PROGRESS REPORT NO. 11

ON

BEARING LUBRICANT ENDURANCE CHARACTERISTICS AT HIGH SPEEDS AND HIGH TEMPERATURES

(Revised July 20, 1965)

PERIOD: April 1, 1965 through June 30, 1965

Contributors

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Project Leader:

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Submitted to:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
21000 BROOKPARK ROAD
CLEVELAND, OHIO 44135

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SKF INDUSTRIES, INC
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BEARING LUBRICANT ENDURANCE CHARACTERISTICS AT HIGH SPEEDS AND HIGH TEMPERATURES

INTRODUCTION

This is the eleventh and final quarterly progress report on research performed under Contract NASw-492, "A Study of Bearing Lubricant Endurance Characteristics at High Speeds and High Temperatures". A Summary Report will follow and complete the project.

Research studies have been concluded in two phases on this program:

a. In Phase I, the most recent advances made in bearing and lubricant technology have been screened at high speeds and temperatures in 7205-size ball bearings to define the limiting load, speed and temperature for reliable operation.

b. In Phase II, optimum bearing-lubricant combinations, evolved from Phase I test results, have been endurance tested in multiple bearing groups under predetermined test conditions in order to establish design life and reliability parameters.

Tests were conducted in a nitrogen blanketed environment in high-speed high-temperature test machines developed by SKF Industries, Inc.

CONCLUSIONS

1. A fully successful bearing-lubricant combination tested on this program was Socony Mobil XRM 177F, a hydrocarbon lubricant with a proprietary lubricity additive, and M1 tool steel bearings having a smoother surface finish on the inner ring than on the outer ring. Ten bearings tested at 600°F and 42,800 rpm using this combination, ran for bearing lives of 300-700 million revs. without any sign of failure, indicating an experimental L_{10} in excess of twice the AFBMA computed L_{10} life under the load and speed conditions used.

2. Two modified polyphenyl ether lubricants, Monsanto MCS 293, and the more viscous version MCS 353, have somewhat improved performance at temperatures of 500 to 600°F in a nitrogen atmosphere over the more conventional 5-ring polyphenyl ether, Monsanto Skylube 600. The modified polyphenyl ethers tested in nitrogen atmosphere have about comparable performance to Skylube 600 tested in air. All polyphenyl ethers tested caused lubrication failures at lives less than calculated L_{10} in these tests.

3. Three modes of lubrication-type failures encountered in high-speed high-temperature thrust-loaded ball bearings have been identified as follows:

a. Surface distress (glazing) occurs in the ball tracks over a relatively long period of running time which results ultimately in early flaking failure of the bearing due to insufficient elastohydrodynamic lubricant film thickness at the ball-race contacts. This failure mode is eliminated by: (1) using a more viscous lubricant at the operation temperature, or (2) lowering the bearing operating temperature, or (3) by improving the surface finish at the critical ball-race contacts in the bearing or, (4) by increasing speed without increasing the heating of the contacts.

b. Gross wear of the sliding contacts on the cage can cause cage failure or an acceleration of the surface distress occurring at the ball-race contacts, thus limiting bearing life. This failure mode can be avoided by changes in the cage material and the cage design to improve the lubrication conditions at the cage sliding contacts.

c. Smearing or gross metal transfer distinct from the glazing-type surface distress described in (a), can occur at ball-race contacts. This failure mode is caused by severe sliding which may arise in addition to the rolling motion at ball-race contacts in thrust-loaded ball bearings, due to unfavorable kinematic conditions. The smearing can be eliminated by either improving the boundary lubricating properties of the lubricant or by reducing the amount of sliding which occurs at the ball-race contacts in the bearing by appropriate modifications in the bearing design. (A new design for this purpose is proposed.)

If the above three failure modes are successfully eliminated, tool-steel bearings can be designed and lubricants selected for an operating life at least equal to the AFBMA computed life for failure by classical rolling-contact fatigue at temperatures at least as high as 600°F.

SUMMARY

1. Phase I Testing

(a) The modified polyphenyl ether: Monsanto MCS 353 (having approximately -20°F pour point) gave about as good performance in a nitrogen atmosphere as the previously tested Monsanto Skylube (+40°F pour point) in an air environment and better than Skylube 600 in nitrogen atmosphere. Four bearings of 10 tested in MCS 353 survived for appreciable lives at 600°F, which reflects the improved boundary lubricating characteristics of this lubricant which has only 3/4 of the viscosity of Skylube 600 at 600°F.

The use of an anti-wear additive in Skylube 600 (the additive containing version is designated MCS 365) did not improve the performance of Skylube 600 in a nitrogen atmosphere. All 6 bearings tested either smeared at start-up or glazed and flaked at quite low lives. In contrast, 4 of 8 bearings tested previously with Skylube 600 in an air environment survived for appreciable lives.

(b) The use of a lighter weight cage design or material provides marginal improvement in bearing performance using either Kendex Bright Stock 0846 or Socony Mobil XRM 177F lubricants. Appreciable lives were obtained without smearing failures in 8 of 10 bearings tested with low weight or plastic cages. This compares with 10 early smearing failures of 14 bearings tested under comparable conditions with the Bright Stock Lubricant and 10 early smearing failures of 16 bearings tested with XRM 177F using the standard heavy-section steel cage.

2. Phase II Endurance Testing

Endurance testing at 42,800 rpm and 459 lbs. thrust load (AFBMA computed L_{10} = 240 mill. revs.) was completed on 4 groups comprising 10 to 18 bearings each and 3 smaller groups of 4 to 8 bearings each. The results of these endurance tests are summarized in the table below:

Lubricant	Brg. Steel	Avg. Temp. °F	No. Brgs. Tested	No. Smearing and Flaking Failures	Estimated Bearing L_{10} Life mill. revs.
Bright Stock	M-1	580	14	7	*
Bright Stock with TCP	M-1	570	4	2	0.2
XRM 109F-1	WB-49	585	8	4	3.1
XRM 109F-1	M-1	580	18	6	1.3
XRM 177F	WB-49	600	16	8	1.4
XRM 177F	M-1	600	10	0	>500
Turbo Oil 35	WB-49	<300	8	4	0.02

*No valid life estimates were obtained since most failures occurred shortly after start-up.

These results show (XRM 177F oil with M-1 bearings) that spectacularly successful operation of tool steel bearings at 600°F is indeed possible. Based on the long life obtained with Socony XRM 177F oil and M-1 bearings, there is no reason to suspect that any high-temperature derating of bearing life from the AFBMA standards used for more ordinary operating conditions is required. It is necessary, of course, to design and manufacture the bearings especially to provide the best possible lubrication conditions for the lubricants available, and to find suitable lubricants. Bearings must have smooth ball-race contact surfaces, accurate contact surface geometry, and be designed so as to minimize the ball-race skidding which is always inherent in high-speed bearings.

DETAILS

1. Description of Test Bearings and Testing Procedure

Angular-contact 7205 bearings, constructed of CVM M-1 and CVM WB49 inner and outer races, CVM M-1 steel balls and fitted with cages of silver plated (55 Rc) M-1 steel or polyimide plastic (DuPont Type SP-2) were tested during this report period at 42,800 rpm, 459 lbs. thrust load and mean temperatures up to 600°F.

Drawings of the test bearings are given in Enclosures 1 and 2, and the various cage designs used are given in Enclosures 3 - 7. The CVM M-1 steel inner races were specially honed to a surface finish of 2.5 - 4.3 microinches, rms, across the groove, while the mating outer races were ground and polished to a surface finish of 6 - 8.5 microinches, rms, across the groove. In the majority of the CVM WB49 steel bearings, the inner and outer races were both specially honed to a surface finish of 1.5 - 2.5 and 2 - 4 microinches, rms, respectively, across the groove. One small group of CVM WB49 steel inner and outer races, which were made from another heat of steel, were ground and polished to a surface finish of 3 - 8 microinches, rms, across the groove. The unmounted radial looseness of the test bearings ranged from 31.0 to 54.0 microns, with most bearings having a looseness of 40-50 microns; and the average radial cage play ranged from 0.006" to 0.013". The individual bearing dimensions before testing can be found in Enclosure 8.

The M-1 steel cages assembled with the bearings were silver plated either in their bores only, as shown in Enclosure 3, or on all surfaces as shown in Enclosure 4. Two tests were conducted with bearings assembled with unplated M-1 steel cages which had been reduced in weight as shown in Enclosure 5. Three tests were run with the bearings assembled with cages manufactured from DuPont polyimide plastic, type SP-2, to the dimensions shown in Enclosures 6 and 7. All the bearing races except those ground and polished from CVM WB49 steel were black oxide coated to reduce the occurrence of lubrication-related surface distress.

A description of the test rigs and operating procedures developed for high-speed running is given in the earlier progress reports (1,2).* Depending upon the temperature-viscosity characteristics of the test lubricants which are given in Enclosure 9, the

*Numbers in parentheses refer to references at the end of the report.

circulating oil flow to each bearing at 42,800 rpm was maintained at 400 - 600 cc/min. The full sump capacity for each test bearing is 1000 cc. Flow calibration curves plotting the oil viscosity vs. the flow rate were obtained at various inboard valve settings and are given in Enclosure 10. Based upon the plot of the corresponding oil and bearing temperatures vs. the inboard valve setting which was obtained without any heater input to the test machine the ideal inboard valve setting for lowest bearing temperature was found to be between 1-1/2 to 2 turns open, as shown in Enclosure 11. Consequently, all tests reported herein were run with an inboard valve setting of 1-1/2 turns open during the test. All the tests conducted during this report period were blanketed in nitrogen gas and additional make up oil was added periodically throughout each test in order to replace that lost through decomposition, evaporation and seal leakage

Cooling fans were employed during each test to dissipate the heat generated in the housing block and to provide satisfactory control of the bearing operating temperatures using 15 - 20% of the heater capacity.

2. Phase I Testing

A summary of the test results obtained during this report period with CVM M-1 and CVM WB49 steel bearings is tabulated in Enclosures 12 and 13, respectively.

Three tests (Runs 60, 61 and 62) were conducted with black oxide coated CVM M-1 steel bearings (honed IR only) using a modified polyphenyl ether, Monsanto MCS 353, which is a more viscous version of the similar Monsanto MCS 293 tested previously. The test conditions were set for 600°F bearing temperature at 42,800 rpm under 459 lbs. thrust load (computed AFBMA L_{10} = 240 mill. revs.). Two tests, #60 and 61, were terminated almost immediately after startup; one of these was considered an aborted test (Run #61) since the rig oil screw pump for one of the test bearings did not prime properly at starting. In both runs one of the two test bearings was smeared and the mating bearings were in good or slightly glazed condition. The smeared bearing from Run #60 is shown in Enclosure 14. The third test, #62, operated satisfactorily for 29.2 hours (74.9 mill. revs.) at mean temperatures up to 588°F after which the test was terminated because the load-end bearing had a flaked ball (see Enclosure 15); otherwise both bearings were in good condition.

Eight black oxide coated CVM M-1 steel bearings (honed inner races only) were run in four tests with Monsanto MCS 365 lubricant, a five-ring polyphenyl ether (Skylube 600) with an EP additive, in a nitrogen environment. Results of only three of the tests: #E73, E74, E75, are reported since one test, #E78, was aborted because of failure to prime the screw pumps. Of these three tests reported, 3 bearings smeared on startup and 2 bearings flaked after only 3.8 hours, and the remaining bearing was in good condition.

Three tests (Runs #63, 64, and 65) were conducted with Monsanto MCS-353 oil lubricating black oxide coated CVM WB49 steel bearings (both races honed) at mean bearing temperatures up to 600°F, 42,800 rpm and under 459 lbs. thrust load. Two tests (#63 and 65) were terminated early. In one test (#63) one of two bearings smeared after 1.1 hours (2.8 mill. revs.) (see Enclosure 16) and the other was slightly glazed. The other test (#65) resulted in a smearing failure of the drive-end bearing immediately after startup (Enclosure 17). Also, the load-end bearing was superficially pitted, (Enclosure 18). The remaining test (#64) operated satisfactorily for 52.8 hours (134.8 mill. revs.) at mean temperatures up to 601°F when it was terminated because of a flaked load-end bearing, whereas the drive-end bearing was superficially pitted as shown in Enclosures 19 and 20.

Three tests (six bearings in Runs #66, 67 and 68) were run with black oxide coated CVM WB49 steel bearings (both races honed), assembled with light weight metal or polyimide plastic cages and lubricated with Kendall Bright Stock 0846 at 42,800 rpm, 459 lbs. thrust load and 600°F. In two of these tests (#66, 68) four bearings were assembled with unplated M-1 steel cages (since silver plated cages were unavailable) which were about half the weight of the previously used silver plated M-1 steel cages. One test, #66, was terminated almost immediately after startup when the drive end bearing smeared (see Enclosure 21) and the load end bearing was only slightly glazed. No appreciable cage wear was evident in either bearing. In the second test, #68, both bearings operated for 22.0 hours (56.5 x 10^6 revs.) at which time the test was terminated because of excessive cage and raceway land wear in the load end bearing (see Enclosure 22) which prevented continued operation. The ball path of this bearing also appeared to be glazed and slightly smeared. The companion bearing (drive end) was slightly glazed and its cage wear was not appreciable. DuPont polyimide, type SP-2, plastic cages, which were approximately five times lighter than the silver plated M-1 steel cages previously used, were assembled with two bearings in the third test, #67. This test was terminated after 75.8 hours (194.6 x 10 revs.) when the load end bearing was superficially pitted and glazed; its cage wear was slight but four ball pockets were cracked. The mating bearing (drive end) was in good condition and its cage wear was slight. (Enclosures 23 and 24).

To obtain a stronger polyimide cage, four black oxide coated CVM WB49 steel bearings (both races honed) were assembled with cages manufactured from the same DuPont polyimide plastic, type SP-2 used above, but having only 11 ball pockets instead of the usual 12, as a means of increasing the strength of the web. (Enclosure 7). Tests were conducted with Socony Mobil XRM 177F hydrocarbon oil with a lubricity additive at mean temperatures up to 599°F and under a 459 lbs. thrust load which gave AFBMA computed L_{10} = 200 mill. revs. (C/P = 5.85). Results are summarized in Enclosure 13. In these tests, (#E97 and #E98), one of the two mating bearings had glazed races and one flaked ball after 16.8 and 58.6 mill. revs., respectively. In each test the mating bearings were in good condition. The cages in only the failed bearings in each test had cracked through both rails at one cage pocket, and the cage bore wear for all the bearings was either negligible (0.1 mill.) or slight (3.4 inches max.).

Reducing the weight of cages to the dimension shown in Enclosure 5 and testing them with CVM WB49 steel bearings lubricated by a previously determined 600°F candidate oil, Kendall Bright Stock 0846, did not improve the performance of the bearing as shown by the results obtained in test run #66 and 68. Perhaps the short test lives were due primarily to the fact that the cages were not silver plated and also due to excessive ball skidding caused by insufficient outer-race ball control. However, the CVM WB49 steel bearings assembled with the polyimide plastic cages shown in Enclosure 6 and tested in run #67 with Kendall Bright Stock 0846 at mean temperatures up to 610°F did perform astonishingly well for a plastic material at these high temperatures. Although several additional tests (Runs #E97 and #98) were conducted with cages manufactured from this material and the results were not as satisfying, there seems to be some justification for using the lighter plastic cages.

3. Phase II Endurance Testing

The following groups of 7205 size bearings were endurance tested under 459 lbs. thrust load at 42,800 rpm until failure or until a time-up life of 90 hours (231.1 mill. revs.) whichever occurred first. (In one bearing group, the time-up life was extended.)

CVM M-1 Steel Bearings with Socony Mobil XRM 109F-1 at 600°F

A group of 18 black oxide coated M-1 bearings (honed inner rings only) were endurance tested at mean temperatures up to 598°F. A summary of these results is given in Enclosure 25. Of the eighteen bearings tested, two bearings (one test, #E59) were in good condition and reached their time-up life. In six other tests, #E53, E54, E55, E58, E60 and E61, twelve bearings were terminated at lives ranging from 2.2 to 17.5 mill revs. when six bearings either glazed and flaked or smeared while the companion bearings were in good condition or had suffered some surface distress. Two of the remaining four bearings (2 tests, #E56 and E57) were terminated at 8.5 and 2.4 mill. revs. respectively, when it was found they had sustained lubrication-related surface distress, while their companion bearings were in good condition.

CVM WB49 Steel Bearings with Socony Mobil XRM 109F-1 at 600°F

Since it was suspected that the very early failures experienced in the high-speed tests reported here and in previous tests (3) were the result of excessive ball slip on honed bearings, uncoated CVM WB49 steel bearings with ground and polished races were endurance tested with Socony Mobil XRM 109F-1 at mean temperatures up to 610°F. A summary of these results is given in Enclosure 26. Of the eight bearings tested, one bearing in each of the four tests, #E69, 70, 71 and 72 either smeared or underwent lubrication-related surface distress, which prevented continued testing, at lives ranging from 0.13 to 106.5 mill. revs. In three of the four tests the companion bearings were in good condition while in the remaining test the mating bearing exhibited surface distress.

CVM M-1 Steel Bearings with Kendall Bright Stock 0846 at 600°F

In view of short lives obtained with the Socony Mobil XRM 109F-1 oil, a group of 14 black oxide coated CVM M-1 steel bearings (with honed inner races only) were endurance tested using Kendall Bright Stock 0846 as the lubricant at mean temperatures up to 599°F. One bearing in each of the seven tests, #E62 to E68, inclusive, either smeared or glazed and flaked at lives ranging from 0.13 to 201.8 mill. revs. while the mating bearings were in good condition. As shown in the summary of the results given in Enclosure 27, four of the seven failures were obtained almost immediately after startup and were smearing failures.

Since the endurance results obtained so far indicated that the current 600°F candidate oils, viz: Monsanto Skylube 600 polyphenyl ether, Socony XRM 109F-1 synthetic hydrocarbon and Kendall Bright Stock 0846 did not reliably lubricate the bearings to prevent surface distress from occurring early in a significant proportion of the tests, several groups of bearings were endurance tested using essentially the same oils, but containing anti-wear additives in order to extend the bearing test life. All endurance tests were conducted at 42,800 rpm, 459 lbs. thrust load and temperatures up to 600°F and the bearings were assembled with silver plated M-1 steel cages.

CVM M-1 Steel Bearings with Kendall Bright Stock 0846 (Containing TCP) at 600°F

As shown in Enclosure 28, four black oxide coated CVM M-1 steel bearings (honed inners only) were run in two tests with Kendall Bright Stock 0846 containing 1/2% (by weight) of tricresylphosphate (TCP). One test (#81) was terminated almost immediately after startup when one bearing smeared. A second test (#80) ran only 3.65 hours before both bearings either smeared or glazed.

CVM M-1 Steel Bearings with Socony Mobil XRM 177F at 600°F

Socony Mobil XRM 177F, which is XRM 109F-2 (a new batch of XRM-109F-1) with a proprietary lubricity additive, was used to lubricate twelve black oxide coated CVM M-1 steel bearings (honed inner races only), but the results of only ten bearings (5 tests) are reported because one test (#83) was aborted. All ten bearings ran to 90 hours (231.1 mill. revs.) without failure at mean temperatures up to 608°F. Inasmuch as this was the best performance of any of the bearing-lubricant combinations tested thus far, all ten bearings were remounted and were tested further under the same conditions. As shown in the summarized results given in Enclosure 29, all ten bearings ran successfully to time-up lives ranging from 437.0 to 726.5 mill. revs. with no signs of surface distress or failure.

Enclosure 30 shows the excellent appearance of the longest lived bearings of this group, which ran without failure to over 3 times the AFBMA computed life under these test conditions. The typical appearance of the test rigs and their critical parts after sustained operation under the above test conditions is shown in Enclosure 31. Severe coking of the XRM-177F lubricant occurred on the outside of the rig wherever leaking hot oil was exposed to air. However, all internal nitrogen blanketed parts were exceptionally clean and the filter screens (80 mesh) from the oil sumps, through which all the lubricant supplied to the test bearings was circulated, were remarkably free of decomposition products and other debris.

CVM WB49 Steel Bearings with Socony Mobil XRM 177F at 600°F

Since the performance of the CVM M-1 steel bearings and Socony Mobil XRM 177F was so favorable, a group of sixteen black oxide coated CVM WB49 steel bearings (honed on both races) were tested with the same lubricant at mean temperatures up to 606°F. As summarized in Enclosure 32, one bearing in each test smeared at lives ranging from 1.02 to 190.7 mill. revs. In each instance the mating bearing was in good condition.

CVM WB49 Steel Bearings with Esso Turbo Oil 35 at 500°F

Since the results obtained previously at 500°F, using black oxide coated CVM M-1 steel bearings (honed IR only) lubricated with Turbo Oil 35 was quite favorable, a group of eight black oxide coated CVM WB49 steel bearings (both races honed) were to be tested with the same lubricant at 500°F. As shown in Enclosure 33, one bearing in each of 4 tests (#E87, 88, 89 and 93) smeared immediately after startup before reaching the desired test temperature. The companion bearing in each test was in good condition.

4. Discussion of Test Results

Weibull Plots of Endurance Results

Weibull plots have been prepared for each of the groups endurance tested, using a new plotting technique to account for suspended tests (4). All types of failures, including flaking, lubrication distress (to the extent that the bearings were inoperable) and cage-induced failures, were plotted as failures. Where two bearings failed in the same test, one was treated as a discontinuance, along with the unfailed terminated bearings; aborted tests were not plotted.

Maximum likelihood life estimates, where the data were sufficiently plentiful and well behaved to obtain them (3), were obtained for each test group. The Weibull plots with estimated lives are given in Enclosures 34 to 40.

Computer Estimated Bearing Kinematics

Since the performance of the test bearings at 600°F seems definitely to depend on the detailed surface characteristics of the bearings (XRM 177F oil worked well with M-1 bearings having honed inner rings and polished outer rings, but poorly with WB49 bearings, which have higher hardness and should resist smearing better than M-1 steel, but were honed on both the inner and outer rings), an analysis of the kinematic conditions existing at the ball-race contacts in these bearings under the imposed test conditions, was performed, using a high-speed digital computer. The bearing operating conditions used in this analysis are as follows:

Shaft speed	42,800 rpm
Thrust load	459 lbs.
Oil viscosity	2.5 cs = 2.9×10^{-7} lb.sec./in.^{2}
Torque factor	4
Pressure viscosity coefficient	6.5×10^{-5} in.^{2}/lb.
No. balls	12
Ball diameter	0.3125 in.
Pitch diameter	1.537 in.
Outer race conformity	0.5318
Inner race conformity	0.5216
Mounted operating radial looseness	0.0006 - 0.0016 in.

Under these operating conditions with the above standard design bearing, and assuming a Coulomb-type coefficient of friction of 0.06 at the ball-race contacts, (the spinning torque and the spinning heat generation are proportional to the coefficient of friction assumed), the following selected operating parameters were computed for both the minimum and the maximum radial looseness possible within the tolerances on bearing looseness and mounting fits on the shaft and in the housings used on this program.

Computed Operating Parameter	Standard Bearing Design Loose Fit	Standard Bearing Design Tight Fit	Proposed Modified Design Tight Fit*
Inner ring contact angle, degrees	26.7	21.3	20.4
Outer ring contact angle, degrees	19.5	16.5	15.9
Axial bearing deflection, in.	0.0015	0.0023	0.0024
Ball centrifugal force, lbs.	30.3	29.6	30.7
Inner semi-major contact axis, in.	0.0383	0.0408	0.0361
Outer semi-major contact axis, in.	0.0346	0.0364	0.0417
Normal inner ring ball load, lbs.	81.2	101.0	105.0
Normal outer ring ball load, lbs.	108.8	128.8	134.1
Maximum inner contact stress, kpsi	232.8	257.0	281.8
Maximum outer contact stress, kpsi	242.1	259.1	246.8
Ball spinning torque on inner, in.-lb.	1.90	2.53	2.33
Outer ball spinning torque projected on inner, in.-lb.	2.34	2.93	3.46
Spin-to-roll ratio on inner	0.24	0.18	0.18
Cage speed, rpm	17,580	17,380	17,290
Ball rolling speed, rpm	86,470	85,470	83,680
Ball axis orientation angle, degrees	16.3	13.8	13.2
Spinning heat generated, Btu/hr.	2,766	2,709	2,381
Total heat generated, Btu/hr.	5,109	6,155	5,976
Ball gyroscopic moment, in-lbs.	0.63	0.53	0.53
Minimum friction coefficient to prevent gyro slip	0.021	0.015	0.014
Bearing life (Lundberg-Palmgren), hrs.	86.0	48.3	35.8
Life of inner ring contact, hrs.	109.3	59.8	39.5
Life of outer ring contact, hrs.	326.6	199.9	285.1
EHD oil-film thickness on inner for 2.5 cs. lubricant viscosity, 10^{-6} in.	7.7	7.5	7.6

*Loose fit parameters for the modified design were not computed.

Also given in the above tabulation are the computed operating parameters for a proposed modified 7205 bearing with all design and operating conditions identical to those given above except that the ball-race conformity on the inner ring (the inner-ring groove radius expressed in percent of the ball diameter) is changed from 52.2% to 53% and the conformity on the outer ring is changed from 53.2% to 52.3%.

In order for ball control to exist on the outer race, i.e. for "pure" rolling to occur at the outer-race-ball contacts and all spinning to occur at the inner-race contacts, the ball spinning torque on the inner ring must be less than the ball spinning torque on the outer ring, projected on the plane of the inner-race contact. If it is assumed that the coefficient of sliding friction is the same at both race contacts, then this criterion for outer-race ball control is satisfied for the standard bearing design under the above operating conditions. However, one might expect that the sliding friction at the ball-race contacts will depend on the surface roughness, the lubrication conditions, and the amount of sliding taking place, with its attendant temperature rise in the contact area.

The success of the M-1 bearings tested at 600°F with XRM 177F oil (whose viscosity coefficients at 600°F were used in the above computations) is probably attributable to the rougher surface finish on the outer races than on the inner races, which would insure outer-race control. The completely honed WB49 bearings having the smoother finish on both races proabably do not generate sufficient spinning torque on the outer ring to insure outer-race control so the balls spin or slide excessively on both rings (probably stabilized by gyroscopic forces instead of by race contact forces), thus making it more difficult for the lubricant to prevent surface distress and smearing. It is undesirable to design bearings having different surface roughness on the inner and outer rings, since the roughness in the ball tracks on both rings probably tend to equalize with extended running due to run-in phenomena. Therefore, the modified design described above is proposed to provide a greater margin of outer-race control by an adjustment of the ball-race conformities on both the inner and outer rings.

The elastohydrodynamic (EHD) lubricant film thickness, with the XRM 177F oil at 600°F under the above test conditions is about 7.5 microinches, as shown in the above tabulation. Taking a mean surface roughness of 1.5 microinches, rms, for the honed races, and 7.0 microinches, rms for the ground and polished races, the composite roughness, or variation in film thickness, σ_h, computed according to (5) is:

$$\sigma_h = \sqrt{1.5^2 + 2.5^2} = 2.9 \text{ microinches, rms}$$

for honed races, and

$$\sigma_h = \sqrt{1.5^2 + 7.0^2} = 7.2 \text{ microinches, rms}$$

for polished races. Thus, the critical ratio of EHD film thickness to composite roughness

$$\frac{h}{\sigma_h} = \frac{7.5}{2.9} = 2.6 \text{ for honed races, and}$$

$$\frac{h}{\sigma_h} = \frac{7.5}{7.2} = 1.04 \text{ for polished races.}$$

According to (5), the difference in degree of asperity contact expected between h/σ_h ratios of 2.6 and 1.04 is substantial, thus corraborating the above hypothesis that large differences in the ball sliding friction coefficient must exist between honed and polished races.

Different Modes of Lubrication-Related Bearing Failure

A review of all test data obtained on this program has been conducted with the result that several modes of bearing failure occur in these high-speed high-temperature thrust-loaded ball bearings. Three of these failure modes are lubrication-type failures which, if they can be eliminated, make it possible for bearing lives at least as long as the AFBMA estimated life to be obtained at temperatures at least as high as 600°F. (AFBMA computed life is based on the rolling-contact fatigue flaking of the steels from which the bearing parts are made.) Lubrication-type failures occur at bearing lives of less than a few percent of the AFBMA computed lives. These lubrication-type failures are described as follows:

a. A type of surface distress occurs under certain lubrication conditions which appears as a glazing of the surface so that surface finishing marks are obliterated. This glazed appearance, with continued running, develops into very superficial surface pitting or pulling as shown in Enclosure 23 and ultimately leads to a fatigue flaking of one of the contacting surfaces such as the flaked balls shown in Enclosure 15. Flaking under surface distress conditions occurs at much less than the AFBMA computed life. As discussed in previous reports (6, 7) this type of lubrication distress can be avoided by insuring adequate elastohydrodynamic lubricant film thickness at the ball-race contacts.

b. Severe cage wear is another failure mode often experienced in high-speed high-temperature ball bearings running under marginal lubrication conditions, as illustrated in Enclosure 22. This failure mode can be avoided by the proper selection of cage materials.and cage design to provide adequate lubrication conditions for the cage contacting surfaces. Screening of candidate cage materials is discussed in previous reports (2,6,7).

c. Smearing-type lubrication failures occur when the kinematic conditions during bearing operation allow gross sliding to occur at the ball-race contacts, which results in gross seizure and metal transfer at the contacts. This type of failure was discussed in the previous section of this report.

LIST OF REFERENCES

1. D'Orazio, A. J., "Bearing Lubricant Endurance Characteristics at High Speeds and High Temperatures", Progress Report No. 1, NASA Contract No. NASw-492, February, (1963).

2. Wachendorfer, C. J., "Bearing Lubricant Endurance Characteristics at High Speeds and High Temperatures", Progress Report No. 9, NASA Contract No. NASw-492, January, (1965).

3. Wachendorfer, C. J., "Bearing Lubricant Endurance Characteristics at High Speeds and High Temperatures", Progress Report No. 10, NASA Contract No. NASw-492, April, (1965).

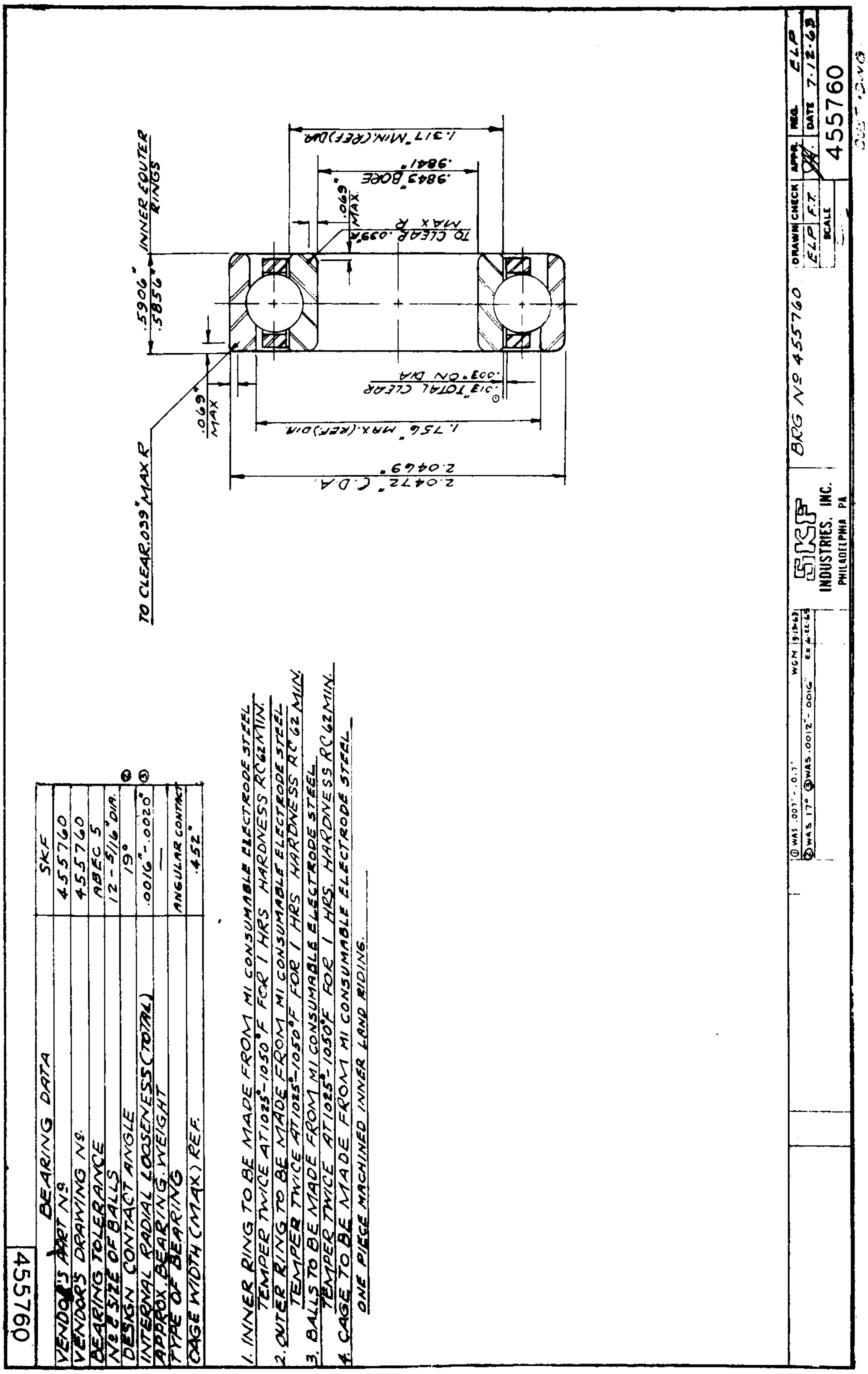
4. Schreiber, H. H., "Zur Mathematisch-Statistischen Auswertung von Lebensdanerversuchen mit Wälzlagarn, Teil I", Qualitätskontrolle, 8 (6), 59-66, (1963).

5. Tallian, T., et al, "Lubricant Films in Rolling Contact of Rough Surfaces", ASLE Trans., 7 (2), 109-126, (1964).

6. Wachendorfer, C. J., "Bearing Lubricant Endurance Characteristics at High Speeds and High Temperatures", Progress Report No. 5, NASA Contract No. NASw-492, January, (1964).

7. Wachendorfer, C. J., "Bearing Lubricant Endurance Characteristics at High Speeds and High Temperatures", Progress Report No. 6, NASA Contract No. NASw-492, April, (1964).

ENCLOSURE 1

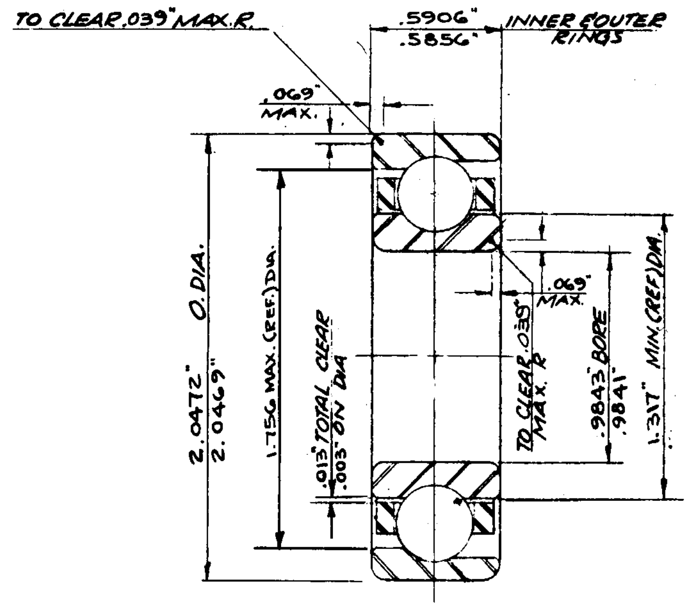

455760
BEARING DATA | SKF
VENDOR'S PART Nº | 455760
VENDOR'S DRAWING Nº | 455760
BEARING TOLERANCE | ABEC 5
Nº & SIZE OF BALLS | 12 - 5/16" DIA.
DESIGN CONTACT ANGLE | 19°
INTERNAL RADIAL LOOSENESS (TOTAL) | .0016" - .0020"
APPROX. BEARING WEIGHT | —
TYPE OF BEARING | ANGULAR CONTACT
CAGE WIDTH (MAX) REF. | .452"
1. INNER RING TO BE MADE FROM MI CONSUMABLE ELECTRODE STEEL TEMPER TWICE AT 1025°-1050°F FOR 1 HRS HARDNESS RC62 MIN.
2. OUTER RING TO BE MADE FROM MI CONSUMABLE ELECTRODE STEEL TEMPER TWICE AT 1025°-1050°F FOR 1 HRS HARDNESS RC 62 MIN.
3. BALLS TO BE MADE FROM MI CONSUMABLE ELECTRODE STEEL TEMPER TWICE AT 1025°-1050°F FOR 1 HRS. HARDNESS RC62 MIN.
4. CAGE TO BE MADE FROM MI CONSUMABLE ELECTRODE STEEL ONE PIECE MACHINED INNER LAND RIDING.
TO CLEAR .039" MAX R
.5906"
.5856"
INNER & OUTER RINGS
.069" MAX
2.0472" C.D.A.
2.0469"
1.756" MAX. (REF.) DIA.
.013" TOTAL CLEAR
.003" ON DIA
TO CLEAR .039" MAX R
.069" MAX.
.9843" BORE
.9841"
1.317" MIN. (REF.) DIA.
WAS .007" - .0.7"
WAS 17°
WAS .0012" - .0016"
SKF INDUSTRIES, INC.
PHILADELPHIA PA
BRG Nº 455760
DRAWN ELP
CHECK F.T.
REG. ELP
DATE 7-12-63
SCALE
455760

ENCLOSURE 2

456684

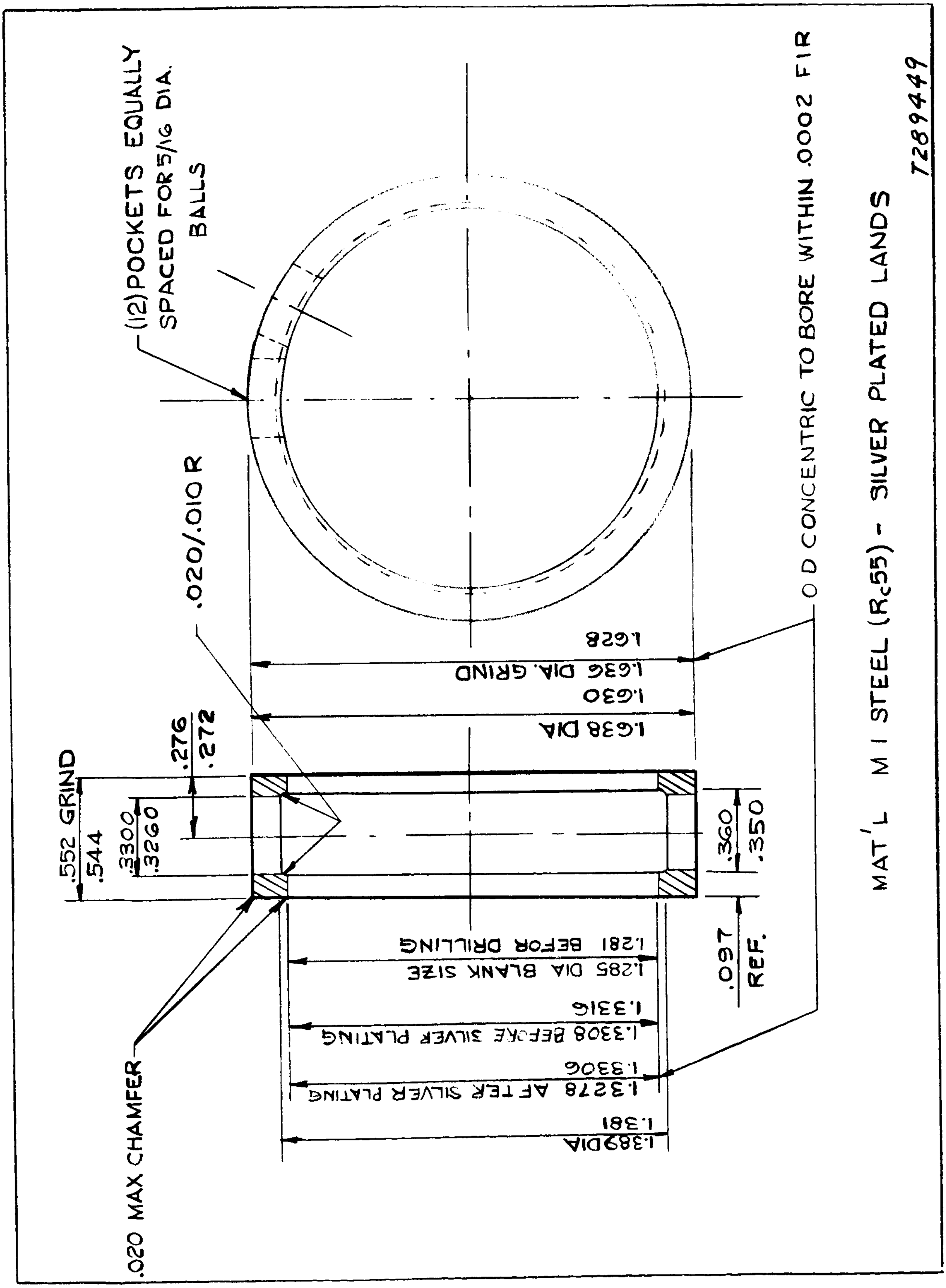
BEARING DATA	SKF
VENDOR'S PART Nº	456684
VENDOR'S DRAWING Nº	456684
BEARING TOLERANCE	ABEC 5
Nº & SIZE OF BALLS	12 - 5/16" DIA.
DESIGN CONTACT ANGLE	19°
INTERNAL RADIAL LOOSENESS (TOTAL)	.0016" - .0020"
APPROX. BEARING WEIGHT	—
TYPE OF BEARING	ANGULAR CONTACT
CAGE WIDTH (MAX.) REF.	.552"

1. INNER RING TO BE MADE FROM WB 49 STEEL, TEMPER THREE TIMES AT 1015°-1040°F FOR 2 HRS. HARDNESS RC67 MIN.
2. OUTER RING TO BE MADE FROM WB 49 STEEL, TEMPER THREE TIMES AT 1015°-1040°F FOR 2 HRS. HARDNESS RC 67 MIN.
3. BALLS TO BE MADE FROM WB 49 STEEL, TEMPER THREE TIMES AT 1015°-1040°F FOR 2 HRS. HARDNESS RC67 MIN.
4. CAGE TO BE MADE FROM WB 49 STEEL, ONE PIECE MACHINED INNER LAND RIDING.

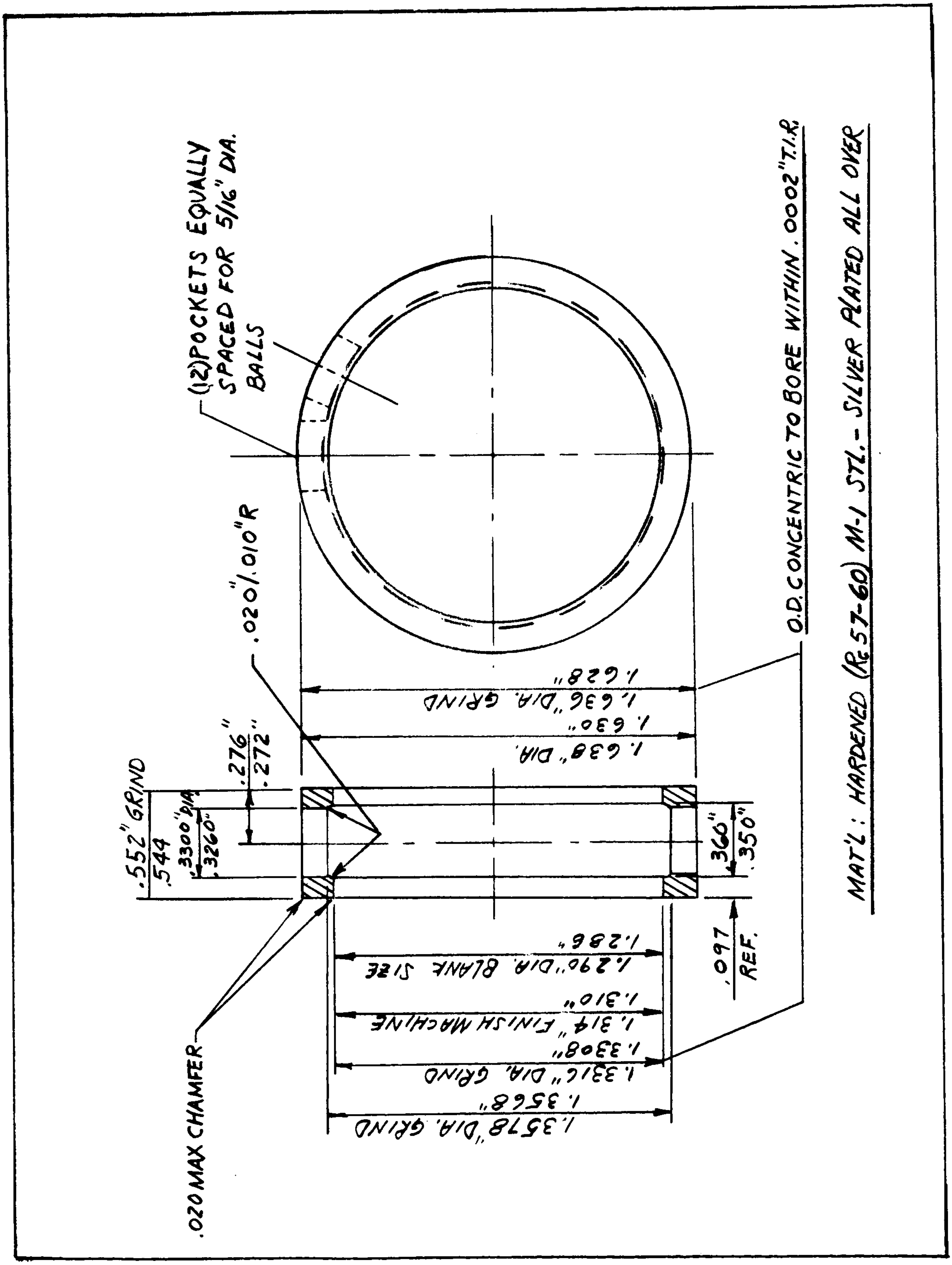


SKF INDUSTRIES, INC. PHILADELPHIA, PA.	BRG. Nº 456684	DRAWN E.K. / CHECK J.H / APPR. [illegible] / SCALE	REG. E.K. / DATE 6-22-65 / 456684

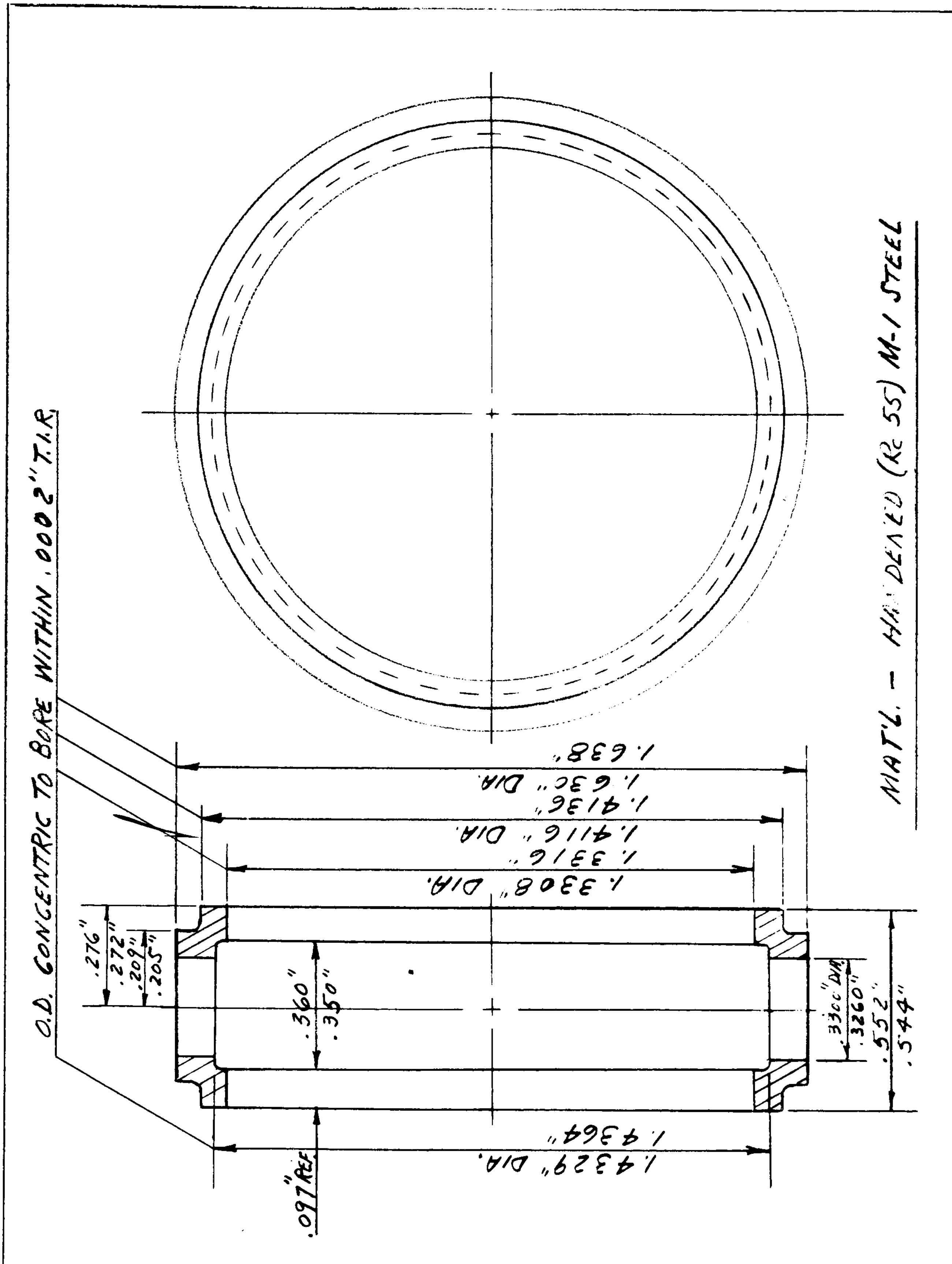
ENCLOSURE 3


(12) POCKETS EQUALLY SPACED FOR 5/16 DIA. BALLS
.020/.010 R
O D CONCENTRIC TO BORE WITHIN .0002 FIR
MAT'L M I STEEL (R_c55) - SILVER PLATED LANDS
T289449
1.628
1.636 DIA. GRIND
1.630
1.638 DIA
.276
.272
.552 GRIND
.544
.3300
.3260
.360
.350
.097
REF.
1.281 BEFOR DRILLING
1.285 DIA BLANK SIZE
1.3316
1.3308 BEFORE SILVER PLATING
1.3306
1.3278 AFTER SILVER PLATING
1.381
1.389 DIA
.020 MAX CHAMFER

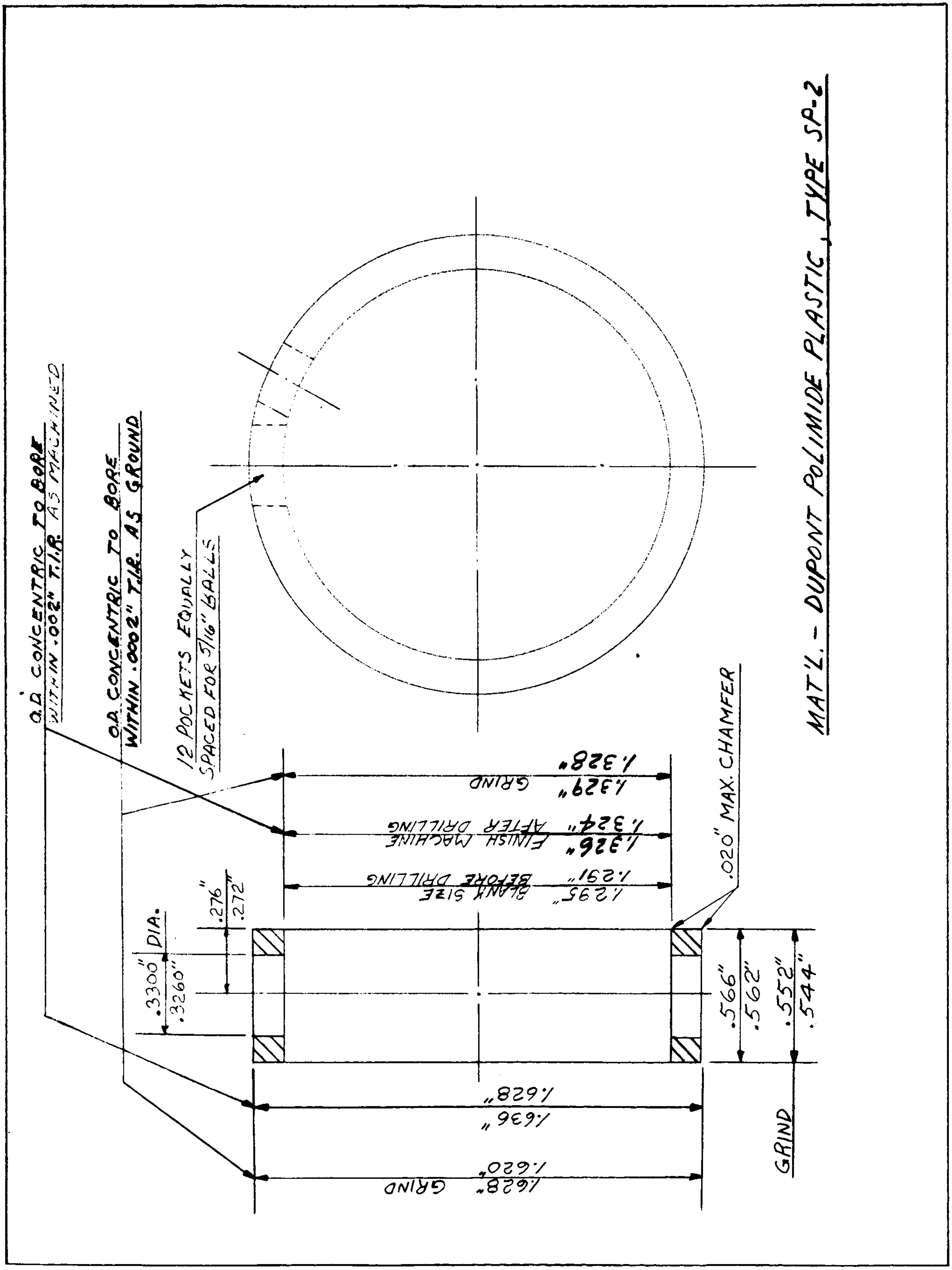
ENCLOSURE 4


(12) POCKETS EQUALLY SPACED FOR 5/16" DIA. BALLS
O.D. CONCENTRIC TO BORE WITHIN .0002" T.I.R.
MAT'L: HARDENED (Rc 57-60) M-1 STL. - SILVER PLATED ALL OVER
.020"/.010"R
1.628"
1.636" DIA. GRIND
1.630"
1.638" DIA.
.276"
.272"
.552" GRIND
.544
.3300" DIA
.3260"
.360"
.350"
.097
REF.
1.286"
1.290" DIA. BLANK SIZE
1.310"
1.314" FINISH MACHINE
1.3308"
1.3316" DIA. GRIND
1.3568"
1.3578" DIA. GRIND
.020 MAX CHAMFER

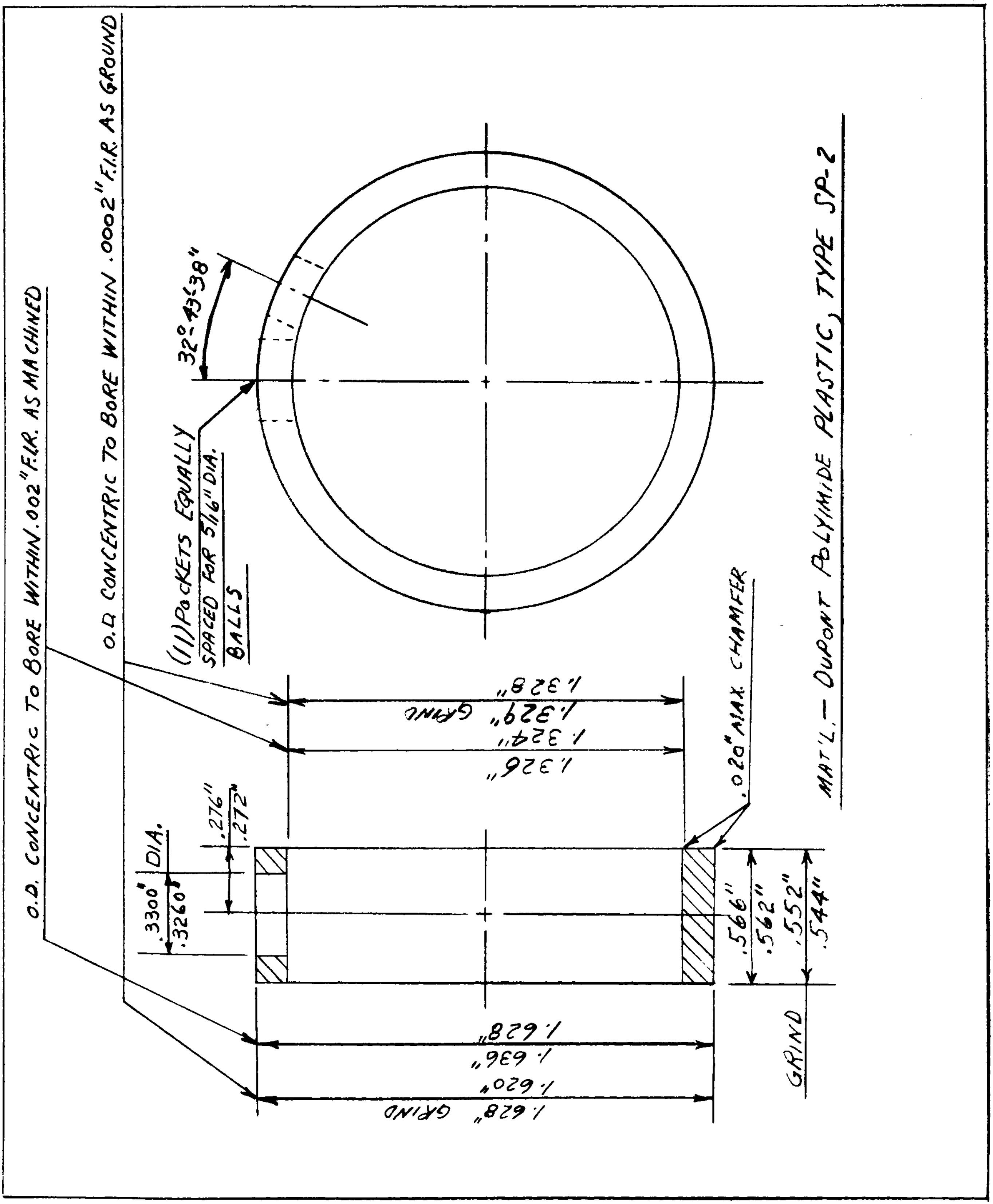
ENCLOSURE 5


MAT'L. - HARDENED (Rc 55) M-1 STEEL
O.D. CONCENTRIC TO BORE WITHIN .0002" T.I.R.
1.638"
1.630" DIA.
1.4136"
1.4116" DIA.
1.3316"
1.3308" DIA.
.276"
.272"
.209"
.205"
.360"
.350"
.3300" DIA.
.3260"
.552"
.544"
1.4364"
1.4329" DIA.
.097" REF.

ENCLOSURE 6


O.D. CONCENTRIC TO BORE
WITHIN .002" T.I.R. AS MACHINED
O.D. CONCENTRIC TO BORE
WITHIN .0002" T.I.R. AS GROUND
12 POCKETS EQUALLY
SPACED FOR 5/16" BALLS
MAT'L. - DUPONT POLIMIDE PLASTIC, TYPE SP-2
1.328"
1.329" GRIND
1.324" AFTER DRILLING
1.326" FINISH MACHINE
1.291" BEFORE DRILLING
1.295" BLANK SIZE
.020" MAX. CHAMFER
.276"
.272"
.3300" DIA.
.3260"
.566"
.562"
.552"
.544"
GRIND
1.628"
1.636"
1.620"
1.628" GRIND

ENCLOSURE 7


O.D. CONCENTRIC TO BORE WITHIN .002" F.I.R. AS MACHINED
O.D. CONCENTRIC TO BORE WITHIN .0002" F.I.R. AS GROUND
32° 43' 38"
(11) POCKETS EQUALLY SPACED FOR 5/16" DIA. BALLS
MAT'L. — DUPONT POLYIMIDE PLASTIC, TYPE SP-2
.020" MAX. CHAMFER
1.328"
1.329" GRIND
1.324"
1.326"
.276"
.272"
.3300"
.3260"
DIA.
.566"
.562"
.552"
.544"
GRIND
1.628"
1.636"
1.620"
1.628" GRIND

Summarized Results of Phase I Testing of 7205 CVM WB49 Steel Bearings #(456684)

Speed - 42,800 RPM

Run No.	Test Bearing(b) No.	Test Bearing(b) Location	Lubricant	Test Duration Hours	Test Duration 10^6 Revs	Thrust Load (lbs)	Mean Temperature, °F Brg.	Mean Temperature, °F Housing	Mean Temperature, °F Oil in Sump	Oil Consumed	(a) Brg. Condition After Test: Cage Bore Wear,	(Mils)	Raceways & Balls
	608	Drive					488				Slight	1.5	I.R.&O.R.-Slightly glazed Balls-OK.
63			Monsanto MCS 353	1.1	2.82	459		445	430	200			
	607	Load					446				Slight	7.5	I.R,O.R. & Balls smeared.
	613	Drive					585				Slight	2.4	I.R. Superficially pitted O.R. Superficially pitted & glazed Balls O.K.
64			Monsanto MCS 353	52.5	134.8	459		596	606	700			
	609	Load					601				Slight	2.2	I.R. Flaked O.R.Glazed & Slight.
	616	Drive					414				Very Slight	0.6	I.R,O.R & Balls smeared
65			Monsanto MCS 353	0.1	.26	459		-	-	-			
	604	Load					389				Very Slight	0.5	I.R.,OR & Balls OK.
	619	Drive					443				Not appreciable	0.1	I.R.,O.R.& Balls smeared
66(c)			Kendex Bright Stock 0846	0.5	.13	459		-	-	-			
	602	Load					414				Not appreciable	0.1	I.R.,O.R.Slightly glazed Balls OK.
	610	Drive					572				Slight	2.8	I.R.,O.R. & Balls OK.
67(d)			Kendex Bright Stock 0846	75.75	194.6	459		590	624	2955			
	600	Load					610				Slight	2.6	I.R. Superficially pitted & glazed O.R. Slightly glazed Ball superficially pitted.
	627	Drive					571				Not appreciable	0.1	I.R.,O.R. Slightly glazed & Fragment dented Balls OK.
68(c)			Kendex Bright Stock 0846	22	56.5	459		648	635	1250			
	612	Load					606				Excessive	103	I.R.Glazed & Slightly smeared O.R.Glazed & smeared (lands grooved)Balls-OK
	640	Drive					596		448		Not appreciable	0.1	I.R., O.R., Balls OK
E-97(e)			XRM 177F	6.7	16.8	459				125			
	632	Load					592		448		Slight (cage pocket brake through its side rail)	3.4	I.R., O.R. Slightly glazed Balls - 1 flaked 10 OK
	645	Drive					599		594		Not appreciable	0.1	I.R., O.R. Balls OK
E98(e)			XRM 177F	22.8	58.6	454		615		525	Not appreciable		I.R., O.R. glazed
	642	Load					549		582		Slight	1.5	Balls-1 flaked 10 OK

(a) A bearing is considered to be in good condition if after testing the finishing marks produced in manufacturing of the bearing are still evident in the ball path. A slightly glazed bearing is one in which these finishing marks are not as outstanding or are partially removed.

(b) The inner race and outer race grooves of these bearings were both honed.

(c) The cages used in these tests were M-1 (Rc 55) steel cages (unplated) which were reduced in weight as shown in Enclosure 5.

(d) The cages used in this test were made of Dupont polyimide plastic type SP-2 as shown in Enclosure 6.

(e) The cages used in this test were made of Dupont polyimide plastic type SP-2 as shown in Enclosure 7. Consequently, the bearings were assembled with 11 balls for a reduced AFBMA $L_{10} = 200 \times 10^6$ Revs. cc/P = 5.85.

ENCLOSURE 13

AL65T056

ENCLOSURE 8

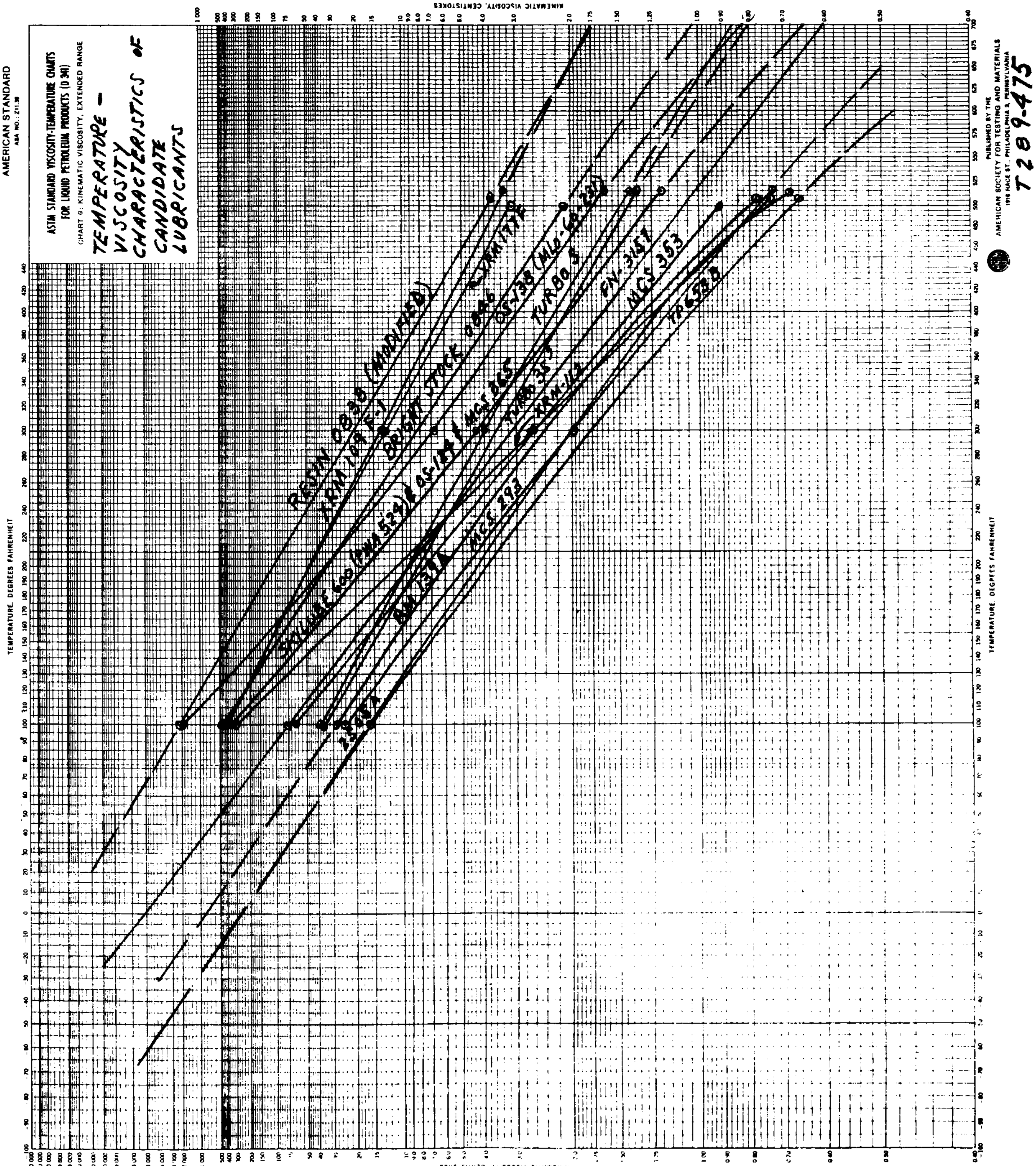
SKF 7205 ANGULAR CONTACT TEST BEARING DIMENSIONS* BEFORE TEST

Bearing No.	Surface Finish (10⁻⁶ In., RMS) I.R.	Surface Finish O.R.	Average Outside Diameter (Microns)	Average Bore Diameter (Microns)	Contact Angles (Degrees)	Average Radial Looseness (Microns)	Average Radial Cage Play (Inches)	Taper (Microns) O.R.	Taper I.R.	Out of Roundness (Microns) O.R.	Out of Roundness I.R.
136	-	-	51.995	24.999	18.0	47	.0080	2.5	1.0	3.0	2.0
138	-	-	51.997	24.996	15.8	46	.0080	2.5	1.0	3.0	2.0
198	4.0	6.5	51.997	24.997	-	47	.0079	1.0	1.0	2.0	1.0
200	4.3	8.0	51.997	24.997	21.8	54	.0065	4.0	1.0	2.0	1.0
215	8.5	8.5	51.999	24.996	26.4	47	.0084	2.0	0.0	2.0	1.0
278	3.5	7.3	51.995	24.996	19.3	47	.0071	1.0	0.0	2.0	1.0
286	3.0	7.8	51.997	24.995	21.1	45	.0100	1.0	2.0	2.0	1.0
287	2.6	7.0	51.999	24.997	20.7	49	.0090	0.5	1.5	2.0	2.0
188	4.2	6.7	51.996	24.996	19.0	47	.0085	3.0	1.0	4.0	2.0
289	3.0	8.5	51.995	24.996	20.1	50	.0060	1.0	1.0	2.0	1.0
290	4.3	7.8	51.997	24.996	20.6	48	.0080	1.0	0.0	2.0	2.0
291	3.2	8.0	51.999	24.998	19.9	48	.0082	2.0	2.5	3.0	2.0
292	3.7	6.5	51.998	24.996	20.4	45	.0090	3.5	1.0	2.0	1.0
293	2.5	6.8	51.999	24.997	20.8	50	.0080	2.0	0.0	2.0	1.0
294	3.0	6.7	51.997	24.995	19.2	47	.0080	0.5	0.0	2.0	1.0
295	3.5	7.0	51.997	24.998	21.3	51	.0075	1.0	1.0	2.0	1.0
296	3.1	7.0	51.995	24.997	20.4	48	.0075	3.5	1.0	3.0	1.0
297	3.3	7.2	51.998	24.998	19.9	43	.0056	3.0	1.5	2.0	2.0
298	2.6	6.7	51.995	24.997	20.8	51	.0076	3.5	1.0	2.0	2.0
299	2.3	7.2	51.997	24.997	20.1	49	.0077	3.5	0.0	3.0	2.0
300	3.7	7.5	51.996	24.997	21.5	49	.0076	3.5	0.0	3.0	2.0
319	3.9	5.2	51.994	24.997	19.9	50	.0085	2.5	2.0	3.0	1.0
329	3.7	6.0	51.997	24.999	20.9	49	.0095	0.5	1.0	2.0	1.0
364	3.5	7.5	51.998	24.998	21.3	47	.0090	1.0	0.0	2.0	2.0
365	3.9	6.0	51.997	24.997	21.7	51	.0090	0.5	0.0	3.0	1.0
366	3.1	7.5	51.997	24.996	20.4	46	.0080	2.0	0.0	2.0	2.0
367	3.1	7.1	51.996	24.999	20.9	49	.0080	1.0	3.5	2.0	5.0
370	3.8	5.8	51.996	24.998	21.3	48	.0100	2.0	0.5	2.0	2.0
371	3.0	7.0	51.995	24.996	20.8	48	.0085	0.0	2.0	3.0	1.0
372	2.7	7.0	51.995	24.998	20.6	48	.0075	1.0	1.0	2.0	1.0
374	4.0	7.3	51.999	24.996	19.7	43	.0075	1.0	1.0	[illegible]	1.0
375	3.3	6.8	51.998	24.999	19.7	47	.0070	2.0	1.0	2.0	1.0
376	3.0	7.3	51.999	24.997	21.1	46	.0082	2.0	2.0	2.0	1.0
377	2.8	7.5	51.996	24.996	19.2	43	.0083	1.0	0.5	2.0	2.0
378	2.8	7.0	51.996	24.997	22.5	65	.0080	0.5	1.0	3.0	1.0
379	3.0	8.0	51.996	24.998	19.0	49	.0082	1.5	2.5	3.0	2.0
380	3.6	6.0	51.997	24.997	20.4	48	.0085	3.0	2.0	3.0	1.0
381	3.0	7.3	51.998	24.996	19.9	51	.0085	0.5	0.0	2.0	1.0
382	3.4	7.8	51.998	24.997	18.0	43	.0072	2.0	0.0	2.0	1.0
383	3.0	7.0	51.999	24.996	18.0	33	.0082	0.0	0.0	2.0	1.0
385	3.0	6.5	51.998	24.997	19.0	45	.0073	2.0	1.0	1.0	1.0
386	3.5	6.0	51.997	24.997	20.4	46	.0069	0.0	1.0	2.0	1.0
387	3.1	6.8	51.996	24.996	20.4	47	.0061	2.5	2.0	3.0	1.0
388	3.5	8.3	51.995	24.997	19.0	50	.0070	3.0	0.0	2.0	2.0
389	3.0	7.8	51.997	24.997	19.0	43	.0070	3.0	1.0	2.0	1.0
390	3.3	6.5	51.997	24.997	19.0	50	.0076	2.5	1.0	3.0	1.0
391	3.3	7.8	51.997	24.996	18.5	40	.0080	0.0	0.5	2.0	2.0
396	3.	-	51.998	24.997	18.0	32	.0083	0.0	0.0	2.0	1.0
500	5.0	-	51.996	24.998	17.0	51	.0075	1.5	2.5	0.5	1.0
504	5.5	-	51.995	25.001	23.8	54	.0095	0.5	1.0	0.0	2.5
505	3.8	-	51.998	24.998	23.9	53	.0070	1.0	1.0	0.0	0.5
509	3.5	-	51.997	24.997	20.4	44	.0073	1.5	1.0	0.0	0.0
511	4.4	-	51.999	24.998	23.0	54		2.0	1.0	3.0	1.0
562	-	-	52.001	24.997	19.5	38	.0069	1.0	0.5	0.0	2.0
577	8.0	-	51.999	24.998	14.2	38	.0073	0.0	1.5	1.0	2.0
579	-	-	51.997	24.999	18.5	42	.0095	0.0	3.5	1.0	0.5
600	1.6	2.8	51.996	24.996	-	40	.0048	-	-	-	-
601	1.9	3.0	51.997	24.997	12.0	37	.0079	-	-	-	-
602	2.0	3.5	51.999	24.997	12.7	36	.0089	-	-	-	-
604	2.0	3.0	51.997	24.998	12.7	39	.0084	-	-	-	-
605	3.0	7.0	51.999	24.996	18.0	38	.0082	0.0	0.0	2.0	1.0
606	2.3	3.3	51.999	25.001	12.0	37	.0087	-	-	-	-
607	1.9	3.5	51.998	24.997	13.4	42	.0078	-	-	-	-
608	1.5	3.3	51.999	24.997	16.4	40	.0110	-	-	-	-
609	1.6	3.2	51.999	24.999	12	41	.0078	-	-	-	-
610	1.7	3.3	51.996	24.998	18.5	51	.0050	-	-	-	-
611	1.6	3.0	52.001	24.996	13.4	38	.0080	-	-	-	-
612	1.7	3.0	52.000	24.997	12.7	39	.0100	-	-	-	-
613	1.7	3.5	51.996	24.998	13.4	42	.0078	-	-	-	-
616	1.5	3.8	51.997	24.997	13.4	42	.0083	-	-	-	-
618	1.8	3.0	51.998	24.998	14.0	38	.0081	-	-	-	-
619	1.9	3.8	51.998	24.995	12.7	36	.0095	-	-	-	-
621	1.8	3.5	51.996	24.995	12.0	42	.0075	-	-	-	-
622	1.8	3.3	51.998	24.998	14.0	40	.0074	-	-	-	-
623	1.6	3.5	51.996	24.997	14.0	44	.0079	-	-	-	-
624	1.8	3.8	51.999	24.998	15.3	41	.0080	-	-	-	-
625	1.6	3.5	51.999	24.999	15.8	37	.0080	-	-	-	-
626	1.8	2.5	51.999	24.997	14.0	42	.0073	-	-	-	-
627	1.7	3.0	51.998	24.998	13.4	39	.0098	-	-	-	-
628	1.4	3.0	51.996	24.996	14.7	41	.0071	-	-	-	-
629	2.0	3.0	51.999	24.997	14.0	37	.0080	-	-	-	-
631	2.3	2.8	51.998	25.000	12.7	38	.0080	-	-	-	-
632	1.5	3.3	51.998	24.996	13.4	45	.0110	-	-	-	-
633	1.7	3.0	51.999	24.997	12.0	37	.0078	-	-	-	-
634	1.9	3.8	51.998	24.997	12.0	38	.0080	-	-	-	-
635	2.3	2.5	51.999	24.998	11.3	40	.0080	-	-	-	-
636	1.6	2.5	51.995	24.998	12.7	44	.0080	-	-	-	-
637	1.6	3.5	51.992	24.997	13.4	38	.0073	-	-	-	-
640	1.9	2.8	51.998	24.998	14.0	43	.0130	-	-	-	-
642	2.0	3.0	51.998	24.998	16.4	49	.0130	-	-	-	-
644	1.8	3.5	52.000	24.997	15.3	31	.0081	-	-	-	-
645	1.9	3.5	51.998	24.996	12.7	44	.0110	-	-	-	-
647	1.5	3.0	51.993	24.997	11.3	37	.0078	-	-	-	-
650	1.6	3.5	51.997	24.998	12.7	38	.0069	-	-	-	-
658	1.9	3.0	52.000	24.997	12.0	37	.0081	-	-	-	-
669	2.3	3.3	51.999	24.999	14.0	37	.0081	-	-	-	-

* Blank spaces shown above indicate that these measurements were not obtained.

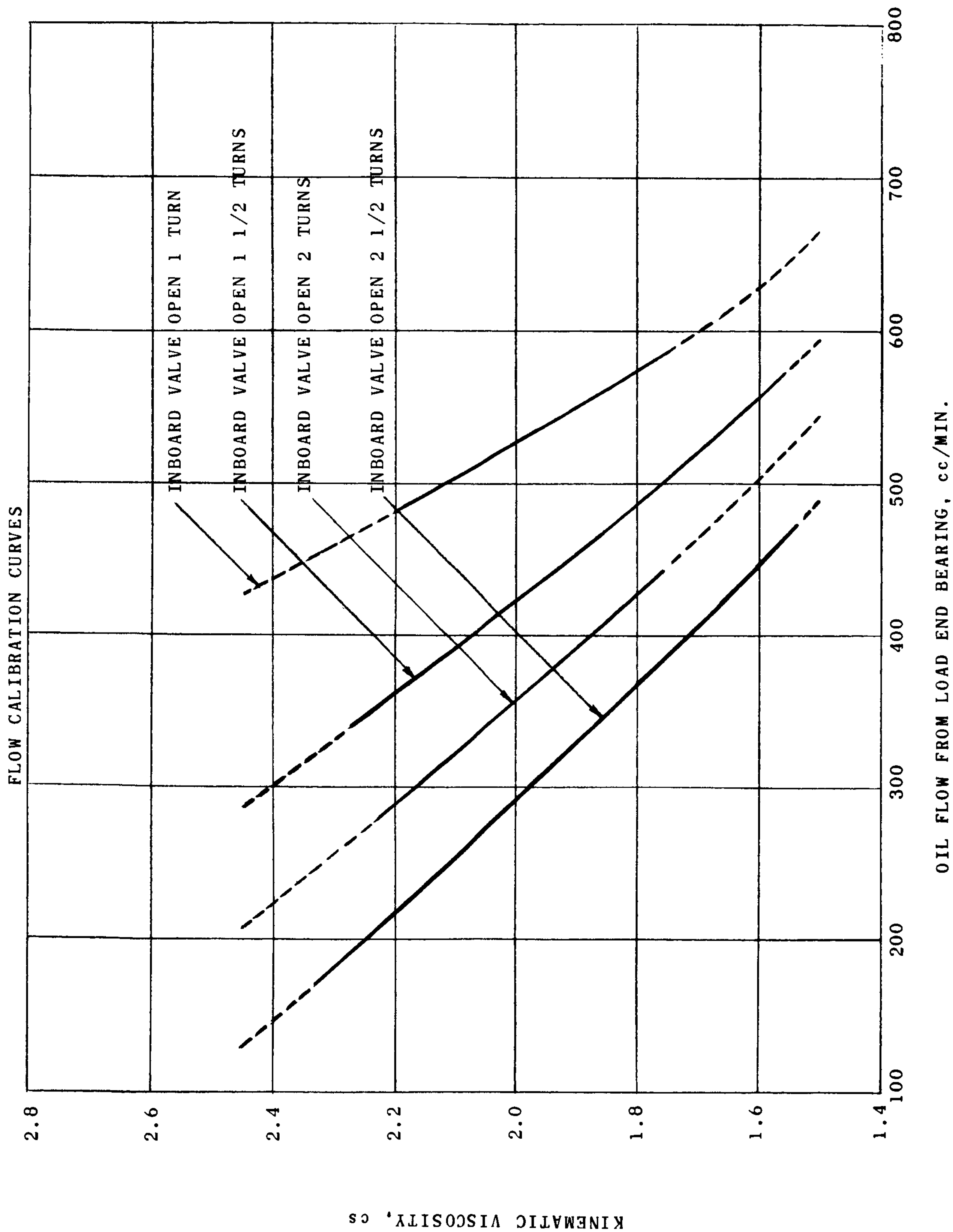
AL65T056

ENCLOSURE 9

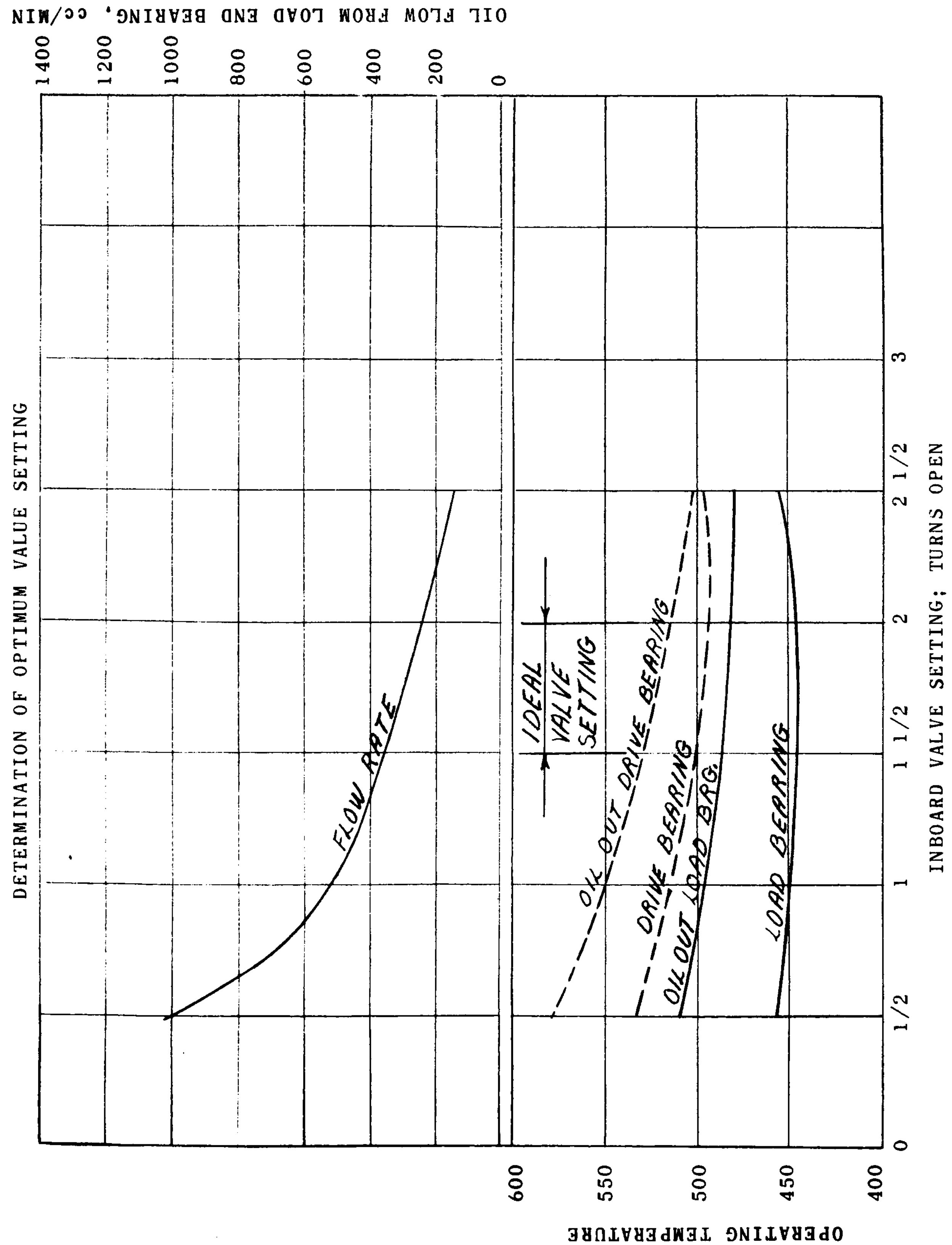


RESEARCH LABORATORY SKF INDUSTRIES, INC.

ENCLOSURE 10



ENCLOSURE 11



ENCLOSURE 12

Summarized Results of Phase I Testing of 7205 CVM-M-1 Steel Bearings #(455760)

Speed - 42,800 RPM

Run No.	Test No.	Bearing(b) Location	Lubricant	Test Duration Hours	Test Duration 10^6 Revs	Thrust Load (lbs)	Mean Temperature, °F Brg.	Mean Temperature, °F Housing	Mean Temperature, °F Oil In Sump	Mean Temperature, °F Oil Consumed	(a) Brg. Condition AFTER TEST: Cage Bore Wear	(Mils)	Raceways & Balls
60	377	Drive	Monsanto MCS 353	0.05	0.13	459	369	-	-	-	Not appreciable	0.1	IR-Smeared OR-Slightly glazed and smeared Balls smeared
	376	Load					363				Very Slight	0.7	I.R, O.R, Slightly glazed Balls-OK.
62	372	Drive	Monsanto MCS 353	29.4	74.9	459	554	601	563	500	Not appreciable	0.1	I.R., O.R. & Balls-OK.
	371	Load					588		596		Slight	1.8	I.R., O.R. & Balls smeared.
E73	379	Drive	Monsanto MCS 365	0.05	0.13	459	415	-	-	-	Not appreciable	0.1	I.R., O.R. & Ball smeared
	378	Load					358	-	-	-	Not appreciable	0.1	I.R., O.R.-Good Balls-ok
E74	198	Drive	Monsanto MCS 365	-	-	459	589	535	-	75	Excessive	10.2	I.R.-Flaked O.R.-Good Balls-ok
	200	Load		3.8	9.76		571		517		Excessive	9.5	IR-Good OR-Slightly smeared Balls-smeared
E75	(c)381	Drive	Monsanto MCS 365	0.05	0.13	459	300	-	-	-	Very slightly	0.4	I.R.-Glazed & slight smeared O.R.-Good Balls-ok
	380	Load					300	-	-	-	Not appreciable	<0.1	I.R.-Good O.R.-Slightly smeared Balls-Smeared

Unused Oil Analysis

	Visc. at 100°F cs.	Acid No.	Solid (mg/100 ml.)
Monsanto MCS353	61.7	0.11	5.0

(a) A bearing is considered to be in good condition if after testing the finishing marks produced in manufacturing of the bearing are still evident in the ball path. A slightly glazed bearing is one in which these finishing marks are not as outstanding or are partially removed.

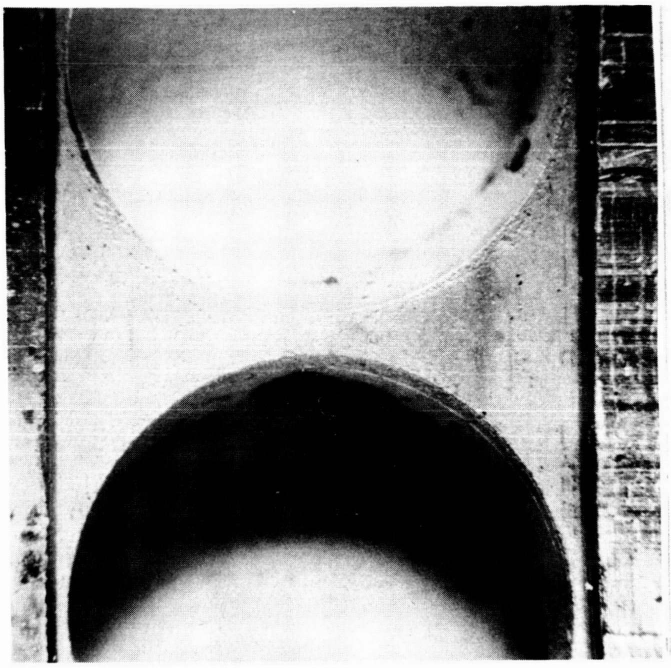
(b) The inner race grooves of these bearings were honed; whereas, their outer race grooves were ground and polished.

(c) The bearing temperatures for this test were estimated since actual temperatures were not obtained due to the short test duration.

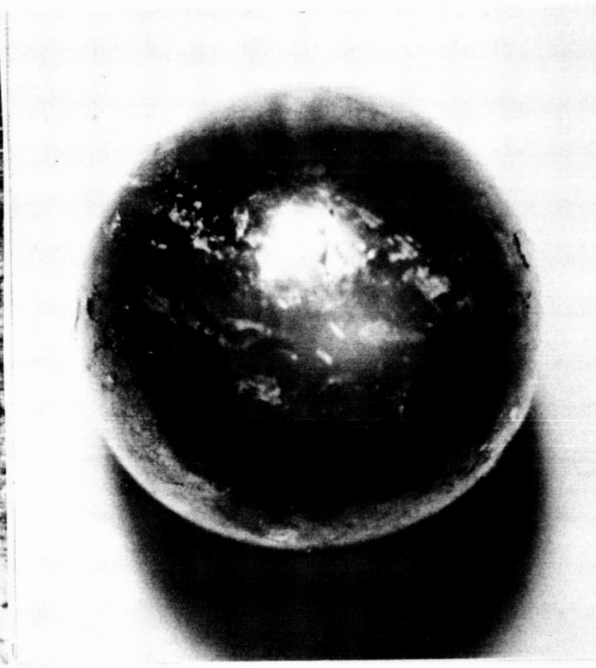
ENCLOSURE 14

FAILED M-1 TOOL STEEL BEARING AFTER RUNNING $.13X10^6$ REVOLUTIONS AT 42,800 RPM, A MEAN TEMPERATURE OF 369°F AND UNDER 459 LBS. THRUST LOAD WITH CIRCULATING MONSANTO MCS353 OIL IN A N_2 BLANKET

(BEARING NO. 377 ON DRIVE END FROM RUN NO. 60)

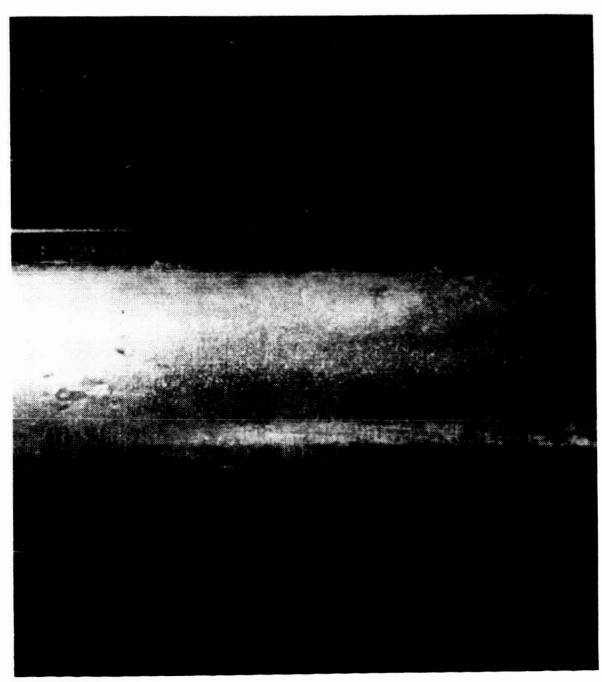


CAGE



BALL

INNER RACEWAY

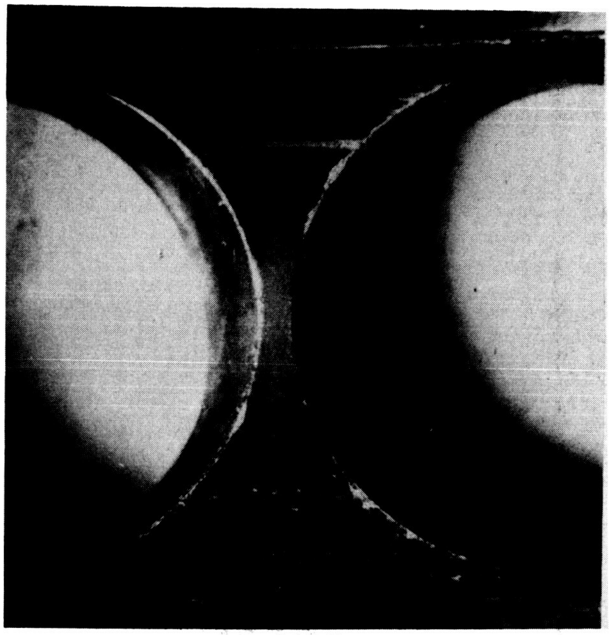


OUTER RACEWAY

ENCLOSURE 15

FAILED M-1 TOOL STEEL BEARING AFTER RUNNING 74.9×10^6 REVOLUTIONS AT 42,800 RPM, A MEAN TEMPERATURE OF 588°F AND UNDER 459 LBS. THRUST LOAD WITH CIRCULATING MONSANTO MCS353 OIL IN A N_2 BLANKET

(BEARING NO. 371 ON LOAD END FROM RUN NO. 62)



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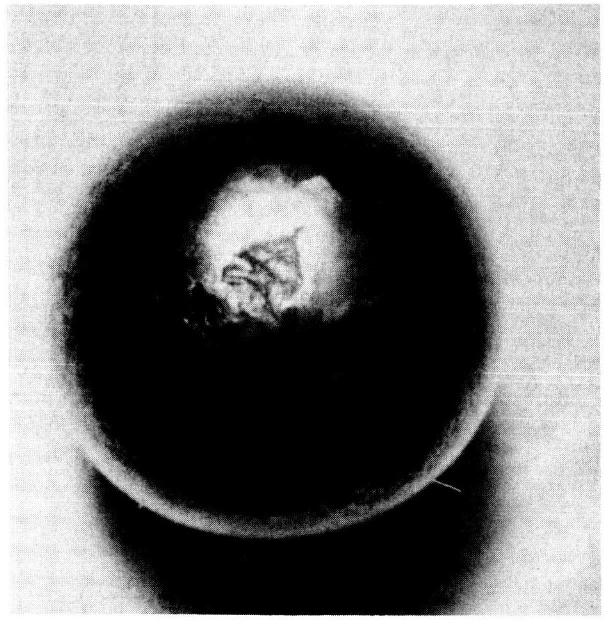

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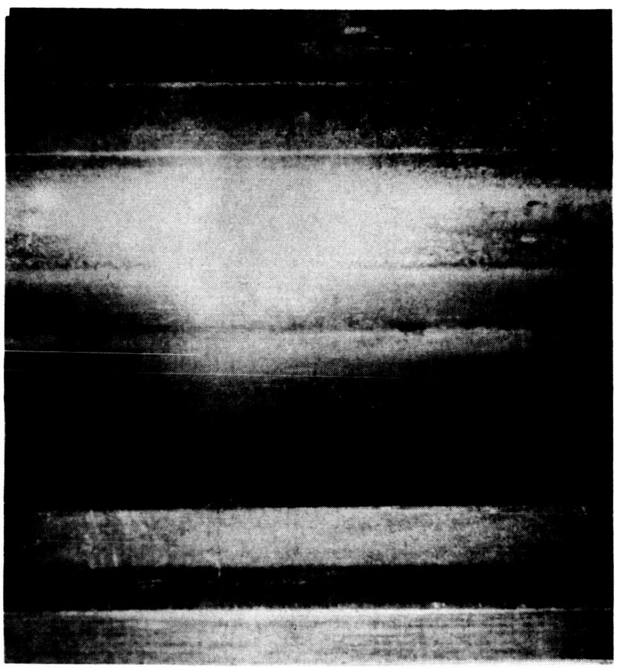
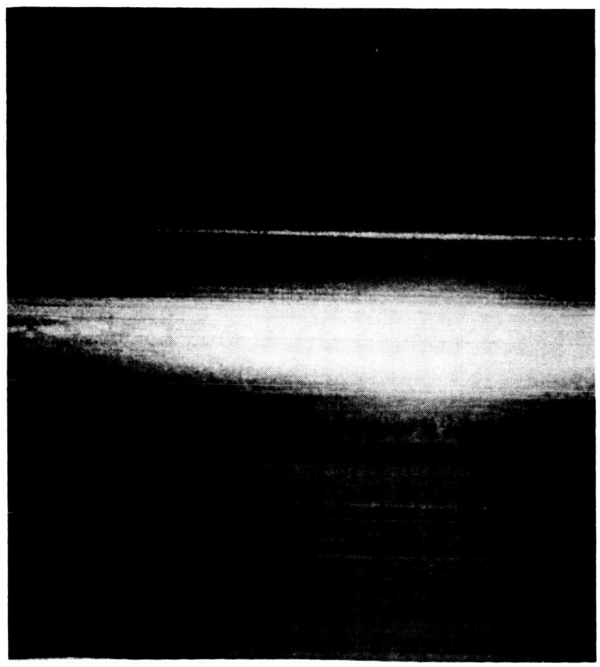


INNER RACEWAY

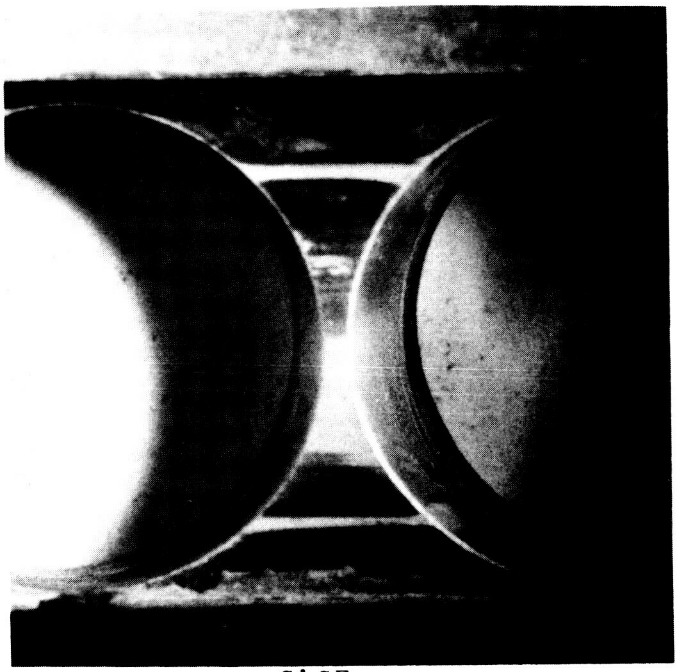


OUTER RACEWAY

ENCLOSURE 16

FAILED WB49 TOOL STEEL BEARING AFTER RUNNING $2.82X10^6$ REVOLUTIONS AT 42,800 RPM, A MEAN TEMPERATURE OF 446°F AND UNDER 459 LBS. THRUST LOAD WITH CIRCULATING MONSANTO MCS353 OIL IN A N_2 BLANKET

(BEARING NO. 607 ON LOAD END FROM RUN NO. 63)



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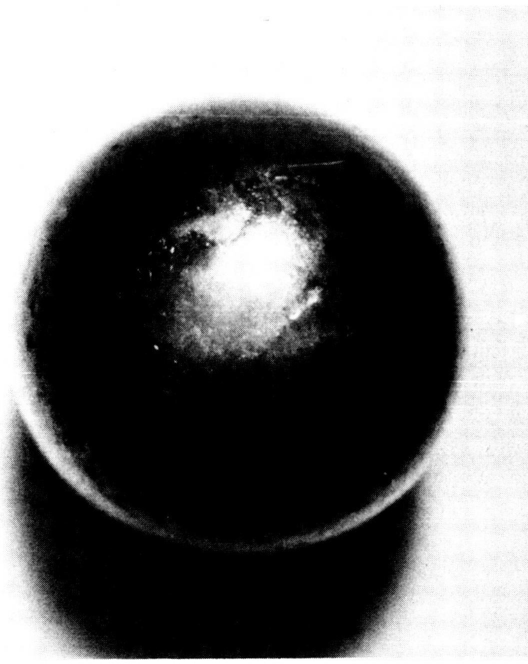
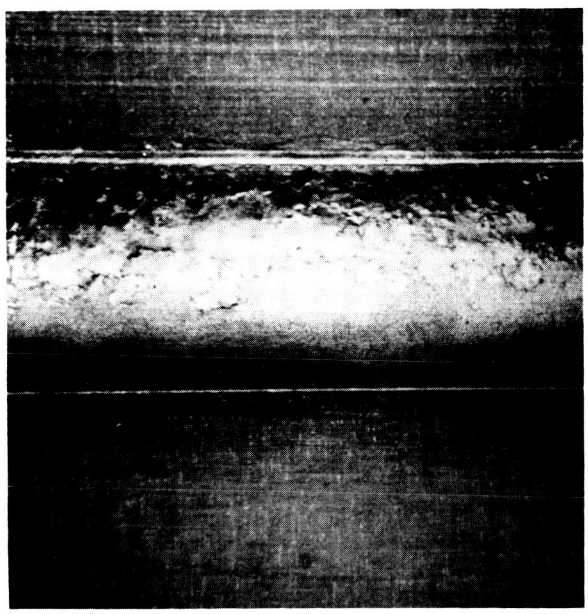


BALL

INNER RACEWAY

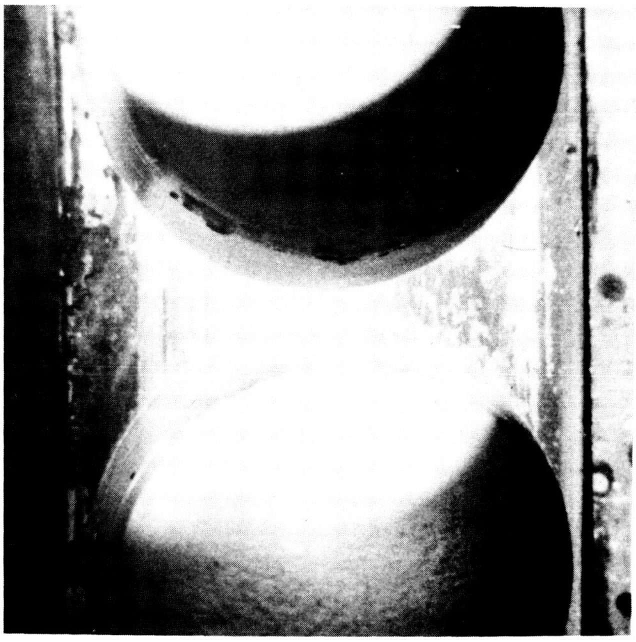


OUTER RACEWAY

ENCLOSURE 17

FAILED WB49 TOOL STEEL BEARING AFTER RUNNING $.26 \times 10^6$ REVOLUTIONS AT 42,800 RPM, A MAXIMUM TEMPERATURE OF 414°F AND UNDER 459 LBS. THRUST LOAD WITH CIRCULATING MONSANTO MCS353 OIL IN A N_2 BLANKET

(BEARING NO. 616 ON DRIVE END FROM RUN NO. 65)



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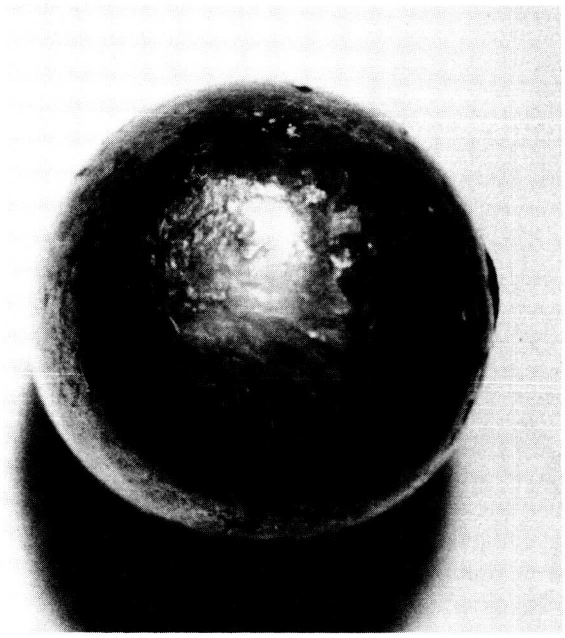

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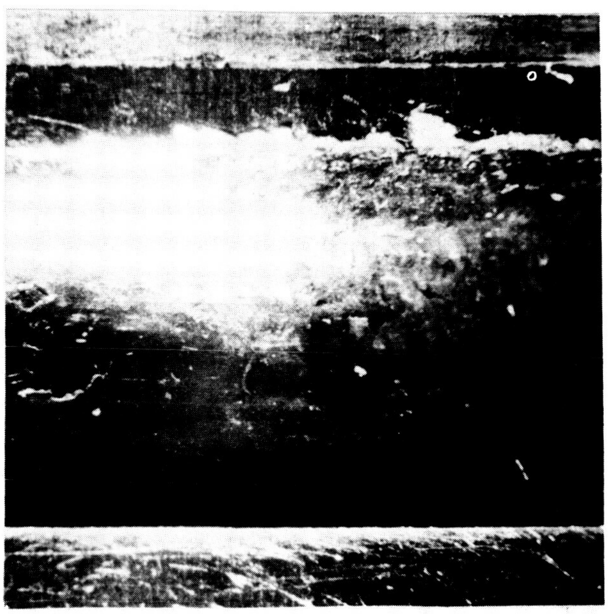


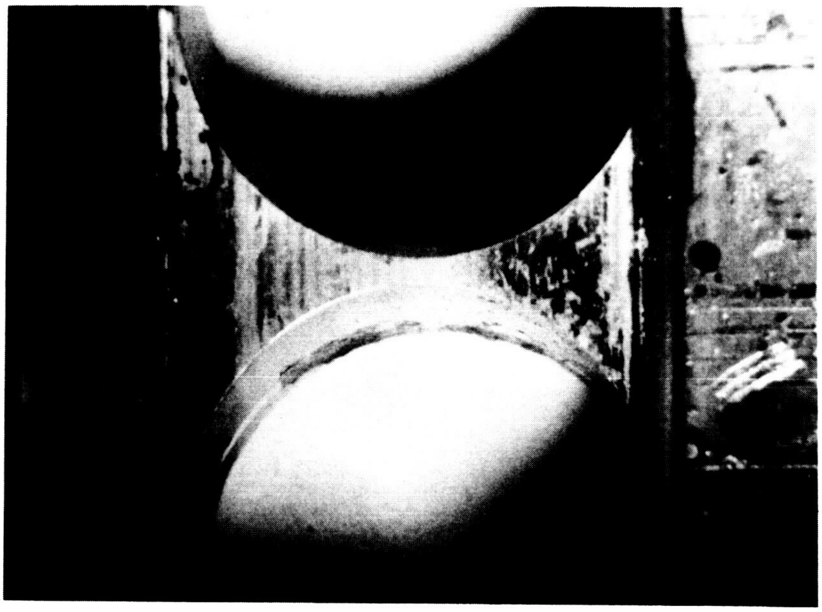
INNER RACEWAY

OUTER RACEWAY

ENCLOSURE 18

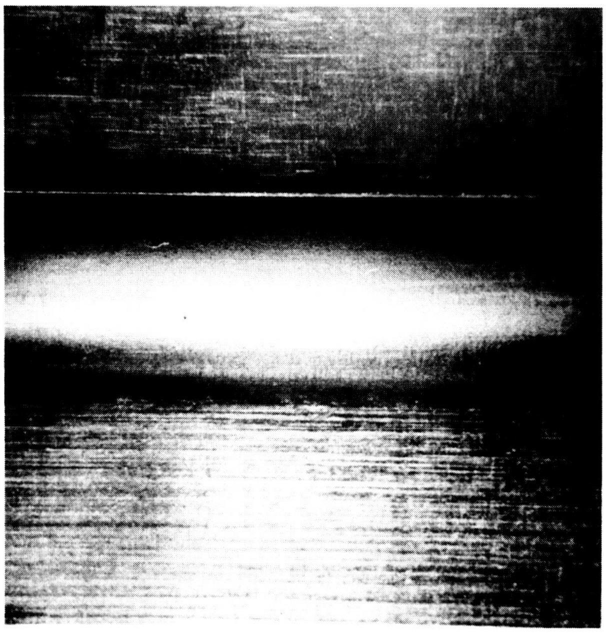
UNFAILED WB49 TOOL STEEL BEARING AFTER RUNNING $.26 \times 10^6$ REVOLUTIONS AT 42,800 RPM, A MAXIMUM TEMPERATURE OF 389°F AND UNDER 459 LBS. THRUST LOAD WITH CIRCULATING MONSANTO MCS353 OIL IN A N_2 BLANKET

(BEARING NO. 604 ON LOAD END FROM RUN NO. 65)



CAGE

INNER RACEWAY

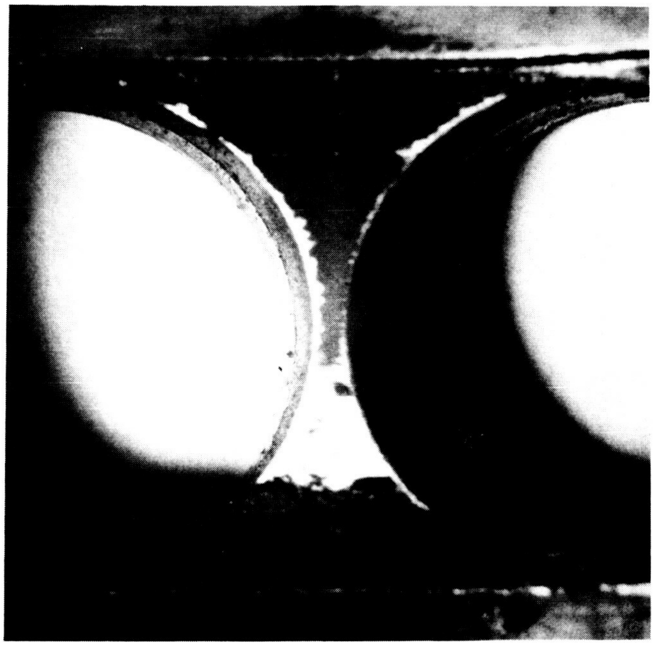


OUTER RACEWAY

ENCLOSURE 19

FAILED WB49 TOOL STEEL BEARING AFTER RUNNING $134.8X10^6$ REVOLUTIONS AT 42,800 RPM, A MEAN TEMPERATURE OF 601°F AND UNDER 459 LBS. THRUST LOAD WITH CIRCULATING MONSANTO MCS353 OIL IN A N_2 BLANKET

(BEARING NO. 609 ON LOAD END FROM RUN NO. 64)



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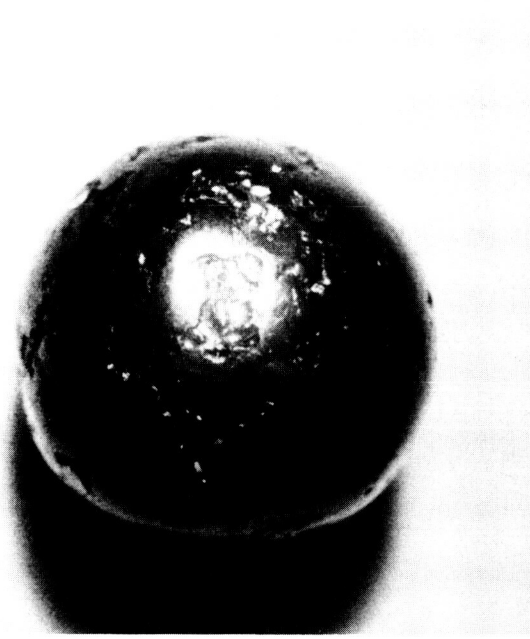
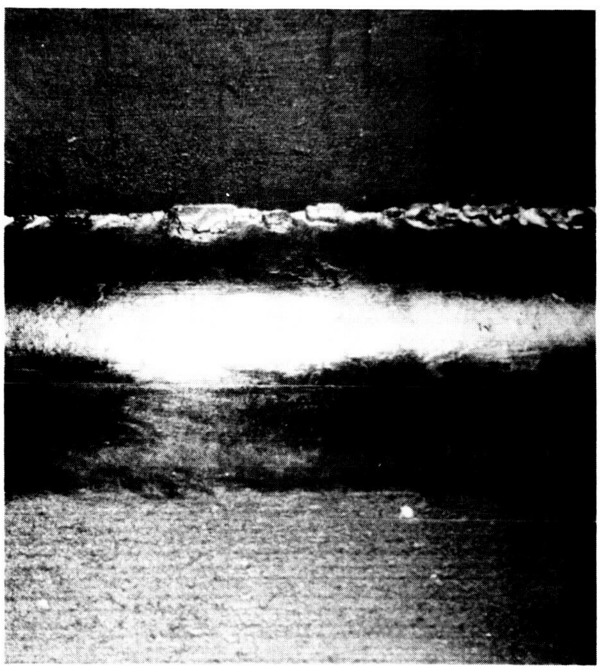


BALL

INNER RACEWAY

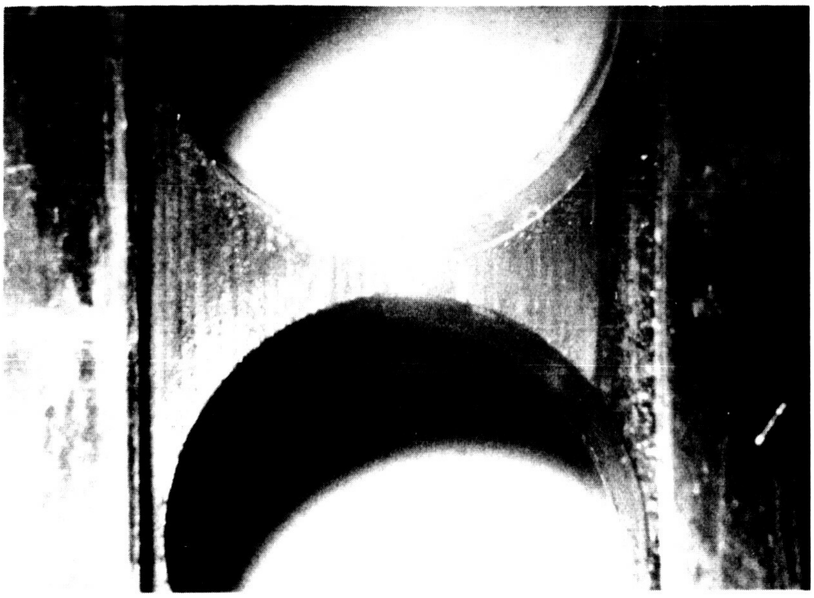


OUTER RACEWAY

ENCLOSURE 20

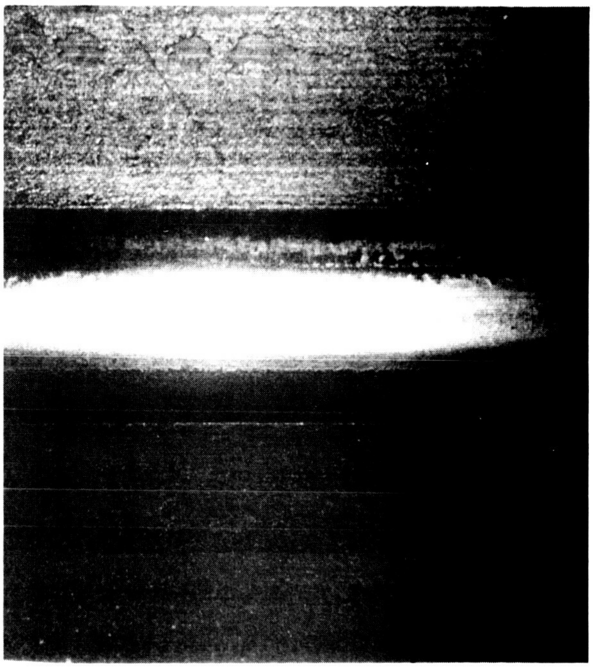
UNFAILED WB49 TOOL STEEL BEARING AFTER RUNNING $134.8X10^6$ REVOLUTIONS AT 42,800 RPM, A MEAN TEMPERATURE OF 585°F AND UNDER 459 LBS. THRUST LOAD WITH CIRCULATING MONSANTO MCS353 OIL IN A N_2 BLANKET

(BEARING NO. 613 ON DRIVE END FROM RUN NO. 64)



CAGE

INNER RACEWAY



OUTER RACEWAY

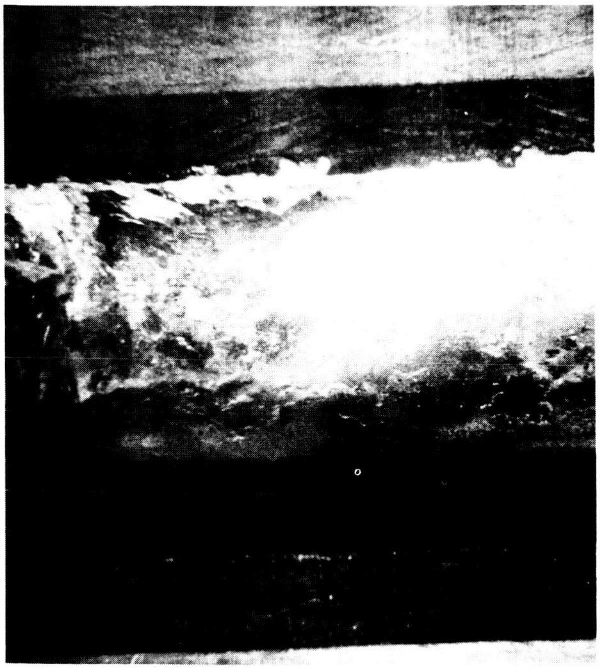
ENCLOSURE 21

FAILED WB49 TOOL STEEL BEARING AFTER RUNNING $.13 \times 10^6$ REVOLUTIONS AT 42,800 RPM, A MEAN TEMPERATURE OF 443°F AND UNDER 459 LBS. THRUST LOAD WITH CIRCULATING KENDEX BRIGHT STOCK 0846 OIL IN A N_2 BLANKET

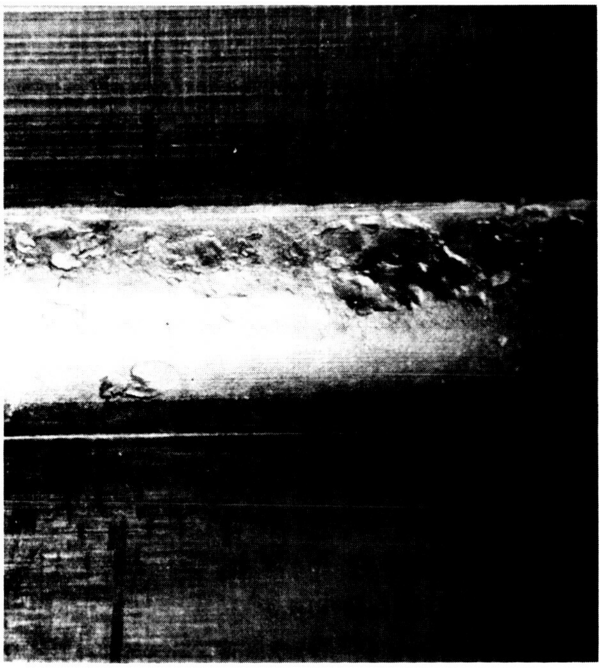
(BEARING NO. 619 ON DRIVE END FROM RUN NO. 66)

CAGE

BALL



INNER RACEWAY



OUTER RACEWAY

ENCLOSURE 22

FAILED WB49 TOOL STEEL BEARING AFTER RUNNING $56.5X10^6$ REVOLUTIONS AT 42,800 RPM, A MEAN TEMPERATURE OF 606°F AND UNDER 459 LBS. THRUST LOAD WITH CIRCULATING KENDEX BRIGHT STOCK 0846 OIL IN A N_2 BLANKET

(BEARING NO. 612 ON LOAD END FROM RUN NO. 68)

CAGE

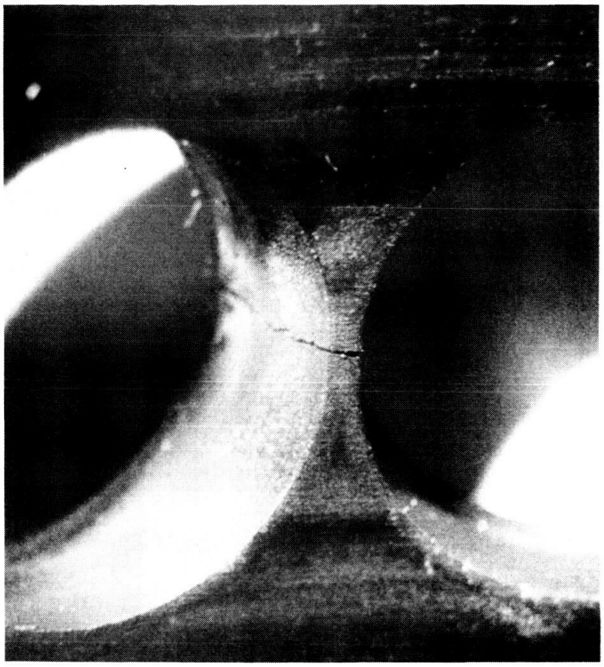
INNER RACEWAY

OUTER RACEWAY

ENCLOSURE 23

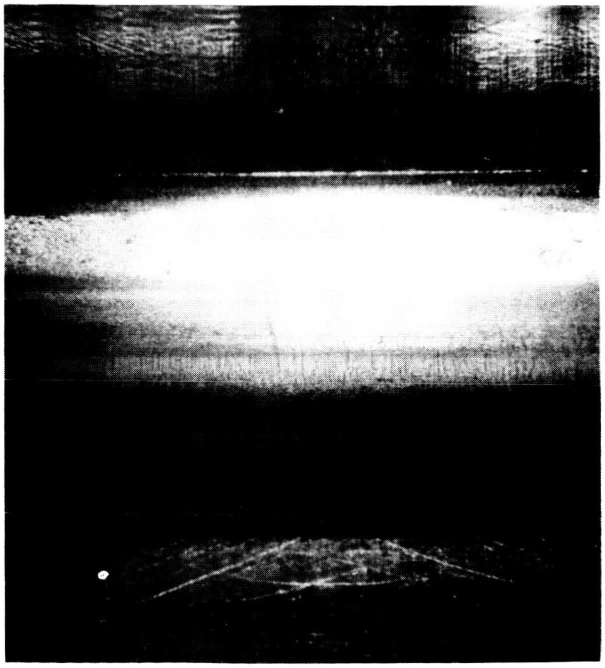
UNFAILED WB49 TOOL STEEL BEARING AFTER RUNNING 194.6×10^6 REVOLUTIONS AT 42,800 RPM, A MEAN TEMPERATURE OF 610°F AND UNDER 459 LBS. THRUST LOAD WITH CIRCULATING KENDEX BRIGHT STOCK 0846 OIL IN A N_2 BLANKET

(BEARING NO. 600 ON LOAD END FROM RUN NO. 67)

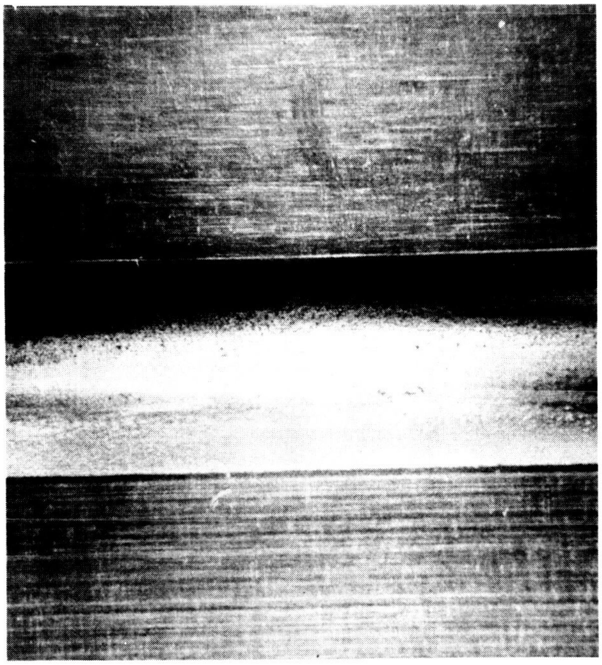


CAGE

BALL



INNER RACEWAY

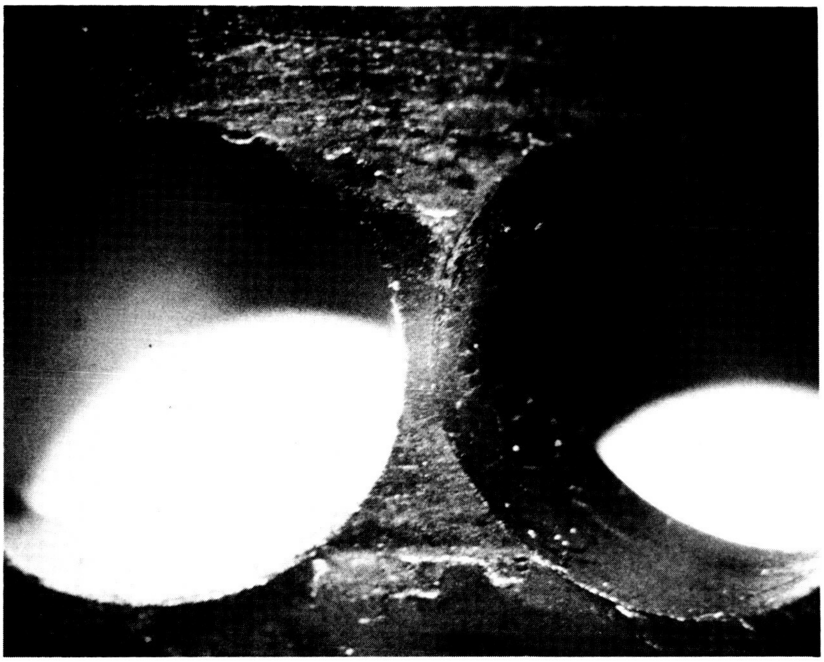


OUTER RACEWAY

ENCLOSURE 24

UNFAILED WB49 TOOL STEEL BEARING AFTER RUNNING 194.6X10^6 REVOLUTIONS AT 42,800 RPM, A MEAN TEMPERATURE OF 572°F AND UNDER 459 LBS. THRUST LOAD WITH CIRCULATING KENDEX BRIGHT STOCK 0846 OIL IN A N_2 BLANKET

(BEARING NO. 610 ON DRIVE END FROM RUN NO. 67)



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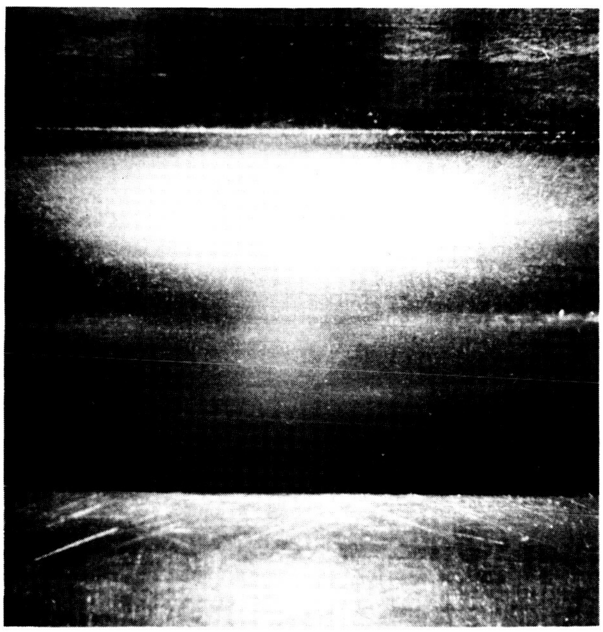
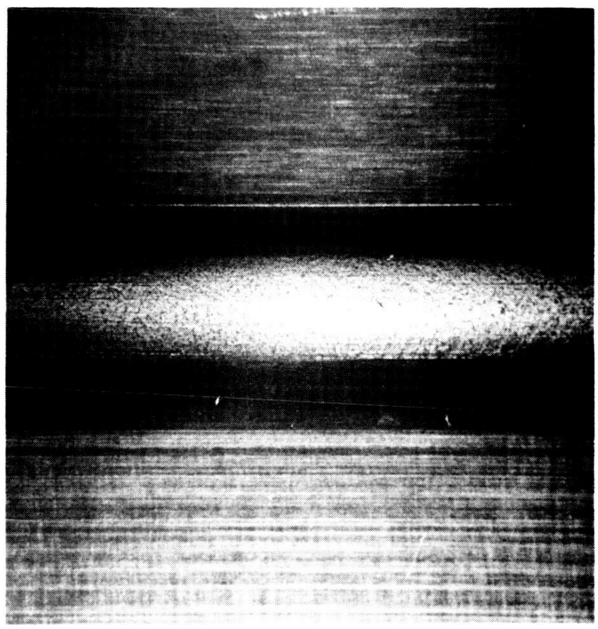


INNER RACEWAY



OUTER RACEWAY

ENCLOSURE 25

Endurance of CVM M-1 Steel 7205 Bearings[4] (#455760)

Thrust Load - 459 lbs. Speed - 42,800 RPM Lubricant - Socony Mobil XRM 109F-1

Test Run No.	Brg. No.	Cage[1] Material	Bore Wear, Mils	Ave Temp. °F	Lub Distressed Element(s)	Part(s) Failed	Life, 10^6 Revs.
E55	363	M-1(Rc 55)STL	< 0.1	540	None	None	2.2
	362	M-1(Rc 55)STL	3.6	517	IR,OR,Balls-Smeared	IR,OR,Balls	2.2
E58	370	M-1(Rc 55)STL	< 0.1	496	IR-Glazed-Superficial Pitting	None	2.3
	286	M-1(Rc 55)STL	< 0.1	518	IR-Glazed OR-Glazed, flaked	OR	2.3
E57	369	M-1(Rc 55)STL	< 0.1	506	None	None	2.4
	368	M-1(Rc 55)STL	< 0.1	490	IR & OR, Glazed-Superficial pulling Balls-Slightly smeared	None	2.4
E54	359	M-1(Rc 55)STL	0.5	533	IR-Superficial pulling OR-Slight Glaze	None	3.0
	358[2][3]	M-1(Rc 55)STL	> 1.0	524	IR,OR,Balls-smeared	IR,OR,Balls	3.0
E60	367	M-1(Rc 55)STL	< 0.1	560	IR,OR,-Glazed	None	3.3
	366	M-1(Rc 55)STL	< 0.1	490	IR,OR,Balls-smeared	IR,OR,Balls	3.3
E61	288	M-1(Rc 55)STL	< 0.1	529	None	None	4.8
	287	M-1(Rc 55)STL	< 0.1	515	IR-Glazed OR-Glazed, flaked	OR	4.8
E56	361	M-1(Rc 55)STL	1.2	598	None	None	8.5
	360[3]	M-1(Rc 55)STL	1.6	567	IR,OR-Glazed-superficial pulling Balls-Slightly smeared	None	8.5
E53	355	M-1(Rc 55)STL	3.3	536	IR,OR-Glazed & flaked	IR, OR	17.5
	344	M-1(Rc 55)STL	1.4	563	None	None	17.5
E59	365	M-1(Rc 55)STL	2.0	570	None	None	231.1
	364	M-1(Rc 55)STL	< 0.1	595	None	None	231.1

1. The cages were silver plated in their bores as shown in Enclosure 3.
2. The inner race cage land riding surfaces of this bearing was worn.
3. The cage for this bearing split circumferentially in two and shattered.
4. The ball groove in the inner race of these bearings was honed whereas the outer race groove was ground and polished.

ENCLOSURE 26

Endurance of CVM WB 49 Steel 7205 Bearings[4] (#456684)

Thrust Load - 459 lbs. Speed - 42,800 RPM Lubricant - Socony Mobil XRM 109F-1

Test Run No.	Brg. No.	Cage Material	Cage Bore Wear, Mils.	Avg. Temp. °F	Lub Distressed Element(s)	Part(s) Failed	Life 10^6 Revs.
E72[2,5]	562	M-1(Rc 55)STL	<0.1	380	IR,OR, & Balls-Smeared	IR,OR,Balls	0.13
	511	M-1(Rc 55)STL	<0.1	378	None	None	0.13
E70[1]	505	M-1(Rc 55)STL	<0.1	585	IR,OR, & Balls-Smeared	IR,OR,Balls	27.5
	500	M-1(Rc 55)STL	4.5	581	IR,OR, Glazed & Superficial pitted	None	27.5
E71[3]	579	M-1(Rc 55)STL	<0.1	583	None	None	70.9
	504	M-1(Rc 55)STL	4.9/0.5	592	IR,OR,-Superficial Pitted	IR,OR,BALLS	70.9
E69(2)	577	M-1(Rc 55)STL	1.3	576	IR,OR, & Balls-Smeared	IR,OR,Balls	106.5
	509	M-1(Rc 55)STL	0.9	610	None	None	106.5

1. The cages for the bearings used in this test were silver plated in their bores as shown in Enclosure 3.

2. The cages for the bearings used in this test were silver plated on all surfaces as shown in Enclosure 4.

3. The cage bore wear for bearing No. 504 used in this test is given first for original cage which ran 24.9 x 10^6 revs. and then its replacement cage which ran for 46.0 x 10^6 revs.

4. The ball grooves in both races of these bearings were ground and polished.

5. This test was run with a new batch of oil designated XRM 109F-2.

ENCLOSURE 27

Endurance of CVM M-1 Steel 7205 Bearings (#455760)[4]

Thrust Load - 459#   Speed - 42,800 RPM   Lubricant - Kendall Bright Stock 0846

Test Run No.	Brg. No.	Cage Material	Cage Bore Wear, Mils	Avg. Temp. °F	Lub Distressed Element(s)	Part(s) Failed	Life, 10^6 Revs.
E67[1]	278	M-1(Rc 55)STL	<0.1	374	IR,OR,& Balls-Smeared	IR,OR,Balls	0.128
	215	M-1(Rc 55)STL	<0.1	291	None	None	0.128
E63[1][3]	292	M-1(Rc 55)STL	<0.1	300	IR,OR, & Balls-Smeared	IR,OR,Balls	0.26
	291	M-1(Rc 55)STL	<0.1	300	None	None	0.26
E64[2][3]	294	M-1(Rc 55)STL	<0.1	300	IR,OR,& Balls-Smeared	IR,OR,Balls	0.26
	293	M-1(Rc 55)STL	<0.1	300	None	None	0.26
E66[2]	298	M-1(Rc 55)STL	<0.1	443	None	None	0.385
	297	M-1(Rc 55)STL	1.0	396	IR,OR, & Balls-Smeared	IR,OR,Balls	0.385
E65[2]	296	M-1(Rc 55)STL	<0.1	558	IR,OR, & Balls-Smeared	IR,OR,Balls	6.9
	295	M-1(Rc 55)STL	<0.1	526	None	None	6.9
E68[1]	329	M-1(Rc 55)STL	<0.1	599	IR,OR, & Balls-Smeared	IR,OR,Balls	54.9
	319	M-1(Rc 55)STL	<0.1	577	None	None	54.9
E62[1]	290	M-1(Rc 55)STL	2.0	585	None	None	201.8
	289	M-1(Rc 55)STL	4.0	586	IR-Glazed, flaked & pulled OR-Glazed & superficial pitting Balls-(6) flaked	IR BALLS	201.8

1. The cages for the bearing used in this test were silver plated in their bores as shown in Enclosure 3.
2. The cages for the bearings used in this test were silver plated on all surfaces as shown in Enclosure 4.
3. The bearing temperatures in these tests were estimated since actual temperatures were not obtained due to the short test duration.
4. The ball groove in the inner race of these bearings was honed whereas the outer race groove was ground and polished.

ENCLOSURE 28

Endurance of CVM M-1 7205 Bearings[3] (#455760)

Thrust Load 459#   Speed - 42,800 RPM   Lubricant - Kendall Bright Stock 0846 with TCP

Test Run No.	Brg. No.	Cage[1] Material	Cage[1] Bore Wear, Mils.	Avg. Temp. °F	Lub. Distressed Element(s)	Part(s) Failed	Life, 10^6 Revs.
E81[2]	389	M-1(Rc 55)STL	< 0.1	300	None	None	0.13
	388	M-1(Rc 55)STL	< 0.1	300	IR,OR,Balls,-Smeared	IR,OR,Balls	0.13
E80	387	M-1(Rc 55)STL	6.1	565	IR,OR-Slightly Glazed	None	8.37
	383	M-1(Rc 55)STL	75.8	576	IR,OR,Balls Smeared	IR,OR,Balls	8.37

1. The cages were silver plated on all surfaces as shown in Enclosure 4.

2. The Bearing temperatures in this test were estimated since actual temperatures were not obtained due to the short test duration.

3. The ball goove in the inner races of those bearings was honed, whereas the outer race groove was ground and polished.

ENCLOSURE 29

Endurance of CVM M-1 Steel 7205 Bearings[3] (#455760)

Thrust Load - 459#   Speed - 42,800 RPM   Lubricant - Socony Mobil XRM 177F

Test Run No.	Brg. No.	Cage[1] Material	Cage[1] Bore Wear, Mils	Avg. Temp. °F	Lub. Distressed Element(s)	Parts Failed	Life, 10^6 Rev.
E76[2]	300	M-1 (Rc 55) STL	<0.1/<0.1	587	None	None	658.5
	299	M-1 (Rc 55) STL	0.2/<0.1	605	None	None	658.5
E77	390	M-1 (Rc 55) STL	<0.1	596	None	None	653.4
	382	M-1 (Rc 55) STL	<0.1	593	None	None	653.4
E79	386	M-1 (Rc 55) STL	<0.1	571	None	None	494.4
	385	M-1 (Rc 55) STL	<0.1	600	None	None	494.4
E82	392	M-1 (Rc 55) STL	0.2	601	None	None	726.5
	391	M-1 (Rc 55) STL	<0.1	588	None	None	726.5
E84	138	M-1 (Rc 55) STL	0.4	581	None	None	437.0
	136	M-1 (Rc 55) STL	<0.1	598	None	None	437.0

1. The cages were silver plated on all surfaces as shown in Enclosure 4.

2. The cage bore wears for the bearings used in this test is given first for the original cage which ran 122.0 x 10^6 revs. and then their replacement cages which ran for 109.1 x 10^6 revs.

3. The ball groove in the inner race of these bearings was honed whereas the outer race groove was ground and polished.

ENCLOSURE 30

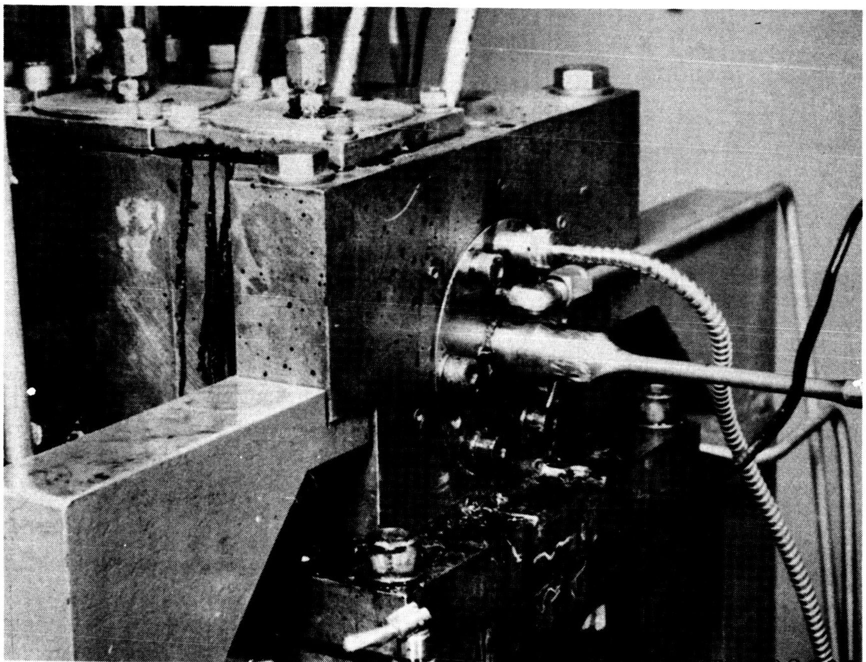
UNFAILED CVM M-1 STEEL BEARINGS AFTER RUNNING 726.5 x 10^6 REVOLUTIONS AT 42,800 RPM, A MEAN TEMPERATURE UP TO 601°F AND UNDER 459 LBS. THRUST LOAD WITH CIRCULATING SOCONY MOBIL XRM 177F OIL IN A N_2 BLANKET

BEARING NO. 392 ON DRIVE END FROM RUN NO. E82

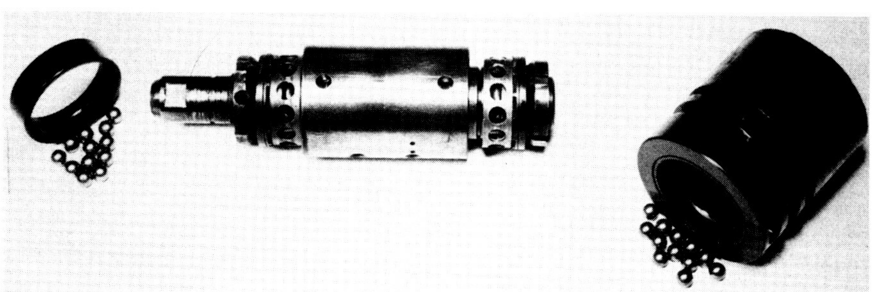
BEARING NO. 391 ON LOAD END FROM RUN NO. E82

ENCLOSURE 31

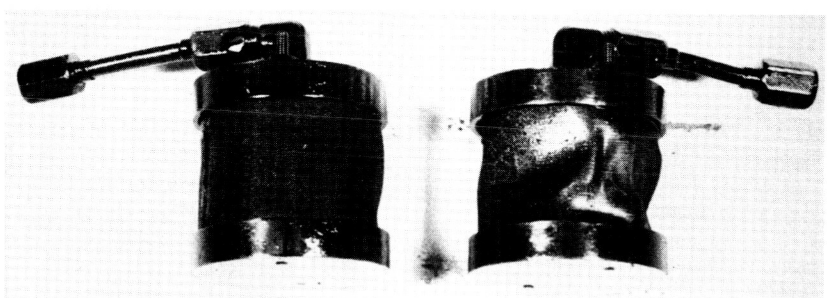
TYPICAL APPEARANCE OF TEST RIG COMPONENTS AFTER 193 HOURS RUNNING WITH SOCONY XRM 177F OIL AT 600°F



T-028005



T-028020



T-028022

ENCLOSURE 32

Endurance of CVM WB 49 Stl 7205 Bearings (#456684)[2]

Thrust Load = 459 lbs. Speed = 42,800 RPM Lubricant - Socony Mobil XRM 177F

Test Run No.	Brg. No.	Cage[1] Material	Cage[1] Bore Wear, Mils	Ave Temp. °F	Lubrication Distressed Elements	Part(s) Failed	Life 10^6 Revs.
E96	636	M-1 (Rc 55) STL	0.1	573	None	None	1.02
	635	M-1 (Rc 55) STL	49.5	573	IR, OR, Balls-smeared	IR, OR, Balls	
E86	624	M-1 (Rc 55) STL	1.8	600	None	None	2.05
	[3]623			600	IR, OR, Balls-smeared	IR, OR, Balls	
E91	625	M-1 (Rc 55) STL	0.1	600	None	None	2.05
	601	M-1 (Rc 55) STL	43.1	600	IR, OR, Balls-smeared	IR, OR, Balls	
E85	622	M-1 (Rc 55) STL	1.8	600	None	None	3.85
	621	M-1 (Rc 55) STL	39.5	600	IR, OR, Balls-smeared	IR, OR, Balls	
E93	628	M-1 (Rc 55) STL	43.6	552	None	None	6.9
	626	M-1 (Rc 55) STL	1.3	533	IR, OR, Balls-smeared	IR, OR, Balls	
E94	631	M-1 (Rc 55) STL	46.3	603	None	None	23.6
	634	M-1 (Rc 55) STL	1.5	596	IR, OR, Balls-smeared	IR, OR, Balls	
E90	629	M-1 (Rc 55) STL	2.0	563	None	None	56.2
	[3]605	M-1 (Rc 55) STL		606	IR, OR, Balls-smeared	IR, OR, Balls	
E92	618	M-1 (Rc 55) STL	338.4	580	IR, OR, Balls-smeared	IR, OR, Balls	190.7
	611	M-1 (Rc 55) STL	300.2	/605	None	None	

1. The cages used were silver plated on all surfaces as shown in Enclosure 4.
2. The ball grooves in both races were honed.
3. Cage bore wear could not be obtained in this bearing since it had broken.

ENCLOSURE 33

(3)

Endurance of CVM WB49 STL 7205 Bearings (#456684)

Thrust Load 459# Speed 42,800 RPM Lubricant - Esso Turbo Oil 35

Test Run No.	Bearing	Cage[1] Material	Cage[1] Bore Wear Mils	Avg. Temp °F	Lubrication Distressed Elements	Parts Failed	Life 10^6 Revs.
E87[2]	658	M-1 (Rc 55) STL	<0.1	300	None	None	0.03
	647	M-1 (Rc 55) STL	<0.1	300	IR, OR, Balls smeared	IR, OR Balls	0.03
E88[2]	669	M-1 (Rc 55) STL	0.2	300	None	None	0.03
	606	M-1 (Rc 55) STL	0.4	300	IR, OR Balls smeared	IR, OR, Balls	0.03
E89[2]	644	M-1 (Rc 55) STL	< 0.1	300	IR, OR Balls smeared	IR, OR, Balls	0.03
	633	M-1 (Rc 55) STL	1.8	300	None	None	0.03
E93[2]	650	M-1 (Rc 55) STL	2.6	200	None	None	0.08
	637	M-1 (Rc 55) STL	<0.1	200	IR, OR, Balls smeared	IR, OR, Balls	0.08

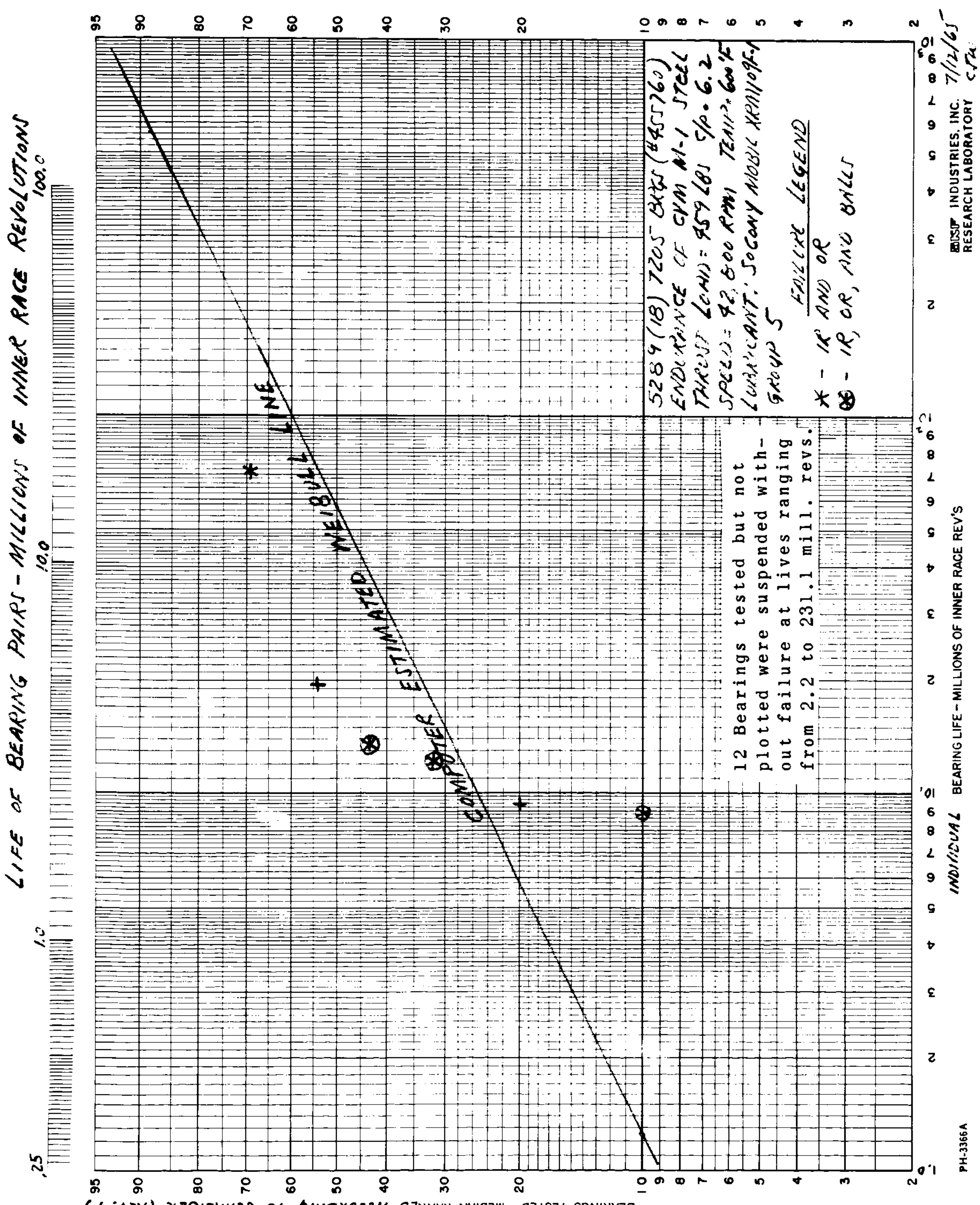
1. The cages were silver plated on all surfaces as shown in Enclosure 4.

2. The bearing temperature in this test were estimated since the actual temperatures were not obtained due to the short test duration.

3. The ball grooves in both races of these bearings were honed.

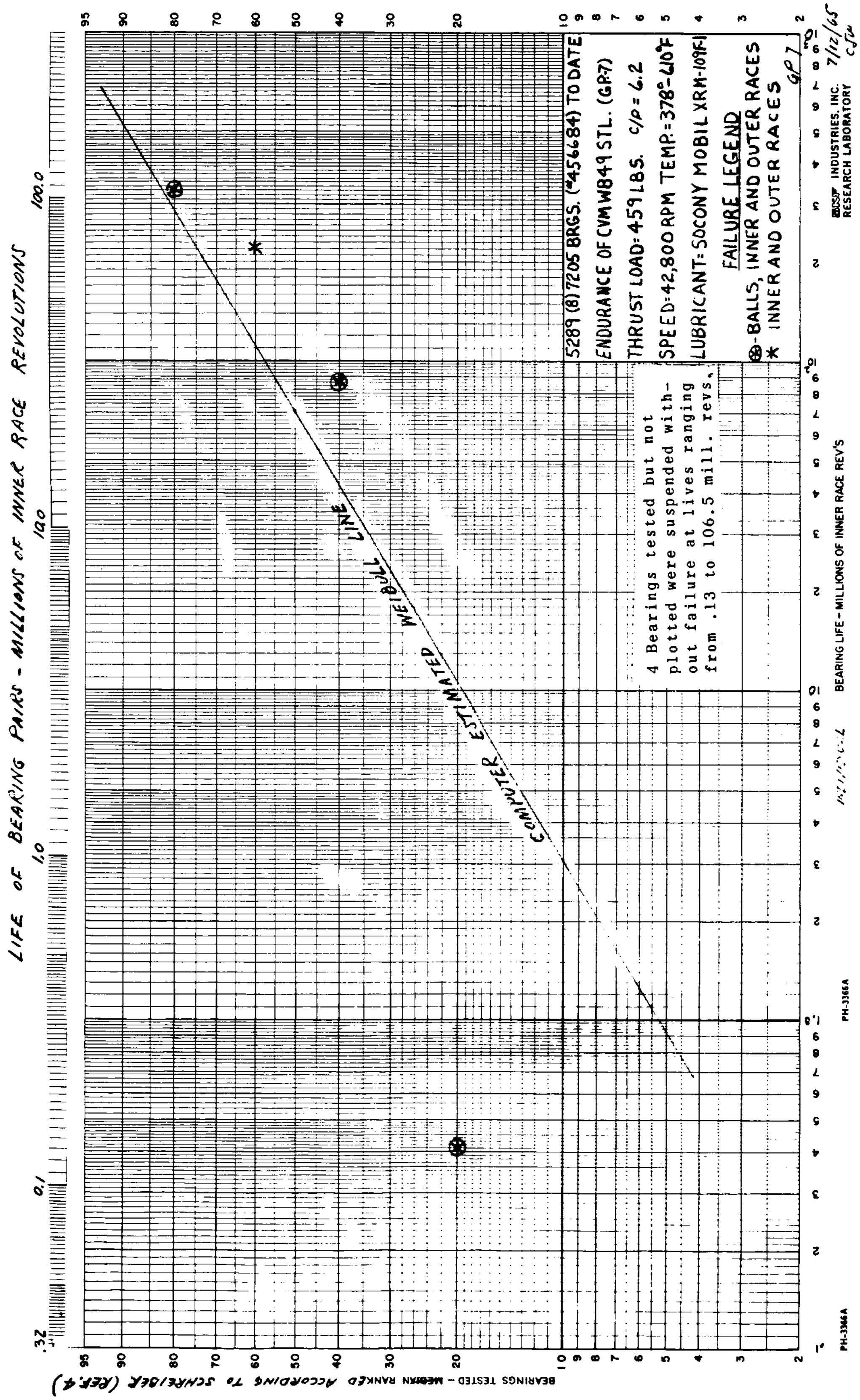
ENCLOSURE 34

WEIBULL PLOT OF CVM M-1 STEEL BEARINGS AT C/P = 6.2 WITH SOCONY MOBIL XRM 109F-1



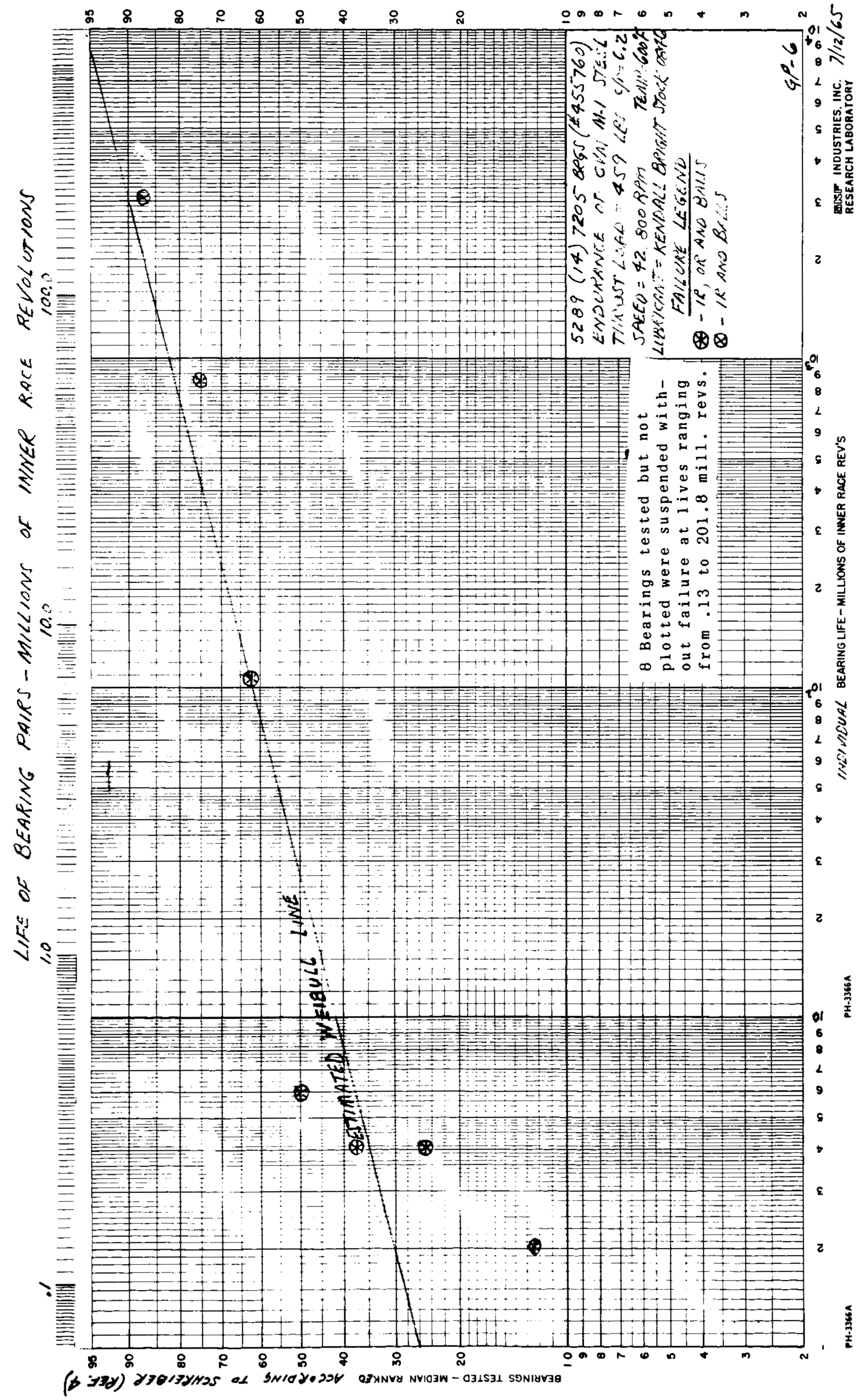
ENCLOSURE 35

WEIBULL PLOT OF CVM WB49 STEEL BEARINGS AT C/P = 6.2 WITH SOCONY MOBIL XRM 109F-1



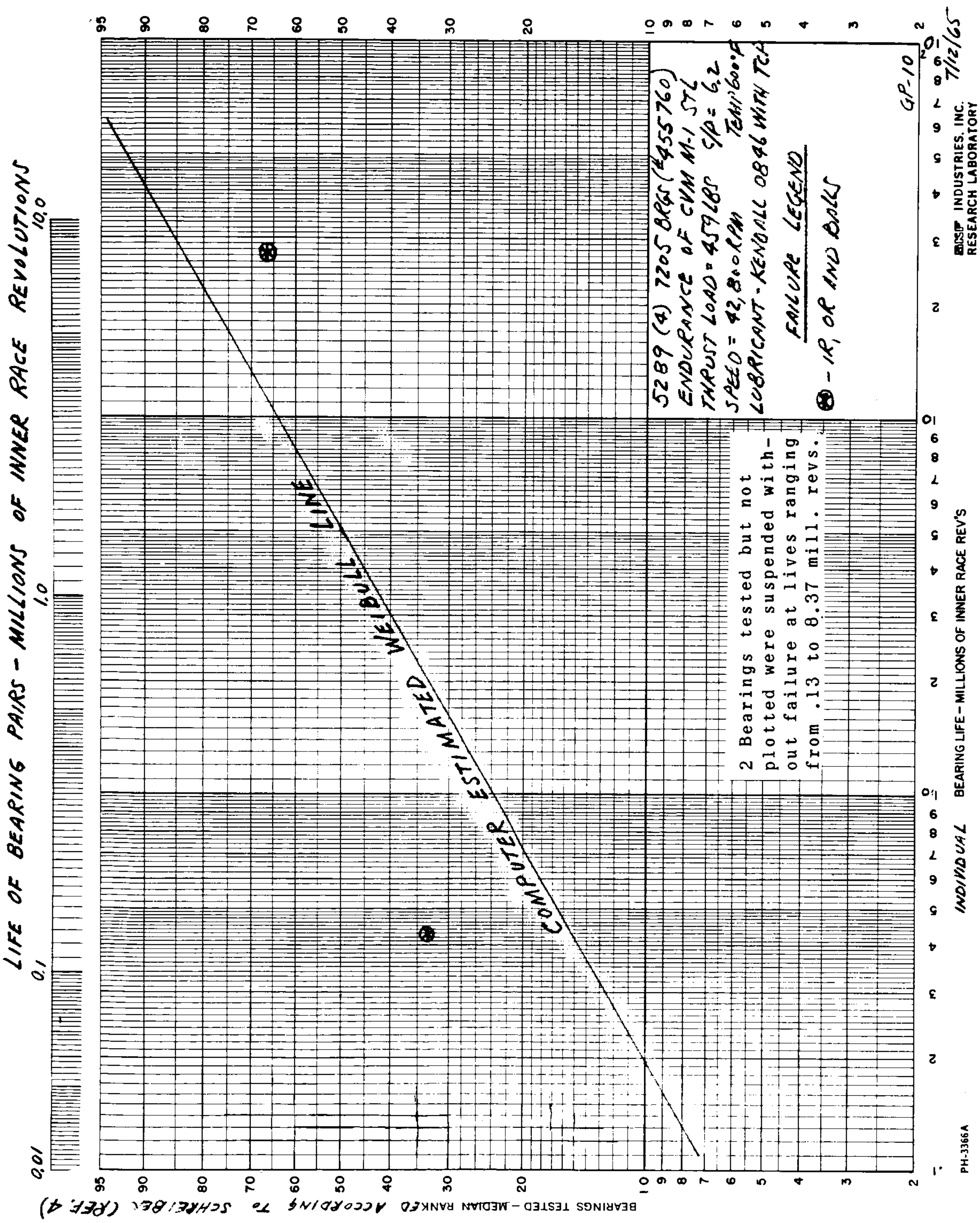
ENCLOSURE 36

WEIBULL PLOT OF CVM M-1 STEEL BEARINGS AT C/P = 6.2 WITH KENDALL BRIGHT STOCK 0846



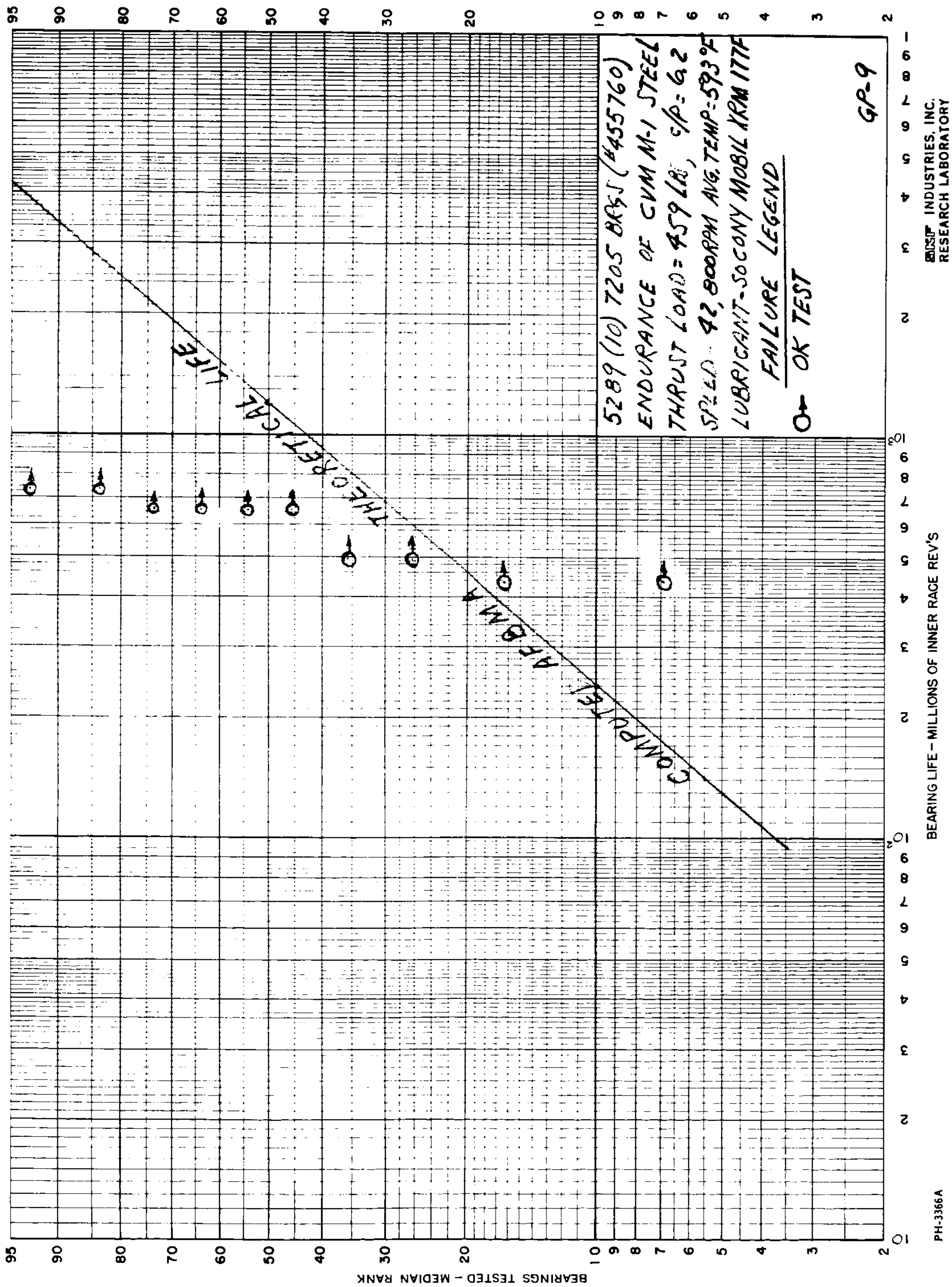
ENCLOSURE 37

WEIBULL PLOT OF CVM M-1 STEEL BEARINGS AT C/P = 6.2 WITH KENDALL BRIGHT STOCK CONTAINING TCP



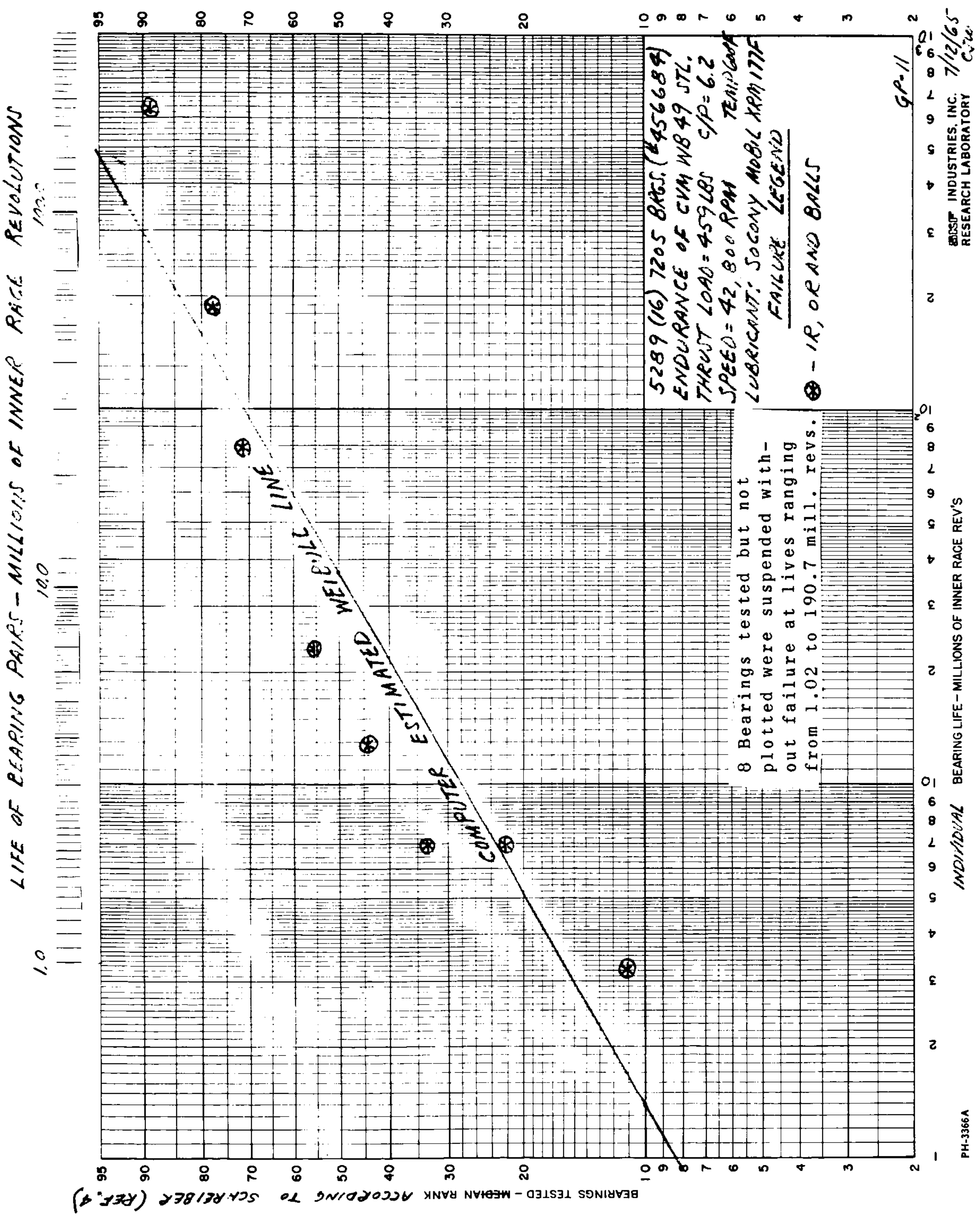
ENCLOSURE 38

WEIBULL PLOT OF CVM M-1 STEEL BEARINGS AT C/P = 6.2 WITH SOCONY MOBIL XRM 177F



ENCLOSURE 39

WEIBULL PLOT OF CVM WB49 STEEL BEARINGS AT C/P = 6.2 WITH SOCONY MOBIL XRM 177F



ENCLOSURE 40

WEIBULL PLOT OF CVM WB49 STEEL BEARINGS AT C/P = 6.2 WITH ESSO TURBO OIL 35