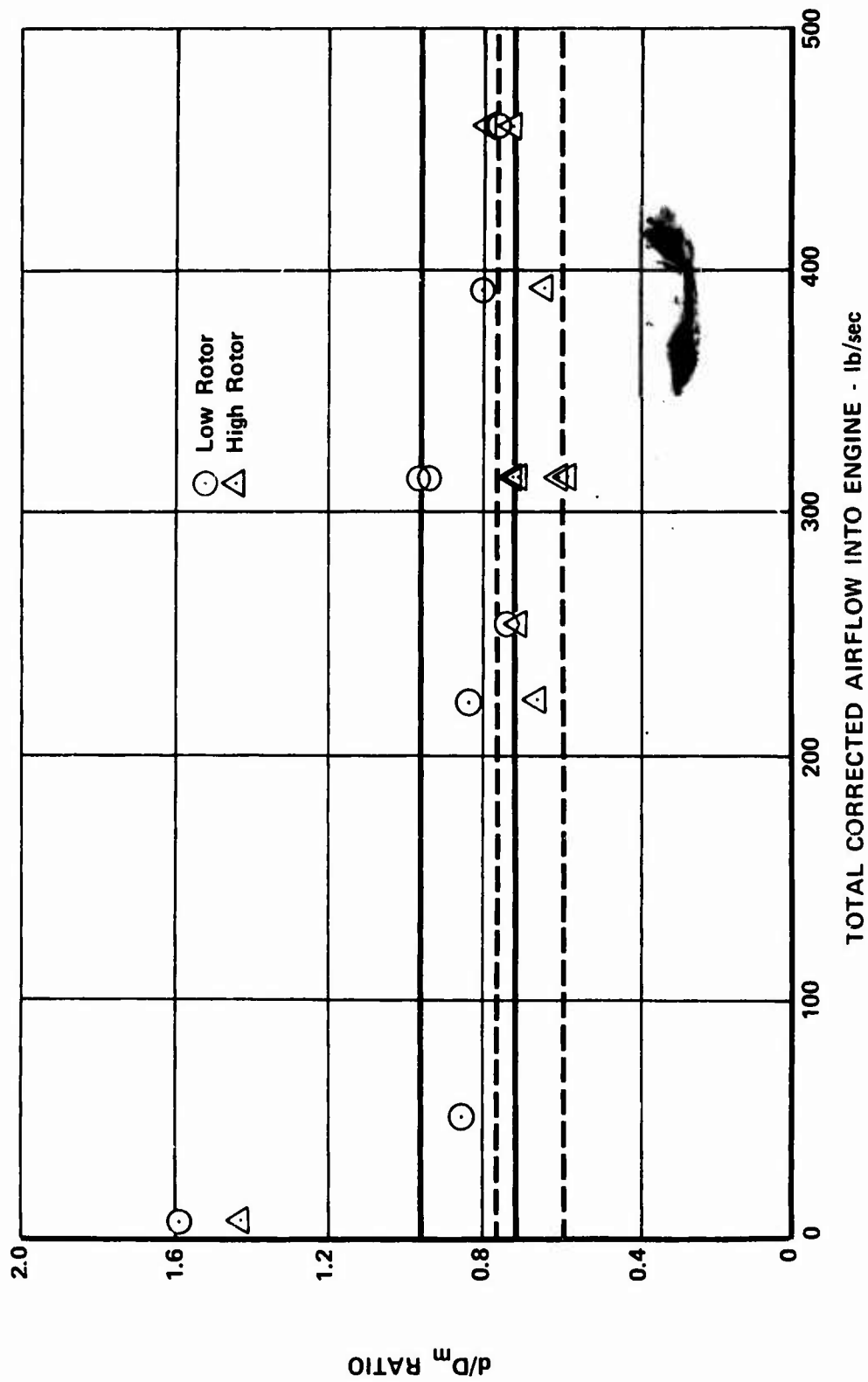


Figure 25. High and Low Rotor Ball Bearings at Sea Level Takeoff; d/D_m Ratio vs Total Corrected Airflow Into Engine.

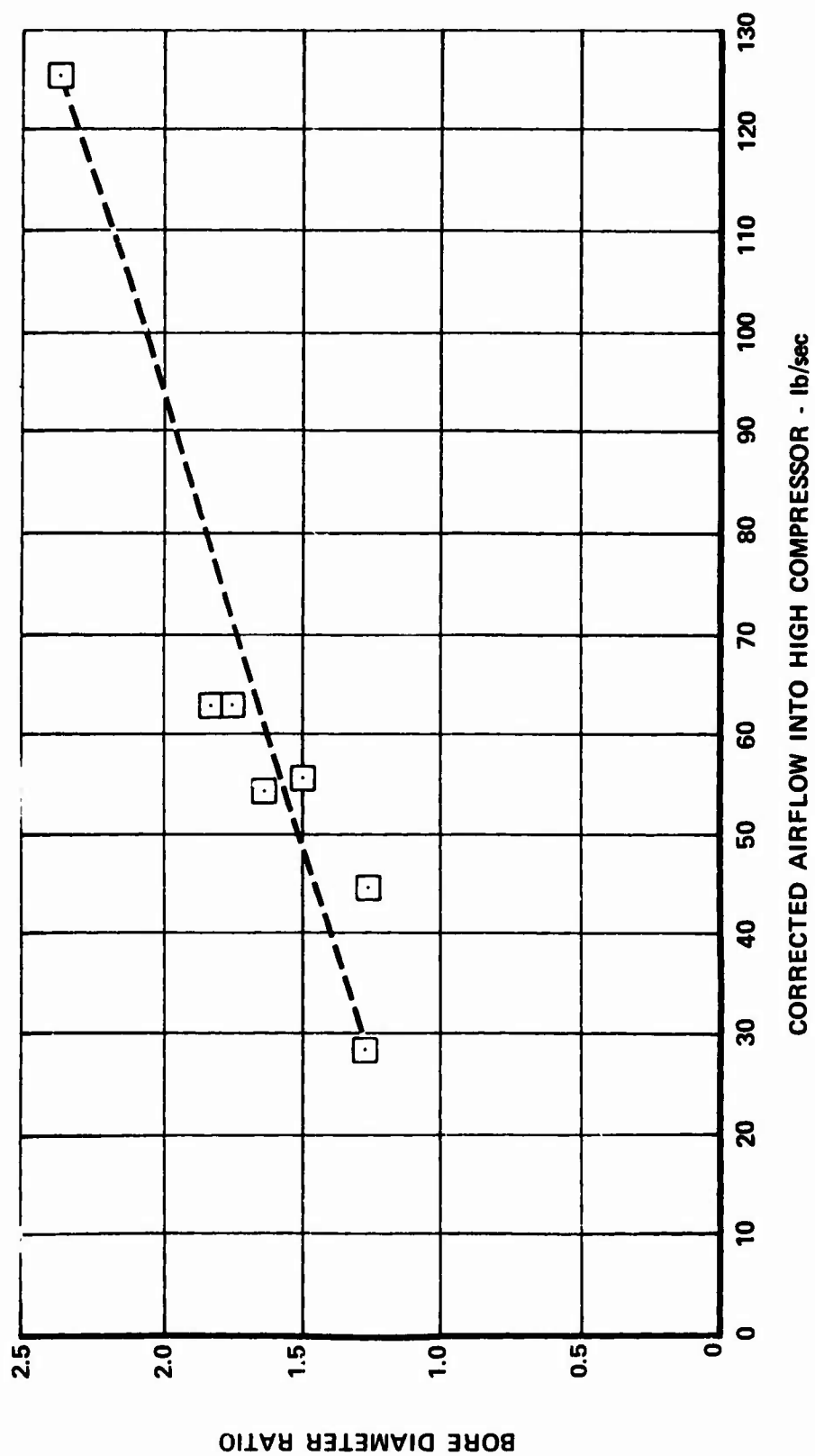


Figure 26. High Rotor Roller Bearings at Sea Level Takeoff; Bore Diameter Ratio vs Corrected Airflow Into High Compressor.

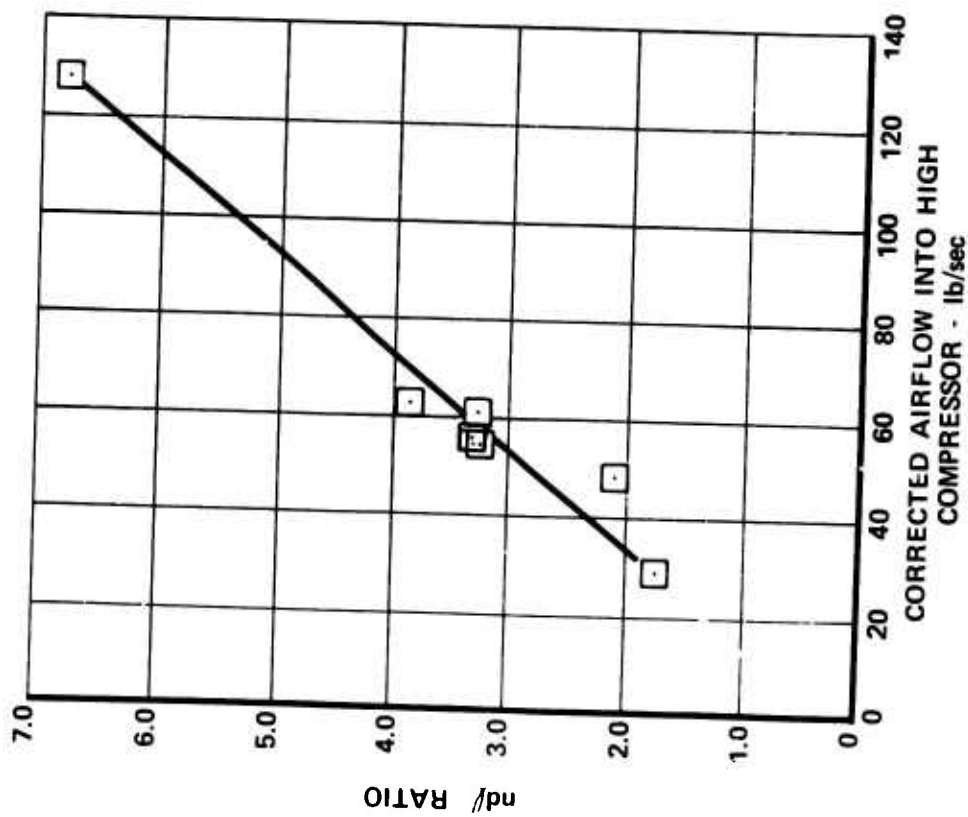


Figure 27. High Rotor Roller Bearings at Takeoff; nd/Ratio vs Corrected Airflow Into High Compressor.

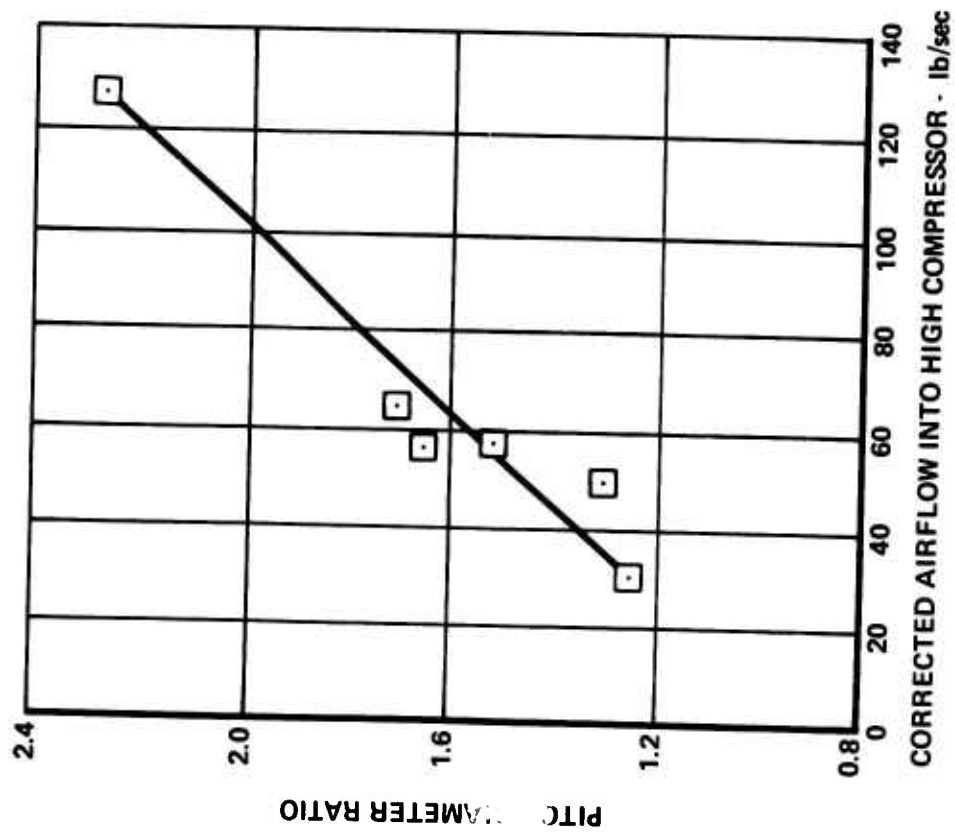


Figure 28. High Rotor Roller Bearings at Sea Level Takeoff; Pitch Diameter Ratio vs Corrected Airflow Into High Compressor.

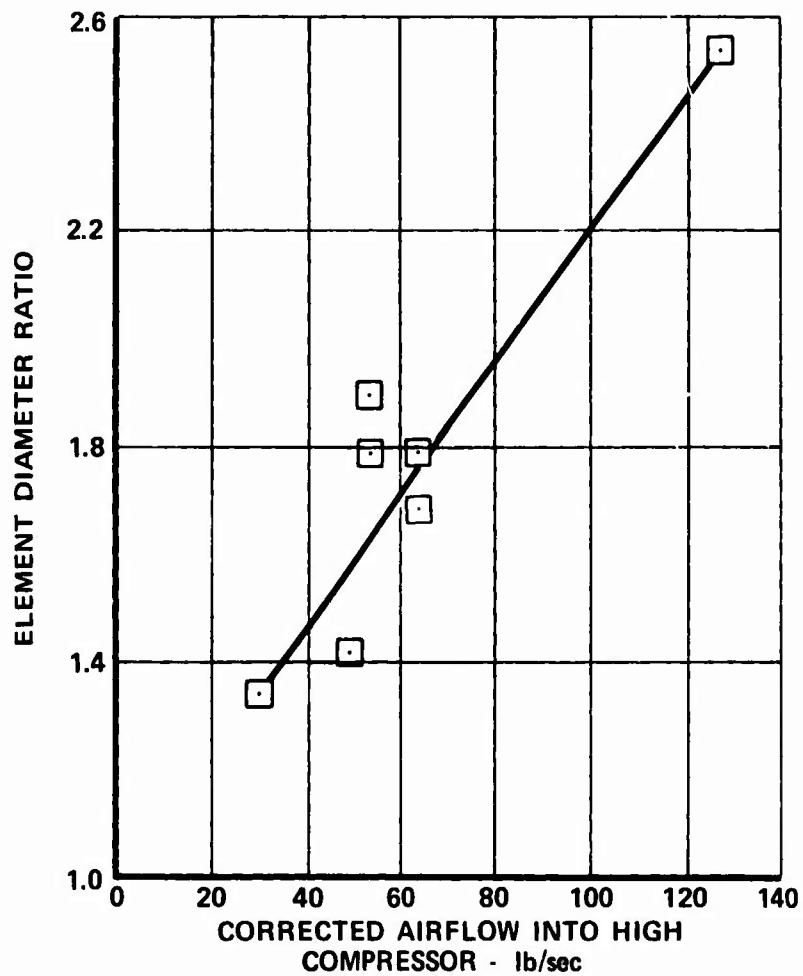


Figure 29. High Rotor Roller Bearings at Sea Level Takeoff; Element Diameter Ratio vs Corrected Airflow Into High Compressor.

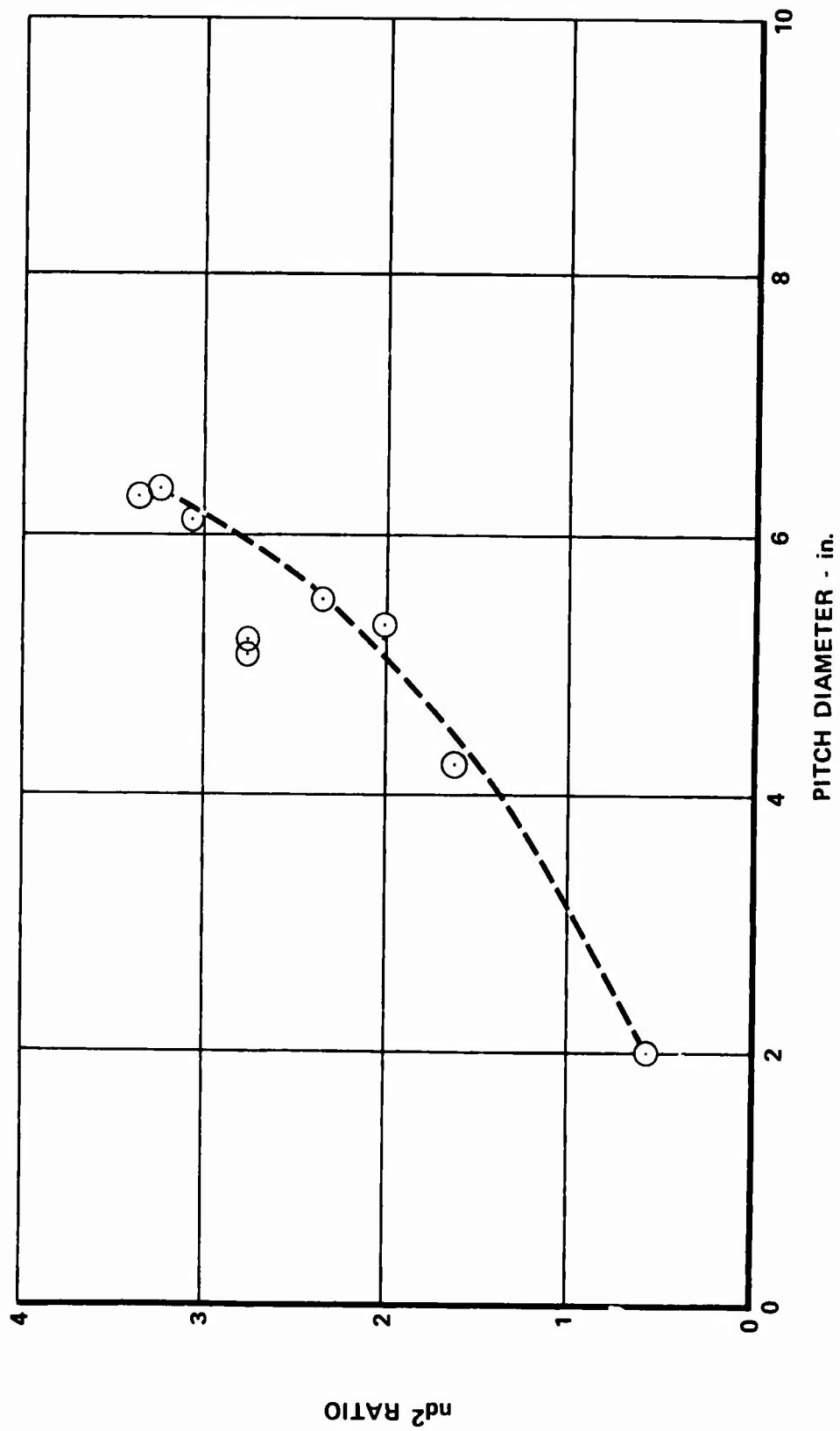


Figure 30. Low Rotor Ball Bearings; nd^2 Ratio vs Pitch Diameter.

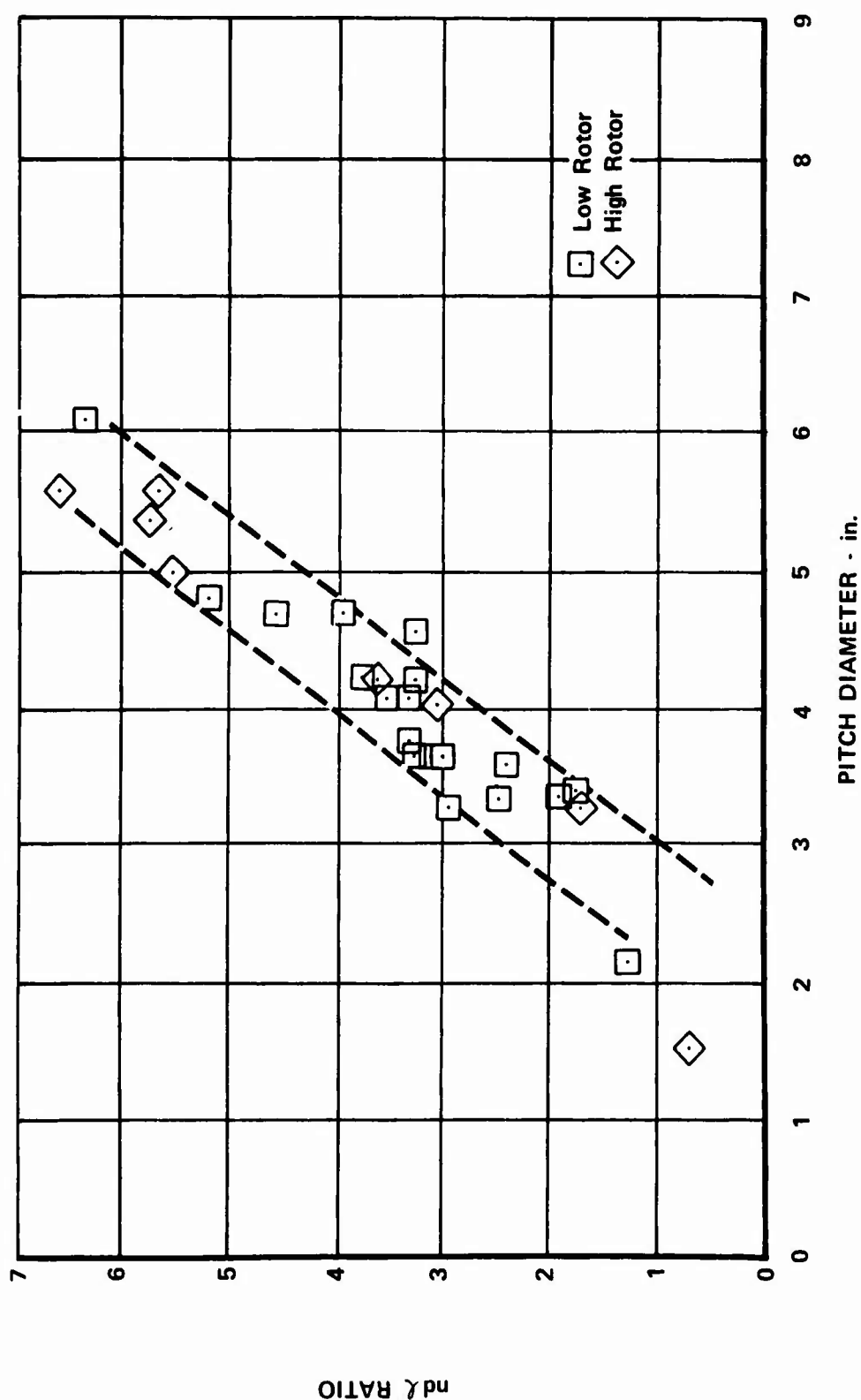


Figure 31. High and Low Rotor Roller Bearings; ndλ Ratio vs Pitch Diameter.

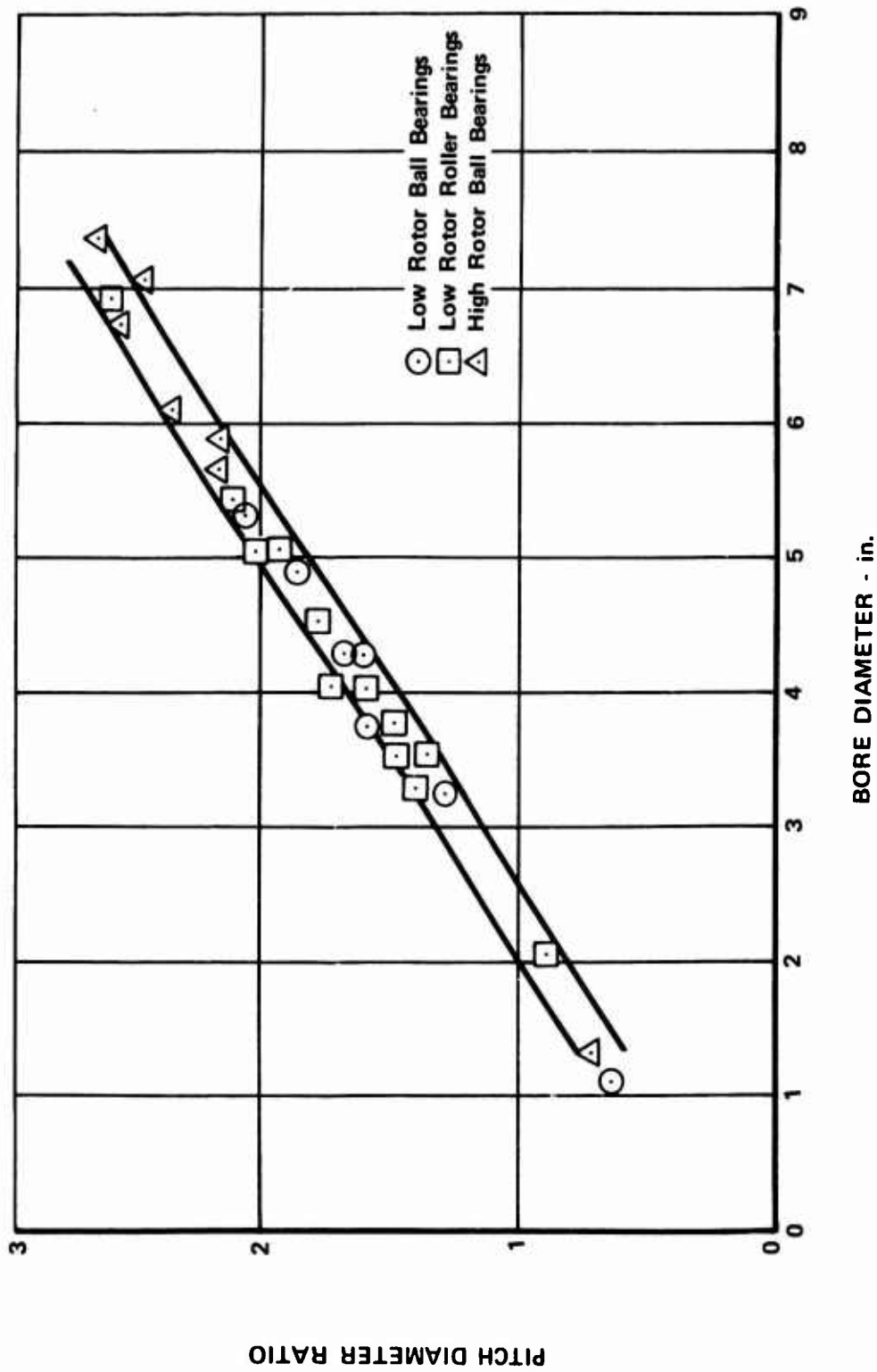


Figure 32. High and Low Rotor Ball Bearings and Low Rotor Roller Bearings; Pitch Diameter Ratio vs Bore Diameter.

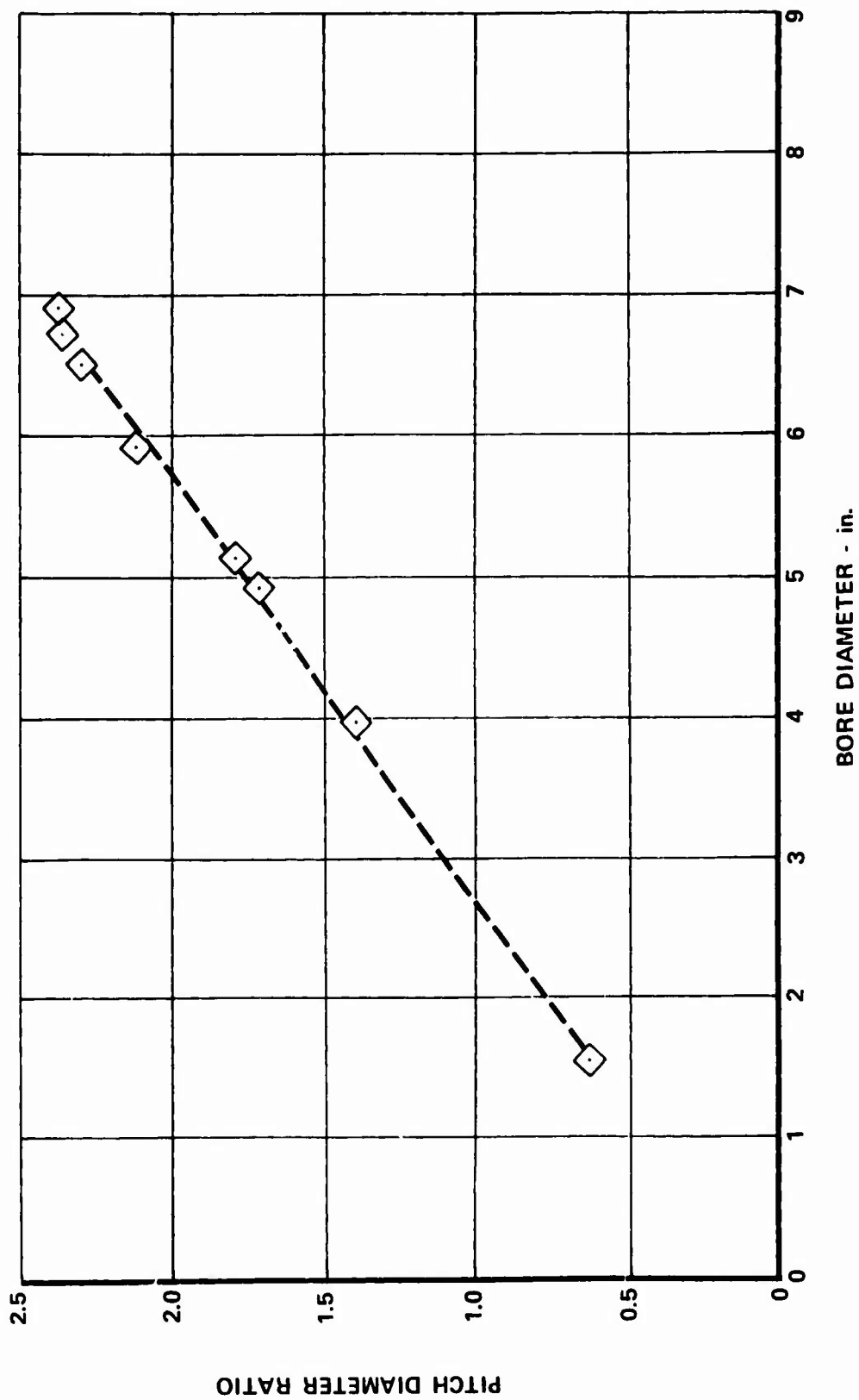


Figure 33. High Rotor Roller Bearings; Pitch Diameter Ratio vs Bore Diameter.

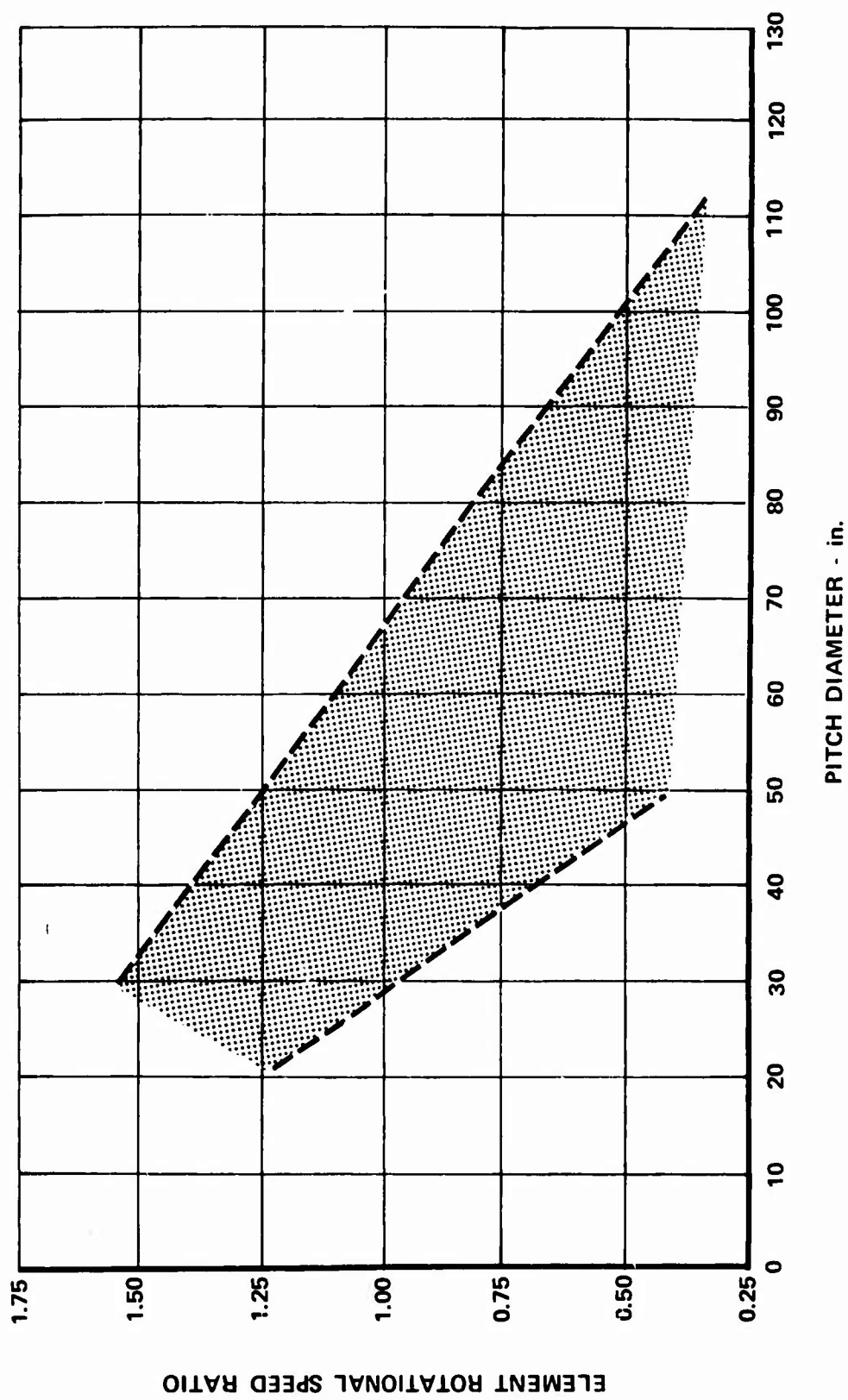


Figure 34. Low Rotor Ball and Roller Bearings at Sea Level Takeoff; Element Rotational Speed Ratio vs Pitch Diameter.

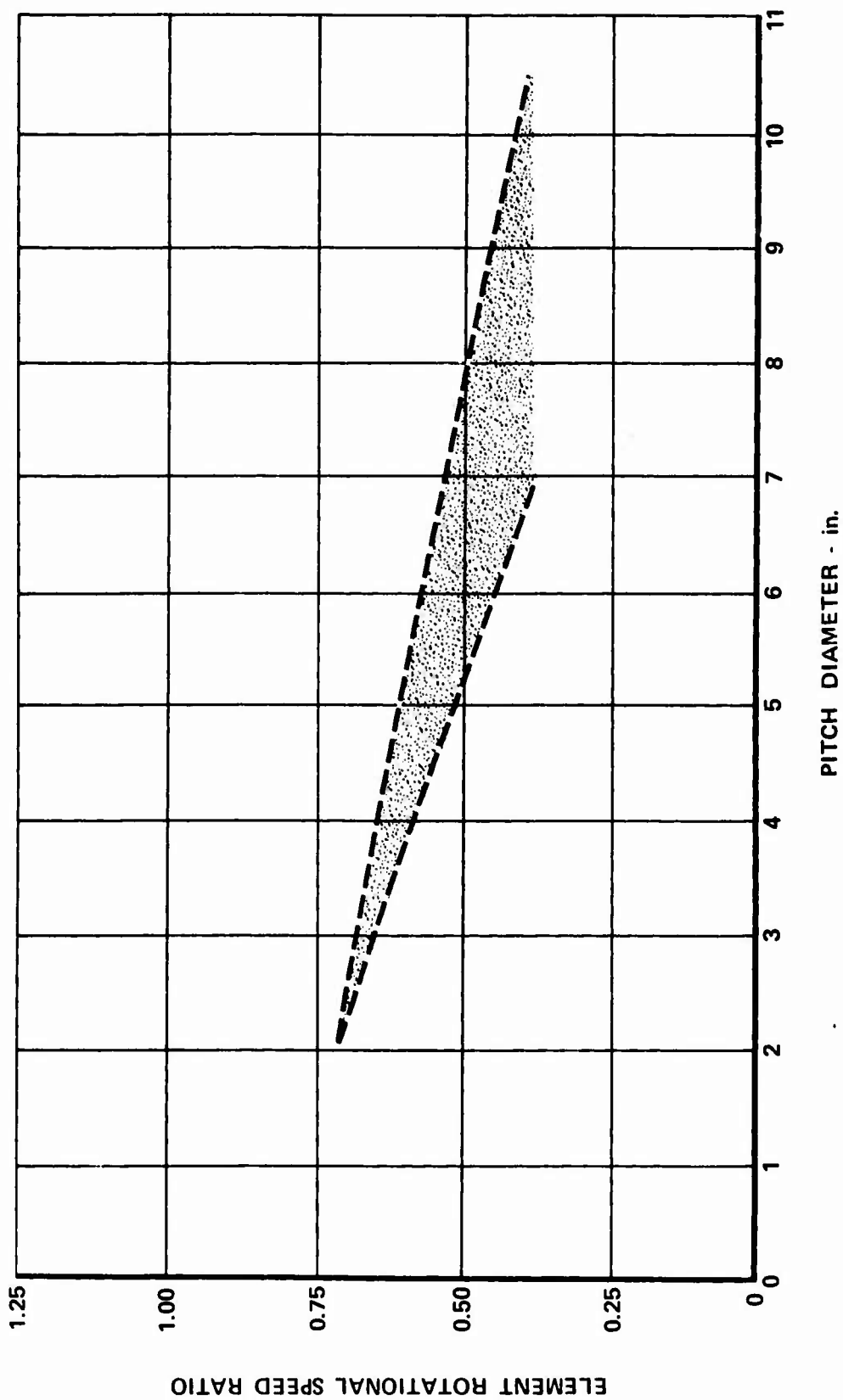


Figure 35. High Rotor Ball Bearings at Sea Level Takeoff; Element Rotational Speed Ratio vs Pitch Diameter.

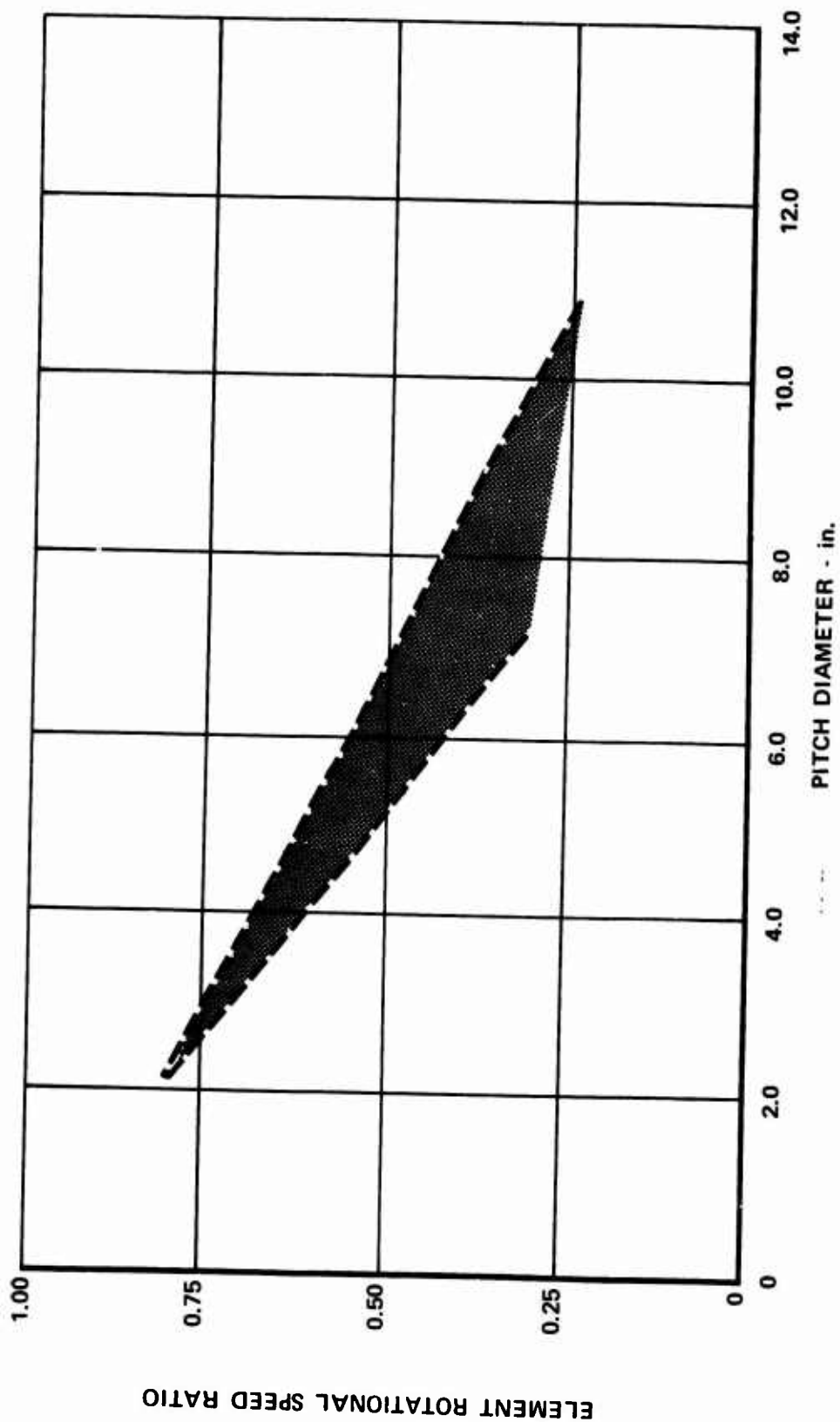


Figure 36. High Rotor Roller Bearings at Sea Level Takeoff; Element Rotational Speed Ratio vs Pitch Diameter.