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ADVANCED TURBINE ENGINE MAINSHAFT LUBRICATION SYSTEM INVESTIGATION

PHASE II

Part 2 - Detailed Face Seals Performance, Mass Spectroscopic Study of a Test Fluid, and Supplementary Test Data

by

W. L Rhoads and L. A. Peacock

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Lewis Research Center
Contract NAS3-6267
William R. Loomis, Project Manager

RESEARCH LABORATORY
SKF INDUSTRIES, INC.
ENGINEERING AND RESEARCH CENTER
KING OF PRUSSIA, PA.

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FINAL REPORT

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NASA Lewis Research Center
Cleveland, Ohio
William R. Loomis, Project Manager
Fluid System Components Division

PH-4185B R100

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FOREWORD

The research described herein, which was conducted by the SKF Industries, Inc. Research Laboratory, was performed under NASA Contract NAS3-6267. The work was completed under the management of the NASA Project Manager, Mr. William R. Loomis, Fluid Systems Components Division, NASA Lewis Research Center.

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AL69T016

FINAL SUMMARY REPORT ON PHASE II
ADVANCED TURBINE ENGINE MAINSHAFT LUBRICATION SYSTEM INVESTIGATION

by

W. L. Rhoads and L. A. Peacock

ABSTRACT

Ball bearings and face seals for use on Mach 3 aircraft gas turbine engine mainshafts have been evaluated in this program with several selected lubricants in a recirculating oil system having provisions for inert gas blanketing. Testing has been conducted at typical advanced engine load and speed conditions with the seals exposed to 1200°F hot air and a pressure differential of 100 psi.

Using M-50 and WB-49 tool steel ball bearings of current design with two of the most promising fluid lubricants (two synthetic paraffinic hydrocarbon base stock fluids, one with a heavy paraffinic resin additive and the other with a proprietary antiwear additive) found in the screening test tasks of this program and newly developed hydrodynamic lift design oil seals, it was possible to run 250-hour tests at 650°F bearing outer ring temperatures with no signs of distress. Reliable longer-term inerted operation at representative advanced engine conditions appears to be feasible.

In a separate task of this work, 125 mm-bore bearings and face seals were run successfully for short periods at speeds to 20,000 rpm corresponding to a DN value (product of bearing bore in millimeters and shaft speed in rpm) of 2.5 million and a seal face speed of 550 feet per second.

This report is the second of two parts on this lubrication system study. This volume, Part 2, contains a detailed writeup of face seal performance, a mass spectroscopic study of a test fluid and supplementary test data tabulations. Part 1 (CR-72854) contains a presentation and discussion of the system performance test results.

APPENDIX I

FACE SEAL TEST RESULTS FROM ADVANCED TURBINE ENGINE MAINSHAFT LUBRICATION SYSTEM INVESTIGATION

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LIST OF ENCLOSURES

FACE SEALS RESULTS FROM ADVANCED TURBINE ENGINE MAINSHAFT LUBRICATION SYSTEM INVESTIGATION

I. INTRODUCTION

This section deals with test results and refinements made over approximately a four year period of use of a tandem pair of face seals on the Advanced Turbine Engine Mainshaft Lubrication System Investigation (NASA Contract NAS3-6267, Phases I and II). In this program the performance of aircraft gas turbine mainshaft ball bearings, seals, and lubricants under simulated (Mach 3) turbine engine conditions is being studied using the most advanced materials, designs, and manufacturing techniques available. Both recirculating and once-through (mist) lubricating systems have been used, predominately under inert gas blanketing.

II. BACKGROUND

a. General

Test conditions to simulate an advanced Mach 3 aircraft gas turbine engine are severe from all points of view. The shaft speed of 14,000 rpm means, that for representative size seals, a rubbing speed of nearly 390 - 400 fps is realized. The thermal requirements are such that one seal of the pair, shown in position in the test rig in Enclosure I-1, is subjected to hot oil in an environment of 600-700°F. The other seal is subjected to 1200°F air and the pair has a pressure drop of 105 psi across it.

Since even the best available candidate lubricants would most probably decompose at the desired operating temperatures, it was decided to employ an inert gas blanket for the test bearing and lubricant. For an inert blanket to be reasonably economical, loss through leakage must be kept low. Considering all aspects, it was decided that the best available state-of-the-art seal was a face seal with bellows secondary. These were procured from Koppers Co.

Initially, shoulder cooling was to be employed but had to be eliminated to allow desired bearing race temperatures to be reached.

b. Face Seal Design

In its simplest form, a face seal consists of a stationary continuous "dam" of some material, usually carbon, which rubs against a shoulder that rotates with the shaft. The dam is held against the shoulder with some small positive load by the vectorial combination of mechanical and pressure forces. The pressure drop occurs across the sealing dam in a non-linear manner (although it can reasonably be assumed linear since the physical width of the dam is small). The balance diameter, experimentally determined for each bellows seal, is the diameter defining the area over which the net pressure acts to give the pressure force. In the seals used on this program, carbon pads or lands are provided on either (or both) the inboard or the outboard side of the sealing dam to distribute the face load over a larger area to reduce wear. These wear pads (should) have sufficient venting area to pass a reasonable face seal leakage so as not to influence the pressure distribution which would change the net face load. An increase in net face load can increase heating appreciably leading to heavy wear, warping of the parts, and failure. A decrease can lead to lift-off and high leakage. To minimize this, the curve of net seating force should be as "flat" as possible so that a disturbance in either the mechanical force or pressure force, results in only a small increase or decrease in load. The "flat" curve of net seating force can be approached by making the mechanical seating force as independent to change as possible; i.e. with as "flat" a spring rate as possible. A more promising approach is to incorporate hydrodynamic lift devices into either the carbon or shoulder surfaces (even with the smooth carbon and shoulder surfaces commonly used, there is some lift). By utilizing this device the mechanical seating force can be increased without danger of undue wear or heating. The lift provided by hydrodynamic effects increases sharply as the carbon and shoulder come closer together. If there is some unseating disturbance which increases the separation of the surfaces the lift decreases sharply and the higher mechanical seating force can minimize the separation and leakage.

The carbon material should be wear resistant, but not abrasive, should not distort under heat, and the binder should not decompose at high temperature in the presence of the lubricant or atmosphere used.

c. Secondary Sealing

Since the carbon face cannot be rigidly mounted to the engine or test structure because there must be allowance for differential thermal expansions of different materials, mechanical seating force, wear, etc., static secondary sealing must be employed. The two general methods used are metallic bellows, which also provide the mechanical seating force, and one or more piston rings, usually of carbon. With a piston ring secondary seal, the mechanical seating force is provided by auxiliary springs.

A bellows secondary, unless ruptured, has zero leakage across it. A face seal using this design secondary therefore will leak less than one with a piston ring secondary under ideal conditions. Unless the net bellows face load is carefully controlled by individual calibration, disturbances in operating conditions can lead to lift-offs (and high leakage) or high wear (and heat generation). Difficulty in controlling bellows face loads is due to the change in spring rate of the bellows caused by pressure or thermal changes in the bellows geometry. Long term relaxation may have an added effect on spring rate change as well as loss of mechanical load.

While piston ring secondary seals have a finite leakage across them and consequently a higher overall leakage when compared to a properly operating bellows seal, the mechanical load and hydraulic balance are more constant with respect to all operating variables than a bellows.

Since the seal is a spring-mass system subjected to excitation by various forces such as rotational imbalance and other rig or engine vibration, some damping is commonly provided. In a bellows seal auxiliary means, such as coulomb friction surfaces, are used. In piston ring seals the piston ring friction is generally sufficient.

The requirements for the carbon piston rings are generally the same as for the face carbon described previously. The bellows material must be such that its mechanical properties are adequate and do not change after continued exposure to high temperatures. Often materials selection for the bellows must be compromised because of fabrication difficulties.

d. Shoulder Design

The commonly utilized shoulder has a smooth face which rubs against the carbon face material. As has been pointed out, hydrodynamic lift pads may be employed on either the carbon or shoulder face. Because the carbon can wear in transient seal operation and possibly change lift characteristics, it is generally felt preferable to incorporate the lift pads in the shoulder if they are used.

Because of the high rubbing velocity between the face and shoulder, heat is generated. The effect of this heat generation can be warpage of seal parts usually in the form of coning. The shoulder is particularly liable to thermal warpage since it is commonly metallic and can have large thermal gradients across its rather large, irregular cross section. A material with a high thermal conductivity is employed to keep thermal gradients as small as possible, and a somewhat flexible interface with the shaft may be utilized to minimize distortions caused by differential expansions between the (possibly dissimilar) materials. Finally, lubricants may be delivered as close as possible to the heat generation zone to remove excess heat before it can be conducted to other areas.

The rubbing contact area of the shoulder is as hard as possible to reduce wear. This is usually accomplished by plating a very hard material on the parent shoulder material since wear resistent materials are usually too costly, difficult to manufacture or have too low a thermal conductivity or poor mechanical properties to be used for the complete shoulder.

III. RESULTS OF CURRENT PROGRAM

a. General

Included in this section is a description, by location and type, of the test seals and modifications used during testing in Phase I and Phase II of this contract. Also included is a description and discussion of seal test results during this work. Detailed descriptions of test conditions and results for all tests conducted are given in References (2, 7, 8, 13)* and in this report.

A total of ten AM 350 steel bellows and two Inco 718 bellows (with better high temperature material properties) were manufactured. These can be used for either air or oil seals if the proper carbon geometry is used. Four AM350 steel bellows were originally made up as air seals and four as oil seals with a shoulder for each. (The air and oil seal shoulders are different). Two AM 350 steel bellows were initially unused but were later utilized as replacements for failed bellows. Both Inco 718 bellows were originally used as air seals; however, one was later converted to an oil seal.

Two piston ring secondary oil seals were manufactured during Phase II and one bellows secondary oil seal and shoulder incorporating the hydrodynamic life design is being made for use at a later time. Extensive re-working, repair, and replacement was carried out on all bellows seals during the program. Attachment I consists of correspondence from Koppers Co. discussing early oil seal problems. A discussion by Koppers Co. on the seals used in Phase I, their performance and additional design information is included in Attachment II. Attachment III contains the results of Koppers examination of a tested piston ring secondary seal. Attachment IV contains an evaluation by Koppers of face seals used in Phase II of this program.

b. Air Seals

Bellows face type seals were used throughout the program in this location. In the test rig they are required to seal 1100-1200°F hot air at a pressure of 106 psi against a mixture of nitrogen and helium at a pressure of 111 psi. There is no liquid cooling media available in the area of this seal. Relative rubbing velocity is approximately 390 fps. Face loading for all air seals used was in the range of 0.35 to 0.50 lbs./inch of circumference (net load 7.9 to 11.5 lbs.). A typical air seal and shoulder is shown in Enclosure I-2. Enclosure I-3 and I-4 present a

*Numbers in parenthesis refer to references at end of Part I.

test history and performance summary of the various seals used (due to lack of mass spectrometer data in some instances it is only possible to give total seal leakage). Except for a bellows weld failure and decomposition of the carbon binder in one long term test, the air seal design performed well. Service life is estimated as being on the order of many hundred; if not thousands of hours with leakage generally less than 5 scfm, based on tests to date.

c. Bellows Secondary Oil Seals

Bellows face type seals were used for a majority of testing, although not for a majority of accumulated hours operation. In the rig they are required to seal 500°F (or hotter) splashing oil under a 6 psi nitrogen blanket against a mixture of nitrogen and helium at a pressure of 111 psi. Relative rubbing velocity is approximately 390 fps. Enclosures I-3 and I-4 present a test history and performance summary of the various seals of this type used.

Seals in initial Phase I tests had a face loading of around 0.5 lbs./inch of circumference. Seals used at the end of this Phase had the loading increased to about 0.6 lbs/inch of circumference. This was done in an attempt to reduce the tendency to lift-off which had been observed. The change was not successful. All of these seals used a chromium plated shoulder, AM350 steel bellows, and USG 2777 carbon. It was noted in several instances that balance diameter and/or bellows free length changed after extended operation. A typical oil seal of this type is shown in Enclosure I-5. No design provisions were included for oil cooling of the shoulder since it was thought that sufficient oil splash would be available. As can be seen from Enclosure I-5 the shoulder mounting on the shaft is rigid. Leakage rates varied from a few scfm to well over 10 scfm. Lift-offs often occurred, and on several occasions high wear rates led to near-catastrophic seal failure. (When transient leakages were high, early rig venting was not adequate to keep ΔP = 105 psi. Therefore, ΔP dropped and because of the face load bellows characteristics, the face load changed to a portion of the curve where the seating was inadequate; lift off ensued. Venting was later increased in the rig.)

One of the major causes for this behavior was, and still is thought to be the difficulties in pressure balancing, i.e. the seating force curve is not "flat" enough so that a slight perturbation can have a large effect on seating force. Several design suggestions for the bellows to correct this are presented in Attachment II.

At the beginning of Phase II, several design changes were made which, while not eliminating the basic problem cited above, did result in promising performance. These changes are shown in Enclosures I-6 and I-7 and include a flexible mounting on the shaft (to prevent coning of the shoulder due to differential expansions between it and the shaft), removal of the outer wear pads to prevent possible lift-off due to carbon coning and decrease of the face load to approximately 0.4 lbs./ inch of circumference to reduce heating. In addition, cooling oil (approx. 0.5 gpm) was provided for the shoulder. The carbon material was also changed to CDJ83 to improve wear characteristics. This carbon proved to be more abrasive and wore through standard chromium shoulder plating in a matter of a few hours. Chromium carbide provided about 32 hours of service before it wore through. Aluminum oxide and tungsten carbide plated shoulders were made in an attempt to further improve service life. There would seem also to be a tendency for these bellows seals to become inoperative (excessive leakage) by coke forming in the bellows area.

Based on results to date it appears that it may be possible to obtain low leakages (a few scfm) for periods of perhaps a few hundred hours with a modified bellows seal and proper materials in the rubbing area.

d. Piston Ring Secondary Oil Seals

In an attempt to eliminate recurring lift-off problems associated with the bellows type oil seals, it was decided to try piston ring secondary seals in this location, even though the steady state leakage might be greater. In addition, hydrodynamic lift pads, a flexible shaft mounting system, and design for oil cooling were incorporated in the shoulder. This seal is shown in Enclosure I-8. The cross-sectional details of the shoulder as well as the inclusion of a windback (low efficiency viscoseal)used to reduce seal exposure to oil and thereby reduce internal seal coking can be seen. Enclosure I-9 shows the lift pad detail. This seal performed well for 573 hours at the specified test conditions. It thus appears that this type of seal is the most promising to date for acceptable long term operation*.

*In endurance testing conducted with Mobil XRM177F, a second seal of this type failed after ten hours at specified conditions. This failure has been traced to inadvertant use of a different grade of carbon which was not suitable for these conditions.

IV. DISCUSSION

a. Air Seals

The original design of a bellows face seal has proven to be satisfactory in this location. Accumulated life of 482.2 hours using an AM350 bellows secondary, 56 HT carbon face and chromium carbide plated shoulder has been achieved.

b. Oil Seals

The original design bellows - face seal proved troublesome, unpredictable, and many times unworkable due to frequent lift offs and high leakage.

By reducing the face load, incorporating several design modifications in the face and shoulder to reduce thermal effects on geometry, and by proper selection of shoulder plating and carbon materials it was possible to secure very low leakage (less than 1 scfm) for up to 32 hours, with the bellows seals. By additional modification in shoulder platings it should be possible to secure longer term operation of the basic design, but the limit on obtainable life appears to be relatively low.

The primary cause for trouble with the bellows oil seals appears to be the high pressure drop (105 psi) across the seal since the air seal, which runs as fast and hotter, is essentially trouble free.

The high leakage (lift off) and/or wear problems are attributed to the "change in load" characteristic of this particular bellows configuration which makes the bellows sensitive to ΔP changes and to thermal effects.

Both piston ring and bellows secondary seals undergo a run-in during which the contacting surfaces adapt themselves to the thermal geometry peculiar to the conditions at which the test is being run. These thermal conditions vary with test conditions so that some additional run-in may be required with a drastic change in test conditions.

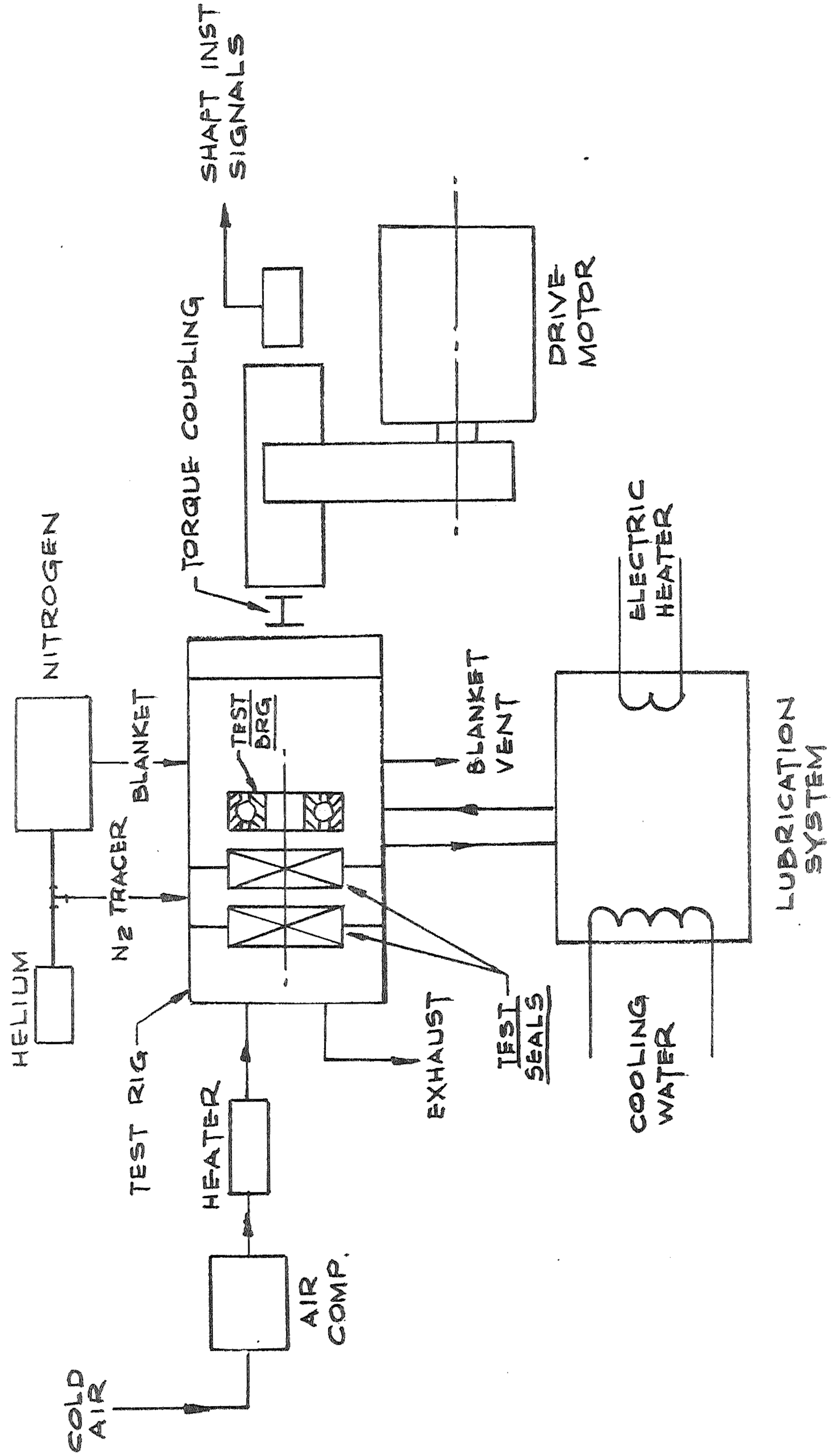
Piston ring secondary face seals with hydrodynamic lift shoulders appear capable of operating satisfactorily for many hundreds and maybe even thousands of hours. Leakage is not as slow as with a properly operating bellows secondary seal (around 3 scfm compared to less than 1 scfm) but there are no lift-off problems.

While the windback in the piston ring secondary seal may not eventually prevent coking of secondary elements, it is believed to reduce it considerably.

The most promising low-leakage design for this location appears to be a redesigned bellows secondary (designed to make "spring" loading curve as "flat" as possible) with an oil-cooled, felxibly mounted shoulder plated with a carbide and provided with hydrodynamic lift pads. A wind back is felt to be desirable to lessen coking in the secondary area.

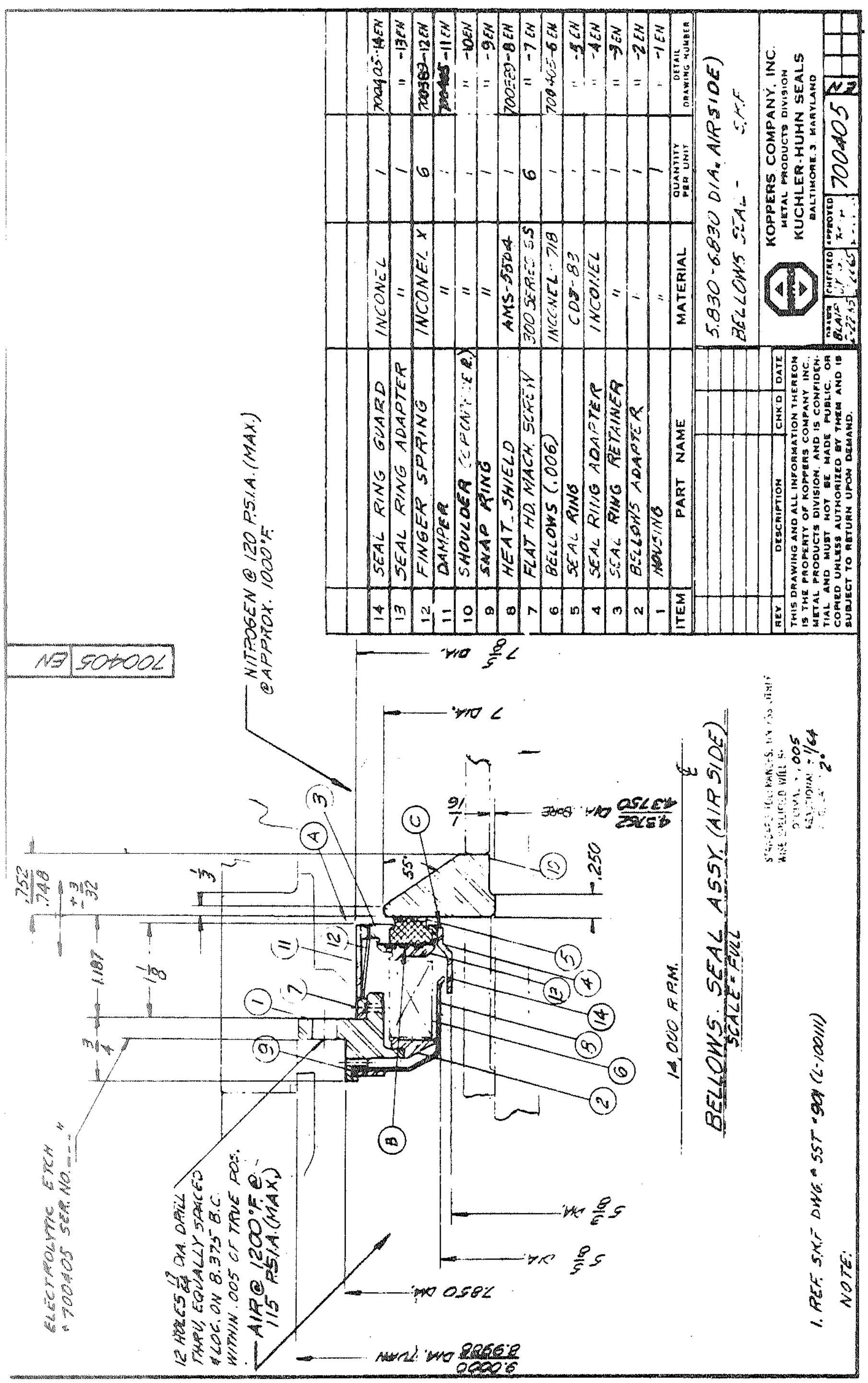
ENCLOSURE I-1

GENERAL TEST RIG LAYOUT SCHEMATIC



ENCLOSURE I-2

TYPICAL AIR SEAL AND SHOULDER DESIGN



A. Improved damping device
B. Thermal barrier
C. Modified end fitting retention

ENCLOSURE I-3

SEAL TEST PERFORMANCE SUMMARY - PHASE I

TEST & OIL	AIR SEAL	OIL SEAL	LEAKAGE SCFM TOTAL	LEAKAGE SCFM AIR SEAL	LEAKAGE SCFM OIL SEAL	HOURS SEAL USED IN THIS TEST/CUM.HRS. AIR	HOURS SEAL USED IN THIS TEST/CUM.HRS. OIL	WEAR AIR/SEAL	COMMENTS
R-1 to R-10* Esso 4040	-	700389 #2	2-20	-	-	20/20	20/20	-	
R-11 to R-12 XRM-177F	-	700389 #2	3-20	-	Maj.of Total	8/28	8/28	-	
M-1 Esso 4040	700397 #5	700389 #8	4-6	-	-	0.5/0.5	0.5/0.5	Negligible	
R-13 Sinclair Turbo-S	700397 #3	700389 #2	7-8	-	Maj.of Total	1.5/1.5	1.5/20.5	Negligible .006	Oil Seal sent to Koppers for reconditioning
R-14 Sinclair Turbo-S	700397 #5	700389 #1	6-8	-	-	5.0/5.5	5.0/5.0	.012/.005	Sealing dam of oil seal had been made in-correct
R-15 MCS 293 (N_2 Blanket)	700397 #5	700389 #8	1	-	-	2.5/8.0	2.5/3.0	Negligible	
R-16 MCS 293 (Open Atmosphere)	700397 #7	700389 #8	2-12	-	-	4.7/4.7	4.7/7.7	.003/ Negligible	
M-2 Esso 4040	-	700389 #10	2	-	-	-	0.5/0.5	Negligible	
R-17 MCS 293 Freon Additive	700397 #5	700389 #8	7-11	1-2	6-9	4.5/12.5	4.5/12.2	Negligible	
R-18 DuPont PR-143	700397 #5	700389 #10	10-13	-	-	4/16.5	4/4.5	.010/ Negligible	
M-3 Mobil XRM-177F	700397 #7	700389 #10	1-2	-	-	6/10.7	6/10.5	.012/.024	
M-4 Mobil XRM-177F	700397 #7	700389 #10	20-25	-	-	5/15.7	5/15.5	.026-.050 .001	The air seal dam completely worn away - recondition
M-5 Mobil XRM-177F	700397 #3	700389 #10	1-2	-	-	1/2.5	1/16.5	Negligible .006	
M-6 Mobil XRM-177F	700397 #3	700389 #10	8-10	-	-	4.5/7.0	4.5/21	.002/.004	
M-7 UCON	-	700389 #10	6-45	-	Maj.of Total	-	1/22		Oil seal scored
M-8 Herculube F	700397 #6	700389 #4	6	-	-	0.3/0.3	0.3/0.3	Negligible .010	
M-9 Sunthetic 18H	700397 #6	700389 #4	4.5-10	-	-	1/1.3	1/1.3	.002/.005	
M-10 Sunthetic 18H	-	700389 #10	5-10	-	-		1/23	-	Oil seal sent to Koppers for reconditioning
R-19 DuPont PR-143	-	700389 #4	5-20	-	-		4/5.3	-	
R-20 DuPont PR-143	-	700389 #4	High	-	Maj.of Total	-	1.5/68	-	Oil seal slightly scored.
R-21 DuPont PR-143	-	700389 #4	5-10	2-5	2-5	-	1/7.8	-	
M-11 Mobil XRM-177F	700397 #6	700389 #4	20	Maj.of Total	-	1.3/2.6	1.3/9.1	.003/.001	
R-22 Sinclair Turbo-S	700397 #6	700389 #4	10-11	-	Maj.of Total	3/5.6	3/12.1	.002-.007 Negligible	
M-12 Mobil XRM-177F	700397 #6	700389 #4	3-10	Maj.of Total	-	1/6.6	1/13.1	.001	The oil seal was damaged extensively. Sent to Koppers for reconditioning
R-23 Sinclair Turbo S	700397 #7	700389 #9	1-2	2-5	0.8-1.6	6/21.7	6/6	Negligible .003-.012	New oil seal
R-24 Mobil XRM-177F	700397 #7	700389 #9	2-3	1-3	Max.2	8/29.7	8/14	.004 .007-.013	.040" removed from flange. Extra notches cut out of outer carbon pads
EM-1 Mobil XRM-177F	700397 #2	700389 #10	3-30	-	-	1/1	1/1	.003 .035-.043	New reconditioned oil seal with extra notches on outer carbon pads. Oil seal and runner destroyed in this test
ER-1 Mobil XRM-177F	700397 #2	700470 #2	1-10	-	-	1/2	1/1	Negligible	Inconel oil seal bellows.

*R-1 denotes first run in recirculating test rig, M-10 denotes tenth run in mist test rig.
All air seals in Phase I testing used an AM350 steel bellows with 56HT carbons. All oil seals in Phase I testing used an AM350 steel bellow with USG2777 carbons except test ER-1 which used an Inco 718 steel bellow with CDJ83 carbon.

ENCLOSURE I-4

SEAL TEST PERFORMANCE SUMMARY PHASE II*

TEST & OIL	AIR SEAL	OIL SEAL	LEAKAGE SCFM TOTAL	LEAKAGE SCFM AIR SEAL	LEAKAGE SCFM OIL SEAL	HOUR SEAL USED IN THIS TEST/TOTAL HOURS AIR	HOUR SEAL USED IN THIS TEST/TOTAL HOURS OIL	WEAR INCHES AIR/OIL	COMMENTS
1 Mobil Jet II	700405#2	700488#1	12-22	9-12	3-10	2.3/2.3	2.3/2.3	Negligible	No O.D. carbon pads
2 Mobil Jet II	700405#2	700488#1	8-15	-	-	0.5/2.8	0.5/2.3	.002/.002-.010	Mounting flange of oil seal was cut back .020 to increase the clamping force by 1.2 lbs.
3 Mobil Jet II	700405#2	700489#4	2.5	-	-	0.3/3.1	0.3/0.3	.001/.001	New oil seal carbon CDJ83
4 Mobil XRM 154D	700405#2	700489#4	3- 5	-	-	2.3/5.4	2.3/ 2.6	.001/negligible	
5 Mobil XRM 177F	700405#2	700489#4	1.7-2.4	1.6-1.8	0.07-0.57	5.8/11.2	5.8/8.4		
	700405#2	700489#4	1.3-20	-	-	7 /18.2	7 /15.4	negligible/.020	
6 Mobil XRM 109F	700405#2	700489#10	1.5-1.6	1.4	0.19-0.24	3.4/21.6	3.4/3.4		
+ 10% Kendall			4 -15.7	4	0.19-11.7	2.7/24.3	2.7/6.1	.006/.003-.012	Lift off occurred during
Heavy Resin 0839									this segment of the test
7 Mobil XRM 109F	700405#2	700489#10	2 -3	.4-1.5	1.5 - 2.6	10/ 34.3	10/ 16.1		
+ 10% by wgt.			2 -3	.2-2.0	1.0 - 1.8	10/ 44.3	10/ 26.1		
Kendall Heavy			2 -3	0.4-2	1.0 - 1.6	10/ 54.3	10/ 36.1		Air seal sealing dam unserviceable
Resin 0839	700397#7		0.3-1.3			2/ 34.7	2/ 30.7		
8 Mobil XRM 154D	700397#7	700489#4	1.4-1.7	0.7-0.9	0.7- 1.1	3/ 34.7	3/18.4	.001/.001	
9 Mobil Jet II	700397#2	101056B#I	7 -10	-	-	1.8/ 3.8	1.8/1.8		
(Open atmos-			4 - 6	-	-	10/ 13.8	10/11.8		
phere)			5 - 7	-	-	10/ 23.8	10/21.8		
			5 - 6	-	-	10/ 33.8	10/31.8		
			5 - 7	-	-	10/ 43.8	10/41.8		
			5 - 6	-	-	8.2/52	8.2/50.0	.003/.003	
10 Mobil XRM 109F	700397#2	101056B#I	9 -11	-	-	10/ 62	10/ 60		
+ 10% by wgt.			9 -11	-	7 -11	10/ 72	10/ 70		
of Kendall Heavy			11 -14	.8-8.4	5 - 9.8	10/ 82	10/ 80		
Resin 0839 +			8 -12	-	-	5.9/87.9	5.9/85.9		
Mobil XRM 127B			19 -24	0 -5	14 -24	10/ 87.9	10/ 95.9		The intake N_2 line broke
			20 -22	9 -12	8 -13	4.1/92	4.1/100	.005/negligible	
11 Mobil XRM 177F	700397#6	101056B#2	4.2-21.2	2.2-2.5	1.7-19.0	10/ 10	10/ 10		
			23.8-48.5	0 -3.6	20.2-48.5	2.8/12.8	2.8/12.8	/.048	Oil seal failed wrong carbon mat'l used on primary face previous life 100 hrs.
		101056B#1	8.5-12.7			8.9/21.7	8.9/108.9		
			9.8-11.9			10/ 31.7	10/ 118.9		
			3.8- 4.6			10/ 41.7	10/ 128.9		
			3.6- 6.1			7.8/49.5	7.8/136.7		
			3.1- 4.8			10/ 59.5	10/ 146.7		
			4.4			1/ 60.5	1/ 147.7		
			3.0- 4.6	0.2-1.9	1.1- 4.4	10.2/70.7	10.2/157.9		
			6.0- 9.3			10/ 80.7	10/ 167.9		
			4.8- 6.8	1.6-3.1	3.7- 6.4	10/ 90.7	10/ 177.9		
			9.7-12.3	0.5-7.9	4.4-10.2	10/ 100.7	10/ 187.9		
			9.5-12.6			10/ 110.7	10/ 197.9		
			10.0-12.7			10/ 120.7	10/ 207.9		
			11.0-14.7			10/ 130.7	10/ 217.9		
			8.9			0.8/131.5	0.8/218.7		
			11.0-13.6			10/ 141.5	10/ 228.7		
			7.6- 9.8			4.4/145.9	4.4/233.1		
			4.0- 5.9			10/ 155.9	10/ 243.1		
			4.1- 6.8			8.5/164.4	8.5/251.6		
			4.1- 5.3			10/ 174.4	10/ 261.6		
			6.1- 9.3	0 -5.4	3.9- 6.1	4.7/179.1	4.7/266.3		
			5.1-13.8			2.1/181.2	2.1/268.4		
			3.7- 7.6			9.1/190.3	9.1/277.5		
			3.5- 4.9	0.3-2.5	2.4- 4.6	10/ 200.3	10/ 287.5		
			4.8- 6.0	0.1-2.3	3.7- 5.9	10/ 210.3	10/ 297.5		
			12.3-15.3			10/ 220.3	10/ 307.5		
			4.7- 7.6			6.5/226.8	6.5/314.0		
			6.9-10.6			6.0/232.8	6.0/320.0	.0065/.002	Both seals are still in useable condition
12 Mobil XRM-109F	700397#6	101056B#1	4.6- 7.9	0.8-4.0	3.9- 7.1	10/ 242.8	10/ 330.0		
+ 10% by wgt.			4.9- 6.6			10/ 252.8	10/ 340		
Kendall Heavy			4.6- 6.0			10/ 262.8	10/ 350		
Resin 0839			4.6- 6.1			10/ 272.8	10/ 360		
			5.3- 6.9			10/ 282.8	10/ 370		
			7.0- 8.1	2.0-5.0	3.1- 5.0	10/ 292.8	10/ 380		
			5.5- 8.0	.8-5.8	2.2- 7.2	10/ 302.8	10/ 390		
			5.6- 7.5	0.1-4.9	2.6- 7.4	7.5/310.3	7.5/397.5		
			9.0-17.4			8.5/318.8	8.5/406		
			9.0-11.0	0.5-7.1	3.9-10.5	10/ 328.8	10/ 416		
			5.5- 7.0	0.5-3.4	3.6- 6.5	10/ 338.8	10/ 426		
			5.3-12.7			4.3/343.1	4.3/430.3		
			5.8- 7.6	0.2-2.7	4.9- 7.4	10/ 353.1	10/ 440.3		
			7.5-11.1	0.6-4.1	3.4-10.5	10/ 363.1	10/ 450.3		
			6.1- 8.5			10/ 373.1	10/ 460.3		
			6.8- 7.7	0.7-4.1	3.6- 7.0	10/ 383.1	10/ 470.3		
			6.2- 7.6	0.3-3.1	4.5- 7.3	10/ 393.1	10/ 480.3		
			6.8- 8.8			10/ 403.1	10/ 490.3		
			6.6- 8.6	3.6-5.9	2.7- 5.0	10/ 413.1	10/500.3		

ENCLOSURE I-4 (CONT'D)

SEAL TEST PERFORMANCE SUMMARY PHASE II

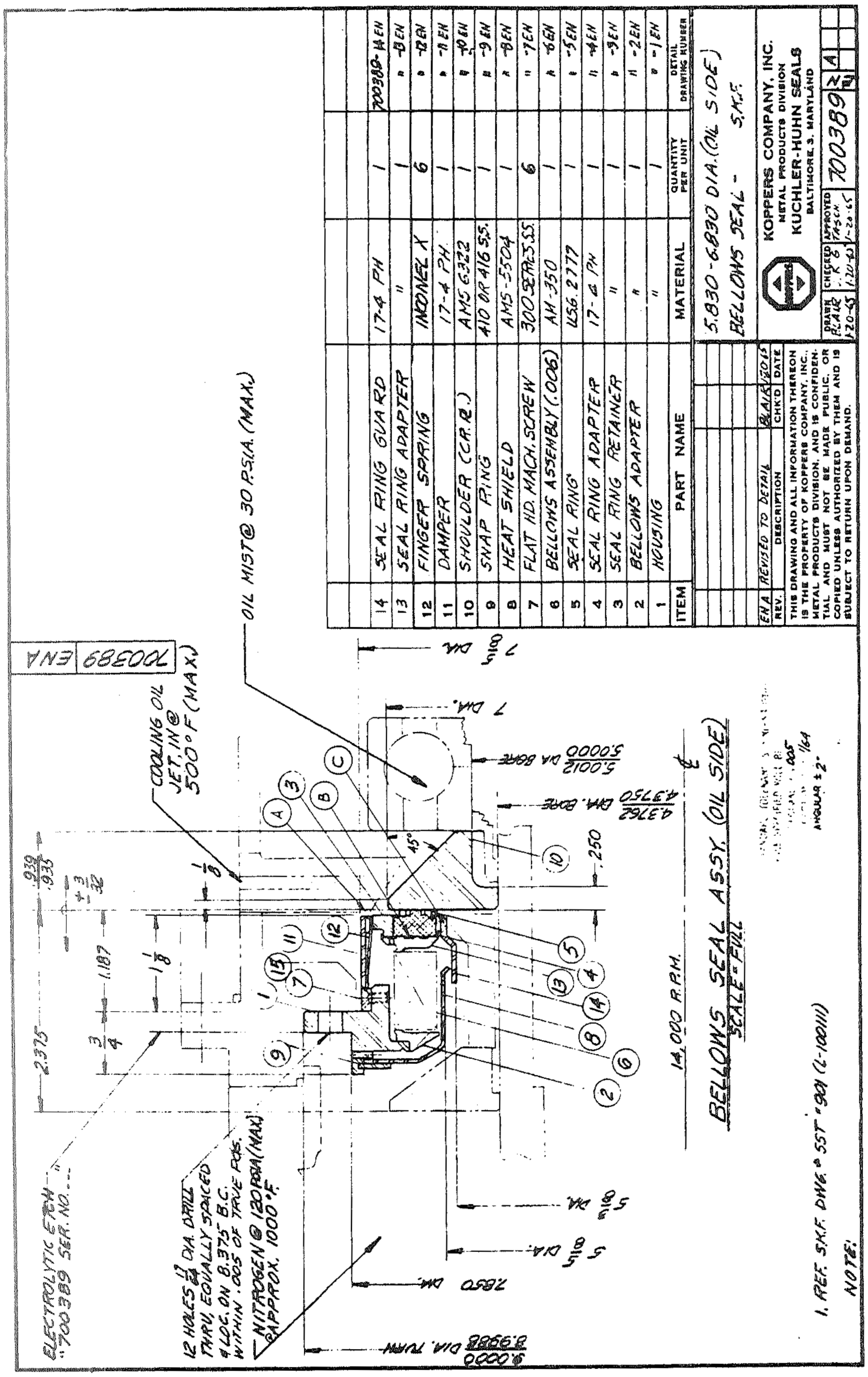
TEST & OIL	AIR SEAL	OIL SEAL	LEAKAGE SCFM TOTAL	LEAKAGE SCFM AIR SEAL	LEAKAGE SCFM OIL SEAL	HOUR SEAL USED IN THIS TEST/ TOTAL HOURS AIR	HOUR SEAL USED IN THIS TEST/ TOTAL HOURS OIL	WEAR INCHES AIR/OIL	COMMENTS
			5.8- 8.3			10/ 423.1	10/ 510.3		
			4.2- 8.6			10/ 433.1	10/ 520.3		
			4.4- 5.7	1.6- 2.7	3.0-4.1	10/ 443.1	10/ 530.3		
			4.4- 5.1			2.9/446	2.9/523.2		
			4.2- 5.1			10/ 456	10/ 543.2		
			4.2- 5.9			10/ 466	10/ 553.2		
			4.4- 6.5			10/ 476	10/ 562		
			4.7- 7.0	0.2- 2.9	4.1-6.8	6.8/482.8	6.8/570	.001/.003	Both seals are still in usable condition
13 Mobil Jet II ** (open atmosphere)	700397#6	101056B#1	12.7-38			2.2/485	2.2/572.2	/.016	Oil seal/shoulder assembly replaced air seal shoulder replaced.
	700397#6	101056B#2				0.6/485.6	0.6/ 0.6		Air seal replaced
	700397#3	101056B#2	5.9-13.2			7.8/ 7.8	7.8/ 8.4	.0005/.005	Test terminated both seals are still in usable condition
14 Mobil Jet II** (open atmosphere)	700495#1	101056B#1	6.4-12.3			5.0/ 5.0	5.0/ 5.0	.002/.008	Test terminated both seals are still in usable condition

* All air seals in Phase II testing used Inco 718 steel bellow with CDJ83 carbons except the later part of test 7 and tests 8, 9, and 10 which used AM350 steel bellows with 56HT carbons. The oil seals in Phase II testing; test 1 and 2 used an AM350 steel bellows with USG2777 carbons, test 3 through 8 used an AM350 steel bellow with CDJ83 carbons and test 9, 10, 11, 12, 13, and 14 used a piston type seal with a CDJ83 primary carbon.

**High speed test.

ENCLOSURE I-5

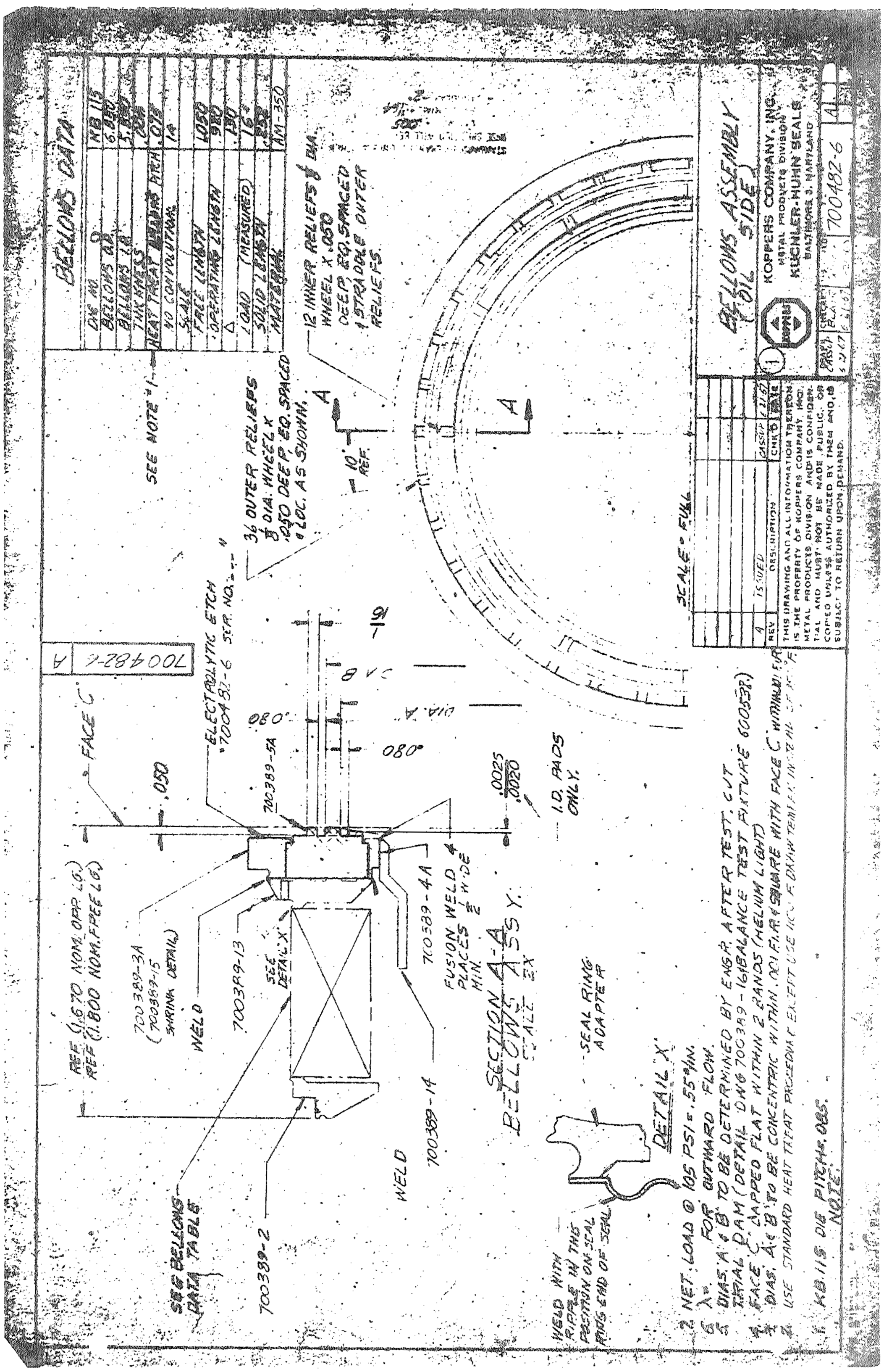
EARLY OIL SEAL AND SHOULDER DESIGN



A. Improved damping device
B. Thermal barrier
C. Modified end fitting retention

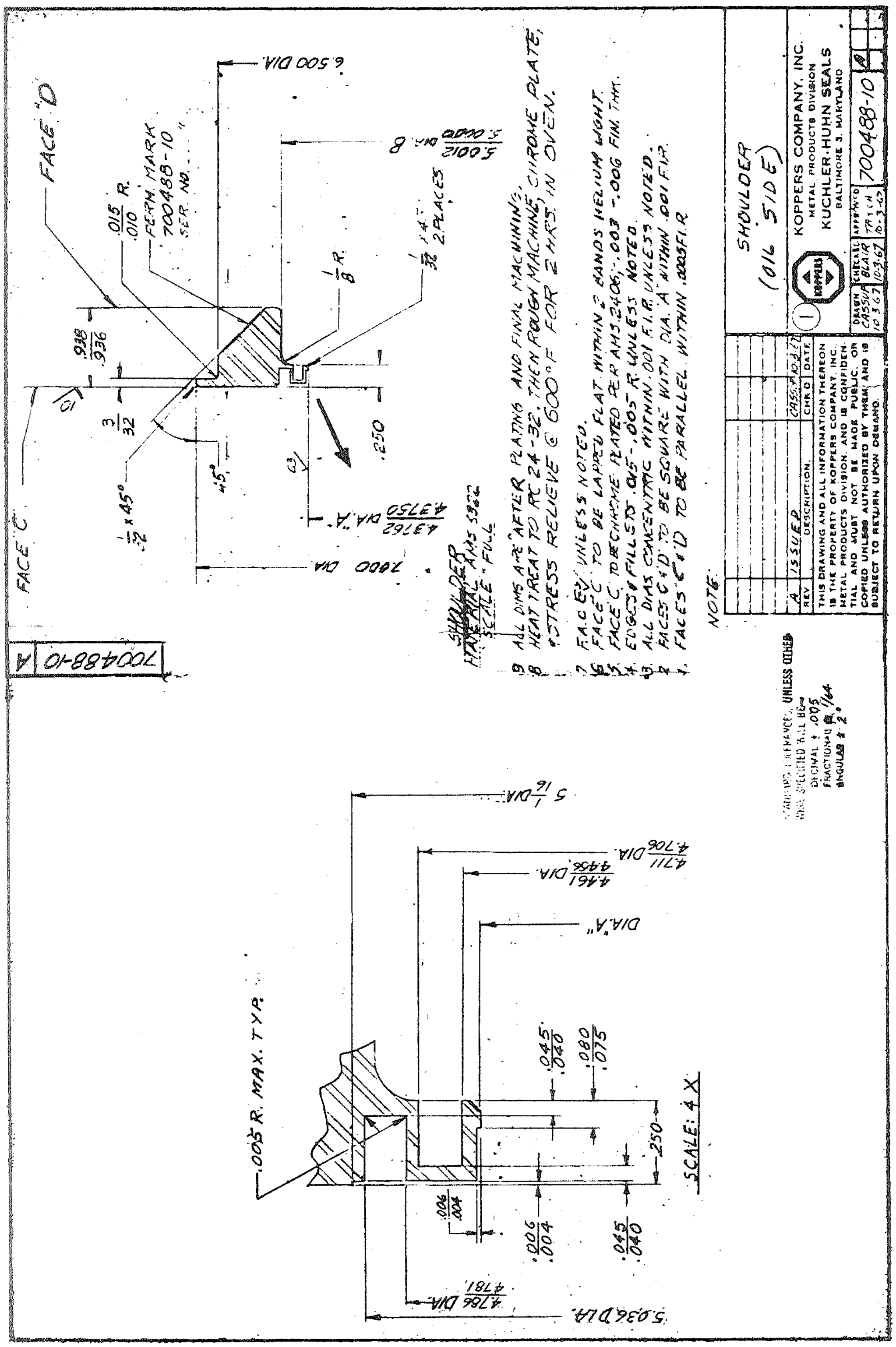
ENCLOSURE I-6

MODIFIED OIL SEAL DESIGN



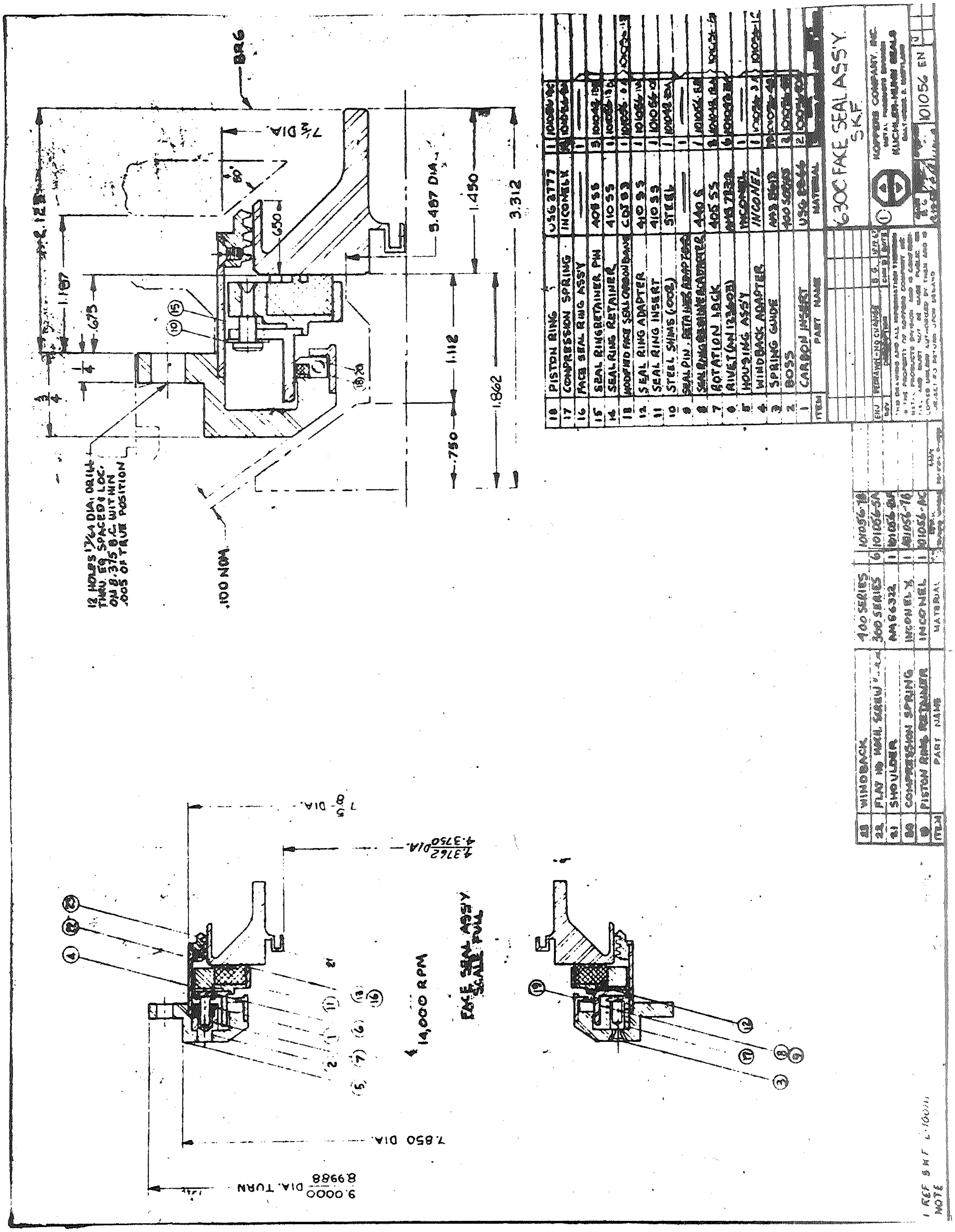
ENCLOSURE I-7

MODIFIED OIL SEAL SHOULDER DESIGN



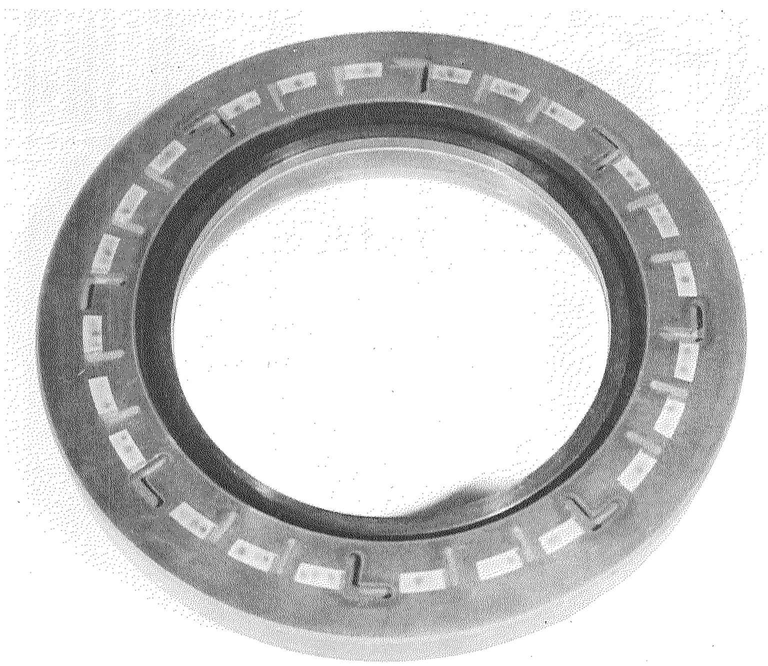
ENCLOSURE I-8

Piston Ring Seal Detail



ENCLOSURE I-9

PISTON RING SEAL SHOULDER



ATTACHMENT I

KOPPERS LETTER REPORT OF 21 NOVEMBER, 1967

Metal Products Division, Koppers Company, Inc.
P. O. Box 626, Baltimore, Md. 21203
Telephone 301-727-2500

KOPPERS

November 21, 1967

SKF Industries, Inc.
Engineering & Research Center
1100 First Avenue
King of Prussia, Pa. 19406

Attention: Mr. L. B. Sibley
Project Leader Engineering

Gentlemen:

The two apparent seal failures, excessive leakage, encountered after reworking of an AM-350 bellows seal, basically to drawing 700488, are obviously very disconcerting. After discussing the actual test data in a telephone conversation on 11/14/67 with Mr. Rhoads and studying the requested Tallysurf traces of both carbons and shoulder, we are still somewhat at a loss to completely rationalize the seal behavior. Although the traces indicate some wear of the I.D. carbon pads, the sealing dam per se apparently remains essentially flat, strongly suggesting coning of the rotating shoulder -- high on the I.D. This coning is explainable by the thermal gradients existing during operation and is a phenomenon generally noted with face seals. The steady seal performance of approximately one hour after warm up and the sealing dam trace indicate rather positively that upstream venting was sufficient and that the pressure breakdown across the sealing face occurred only at the sealing dam; that is, as intended. Theoretically, a leakage in the order of 3-4 scfm represents an average lift of 2.1×10^{-4}.

Operation continued and within approximately 1/2 hour the leakage gradually increased to about 10 scfm. This increase could only have been caused by increase in separation to roughly 3.0×10^{-4}. However, this increase does not imply a change in the hydraulic pressure distribution at the sealing face nor a significant change in the structural "spring" load exerted by the bellows. We cannot explain the change in separation in terms of seal parameters, unless it was caused by a very small increase of the shoulder wobble or a small increase in axial vibration amplitude, neither of which was observed. As long as the back pressure (bearing cavity pressure) is not affected by this increase in leakage, the seal performance should not be drastically affected. If for any reasons however separation is instantaneously increased in such a manner that a pressure surge can occur in a bearing cavity, the seal will unseat because of its sensitivity with respect to pressure differential. (It was stated that the pressure increased suddenly in the bearing cavity to 15 psig), presumably prior to lift-off. It is conceivable, however, that the pressure increase preceded lift-off. The attached curve shows that the structural force will be reduced by about 50%. If the ΔP across the seal is reduced from 105 to 90 psi, the resulting face load may be marginal relative to acceleration, etc. Although AM-350 bellows had to be used and tem-

F-4186A R100

perature was reached for at least 1 1/2 hours, no relaxation was noted.

The above described mechanism is, in our opinion, the only one which will explain the actual test history and the subsequent geometric analysis of the mating surfaces.

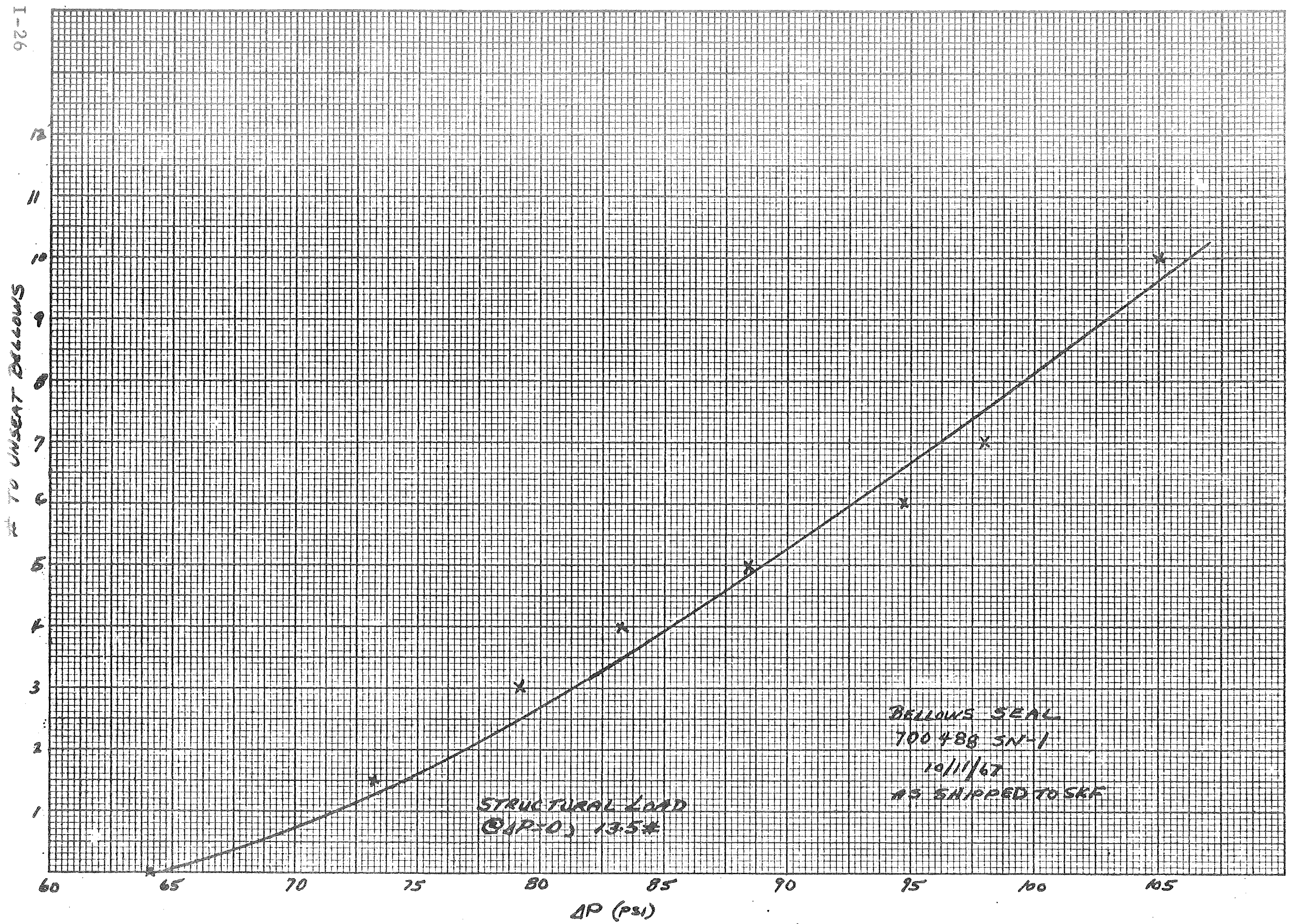
It is obvious that the load-pressure sensitivity is not a desirable condition but exists because of the diaphragm design and welding parameters which were common practice at the time the seals were designed and fabricated. (Our report of 9/15/67, page 7).

Subsequent to the above described tests, in a telephone conversation with the interested NASA personnel, they suggested that a slight increase in initial face load, about 12%, may remedy the problem. Koppers did not then and does not now feel that this slight increase would cause catastrophic wear, although any face load increase was and is undesirable.

The most recent test, after relapping the parts and increasing the face load by a total force of 1.2 lbs. (.020" x 60 lb/in.) was again unsuccessful and visual observation of the face indicated excessive wear (pads and dam worn off). It is my opinion that this result is not so much a result of the face load increase, but is rather caused by upstream choking. The carbon face of this particular seal had already been reworked several times and as finally shipped by Koppers, the vent area was considered about minimum. It is very probable that further reworking reduced these areas sufficiently that unless low leakage was obtained, upstream choking would take place, unbalancing the seal in a seating direction, resulting in an excessive face load.

These two latest results basically confirmed the conclusions reached in our report of 9/15/67 and a subsequent meeting; that is, a face load of less than .5 lbs/in. is required and that a bellows diaphragm design and/or welding method must be developed insuring a spring rate not affected by pressurization.

A piston ring seal, maybe at the cost of higher leakage, must be substituted as the quickest "fix" of the present problem. The carbon inner pads are designed to permit the use of a shoulder incorporating hydrodynamic pockets. Obviously, for equal springing, this design should result in greater separation, hence higher leakage than is obtained with the plane shoulder presently used. The small radial width of the I.D. pads of the current bellows seal do not lend themselves to this alternate.



TO UNSEAT BELLOWS
ΔP (PSI)
60
65
70
75
80
85
90
95
100
105
1
2
3
4
5
6
7
8
9
10
11
12
BELLOWS SEAL
700 488 SN-1
10/11/67
AS SHIPPED TO SKF
STRUCTURAL LOAD
(@ΔP=0) 13.5#

AL69T016

ATTACHMENT II

KOPPERS FINAL REPORT (PHASE I) - SEAL PERFORMANCE FOR SUPERSONIC TRANSPORT LUBRICATION SYSTEM INVESTIGATION

F-4186 A R 100

KOPPERS COMPANY, INC.
METAL PRODUCTS DIVISION
PISTON RING & SEAL DEPARTMENT
BLATIMORE, MD.

FINAL REPORT

SEAL PERFORMANCE

For

SUPERSONIC TRANSPORT LUBRICATION SYSTEM INVESTIGATION

(PHASE I)

Prepared By: T. C. Kuchler
T. C. Kuchler

Date: 9-15-67
September 15, 1967

All seals supplied by Koppers to SKF Industries for the "Supersonic Transport Lubrication System Investigation" consisted of hydraulically balanced carbon face bellows type seals.

The selection of an inert gas (nitrogen) buffer system was predicated on rather extensive prior experience with high temperature air-to-oil seals where sludging of the oil and fouling of the seals presented a serious operational problem.

Designs and operating conditions are as follows:

AIR SIDE

Seal Dwg. 700397 (AM-350 Bellows) Enclosure 1
Seal Dwg. 700405 (Inco 718 Bellows) Enclosure 2

Ambient Pressure:	105-110 psig
Pressure Differential:	Nitrogen (Buffer Fluid) to air 5 psi
Air Temperature:	1200°F.
Nitrogen Temperature:	600-900°F.
Speed:	14,000 RPM (388 ft/sec. rubbing speed)

OIL SIDE (BEARING)

Seal Dwg. 700389 (AM-350 Bellows) Enclosure 3
Seal Dwg. 700482 (AM-350 Bellows) Enclosure 4
Seal Dwg. 700473C (Inco 718 Bellows) Enclosure 5

Pressure Differential:	Nitrogen (Buffer Fluid) to bearing cavity (oil mist at, basically ambient pressure) 100-105 psi
Nitrogen Temperature:	600-900°F.
Bearing Cavity Temp:	500°F. and up
Speed:	14,000 RPM (388 ft/sec. rubbing speed)

I. TEST RESULTS

Before discussing seal performance it should be pointed out that the primary function of this program is testing of oils at elevated temperatures. Hence the lubricating and cooling specifications are defined by the oil-in and out temperature, and not by seal performance.

Very early in the program it was found necessary to eliminate cooling oil jets on the oil side seal shoulder in order to achieve the specified test temperatures at the bearing. This limitation is contrary to aviation gas turbine design practice where the seal shoulder is cooled by special oil jets.

The inert gas buffer seal arrangement proposed and supplied for this test program assumed of necessity that the gas seal would have no external cooling and therefore, by design, the pressure differential on this seal was made as small as practical (5 psi). On the other hand, the high differential pressure was imposed, by design, on the oil side to take advantage of the oil cooling capabilities. Because of the limitations mentioned above, the oil seal cooling in "through flow testing" was restricted to splash or carry over from the bearing lubrication-cooling; the effectiveness of this type cooling is minimal.

The same seal system is used for the "oil mist" tests. Because of this, satisfactory seal performance was considered very marginal, at best, at the time of the initial design. It is a known fact that heat generation of shearing an intermittent thin oil film can cause lacquer, carbonization, excessive heat, and hence seal malfunction.

The basic seal data of new and reworked seals (with the exception of two Inco 718 semi-finished seals retained at Koppers plant) shipped in the course of this development are listed in Encl.6. It should be noted that for the latest reworked seals (1967) the face loads were appreciably increased. This increase was an attempt, not successful, at reducing the effect of speed on leakage. It can also be noted that some not unexpected relaxation of the AM-350 bellows occurred. It is not believed, however, that this is a contributing factor to the intermittent excessive leakage phenomenon.

One structural seal failure occurred during this program. One air side AM-350 seal was forwarded to Koppers because of excessive leakage. It was found that on the first O.D. weld after the "housing" weld a weld arc of about 60° had cracked. Metallographic examination disclosed that the primary reason for the failure was an insufficient weld bead. Examination of the same weld in other areas revealed satisfactory weld beads. (Coulombe's letter of 6/24/66 to Sibley).

It is of interest to note that this weld is in compression and that the static operating stresses are low. It might be possible that this fracture constitutes a fatigue failure as the convolutions per se are not damped. In contrast none of the highly stressed welds (oil seal) failed.

In summarizing the test results with respect to seals it must be stated that as a whole they have performed very erratically, although in quite a few instances tests were aborted but not because of seal failure. In over a dozen cases, however, the seals did not seal properly at speed or trouble was experienced while attempting to attain the specified speed of 14,000 RPM.

Using the following arbitrary oil seal leakage nomenclature:

1.	Good Leakage:	Less than 5 SCFM
2.	Mediocre Leakage:	5-10 SCFM
3.	Poor Leakage:	10-15 SCFM
4.	Unacceptable Leakage:	Over 15 SCFM

10 tests showed good, 17 mediocre, 9 poor and 8 unacceptable leakages. (In all instances, more or less steady state conditions for at least one-half hour were obtained). What seems to be significant, however, is that most "good" leakage tests occurred at the beginning of the program and that, for as yet unexplainable reasons, unacceptable leakages at speeds as low as 8,000 RPM were recorded mostly during the second half of the program.

The leakage specifications given above were based on some testing performed at Koppers some time ago with bellows seals. The AM-350 diaphragm of these seals were identical with the ones presently used, and sealing 950°F. air at 33 psig and a surface speed of 175 ft/sec, leakages below .1 SCFM were consistently obtained for test periods in excess of 60 hours. It is not believed that any other than a bellows seal can approach such low leakage figures. The cooling and lubricating oil was admitted at 400°F. to the seal shoulder and bearing.

Tests as well as theory indicate that after a "critical" rubbing speed is exceeded leakage remains practically constant. Koppers is presently engaged in a hydrodynamic lift seal program and preliminary testing shows that at a rubbing speed of about 100 ft/sec. a measurable finite separation of the Koppers "face" is taking place. Beyond this speed (up to 300 ft/sec.) no appreciable change is recorded. This obviously implies constant leakage with speed, and the tests where leakage increases rapidly with speed definitely do not follow this pattern.

In addition to the leakage problem, some excessive wear rates were recorded in some instances and evidence of oil coking at the O.D. of the carbon was also reported.

One test rates special mention as an oil seal with a faulty sealing dam dimension -- large lifting bias -- was installed and operated for 3.3 hours at 13,500 RPM at temperatures in excess of 575°F. and the recorded leakage of 6-8 SCFM. If the gas flow was choked on the upstream (high pressure) side the resulting reduction in face load would compensate for this dimensional error. This hypothesis, however, is untenable because the downstream flow area was only about twice the one of the upstream area whereas the gas density is about eight times less (15-120 psia); that is, if any choking occurred, it must occur on the downstream side.

What makes this test unique is the fact that no report of seal instability in reaching speed or at top speed of 13,500 RPM was recorded, and if any seal lifted this should have been the one.

As soon as the first report of unacceptable leakage with increased speed was received and subsequent inspection also showed coke accumulation at the O.D. vents, Koppers recommended that the O.D. pads be cut back by about .003". This geometric change of the sealing face served two purposes: First, to ameliorate any possible hydrodynamic lifting effects of oil droplets which may accumulate in this area; and secondly, to radically increase the downstream flow path in order to eliminate any possibility of choking at the O.D. pads where choking will generate a lifting effect. This work was performed by SKF; the results were negative, that is, no change in seal performance was noted.

A meeting of SKF, NASA and Koppers' personnel was held May 10, 1967 in order to evaluate and review the program as a whole in light of the test results. General agreement was reached and the following design changes were initiated. One seal, incorporating all changes listed below was shipped and was to be used in an endurance test which would terminate the existing program.

1. Koppers was of the opinion that the damper and finger spring assembly, items 11 and 12 of Enclosure 4(drawing 700482-A), may have caused "mechanical" hanging of the seal. These parts were remachined to eliminate this possibility.

2. The flow area of the downstream vents was doubled to eliminate all possibility of choking.

3. Wear measurements of both carbon face and to a lesser extent the shoulder face had indicated I.D. (carbon) contact (diverging flow). To reduce the start-up leakage it was decided to taper the area of the pads inside the I.D. dam Enclosure 7, (drawing 700482-6) to insure initial I.D. dam sealing.

4. To minimize the possible effect of "shrinking" the shaft shoulder onto the shaft during operation and thus distort the lapped flat sealing face, a radial "spring" was machined integral with the shoulder at the I.D. Enclosure 8 (drawing 700473-10A).

5. It was also decided to decrease the face load slightly to about .4 #/In. in order to insure better performance. The seal as shipped (AM-350 -- see following discussion) was statically calibrated in its final configuration with the following results. As can be noted, reduction in face load was not possible.

Static Pressure PSIG	Seating Force LBS.	Face Load LBS/IN
103	11	.550
83	7 1/4	.362
72	5 1/4	.262
60	3 1/4	.162
50	1 1/4	.062
45	3 1/4	.162
34	5 1/4	.262
28	7 1/4	.362
20	9 1/4	.462
10	13 1/4	.662
0	16	.80

(Non-pressurized bellows spring scale: 60 #/In.)

6. One Inco 718 seal assembly, incorporating all changes was to be shipped to SKF for final test. Koppers was not able to balance this seal properly and in order not to further delay the final endurance test, the above described AM-350 seal was shipped.

The rig was rebuilt and the final endurance test was started. Again, trouble was experienced in reaching the 14,000 RPM level and seal leakage was excessive. The test had to be stopped.

In addition to the excessive leakage, the measurements indicated high rates of wear, .015" on the air side and .010" on the oil side after only 9.7 hours of operation. The large wear can definitely be explained by the variations of the nitrogen buffer pressure which constituted an attempt to reduce the oil seal leakage.

a) AIR SEAL--This seal is designed for inward flow, sealing a small differential. Due to the high thermal environment the face loadings were held to a minimum, about 1.45 #/In. This minimum is determined by the contact load to which wear allowance and the dimensional stackup must be added. In increasing the buffer pressure an unseating force is created. (For the low differential the bellows spring scale is assumed to remain constant at 60 #/In.). It is not believed that this unseating force actually caused an unseating of the seal. In reversing the flow, decreasing the nitrogen buffer pressure, the face loading is drastically increased. This results in a breakdown of the gas film and hence a large increase in frictional heat input into the rotating shoulder and stationary carbon. In addition, the gas flow across the carbon changes from the inert nitrogen to oxidizing air. Film breakdown causing excessive heating and the air flow will result in a large mechanical wear rate in addition to face deterioration due to oxidation.

b) OIL SEAL--The reduction in buffer pressure will also adversely affect the wear rate of the oil seal because the gas leakage changes from nitrogen to either nitrogen greatly contaminated with air, or to air. The reduction of pressure in the buffer cavity may or may not increase the face load depending on the pressure level (effect of bellows spring rate). Increasing the buffer pressure, although eliminating the nitrogen-air flow across the seal, will drastically increase the face load, hence wear.

It seems, therefore, that the change in pressure was detrimental with respect to wear of both seals. It should also be mentioned that once high wear rates have been established, the wear debris will cause excessive separation and additional flow paths, hence unacceptable seal leakage.

The initially observed phenomenon of a large increase in leakage at about 12,000 RPM is, however, not explained by the above discussion.

II. ORIGINAL SEAL DESIGN

The basic Koppers bellows seal design is characterized by three special features:

1. Past experience with operating bellows seals in a gaseous environment pointed to the necessity of incorporating an axial damping device into the design. In this application a series of leaf springs will supply axial frictional damping to the carbon seal end and will be effective for excitation originating at the rotating shoulder. The damping device is not necessarily effective in suppressing natural bellows frequencies once excitated.

2. The carbon wearing ring is retained within a metallic retainer by means of a shrink fit. The design is such that the resultant shrinkage forces, which will obviously vary with temperature, produce a minimum twisting moment (resultant shrinkage force vector as close to the carbon centroid as possible) hence reduces the sealing face distortion to a minimum. The back of the carbon ring is vented to downstream pressure to eliminate any pressure build up in this area which would cause not only face distortion, but also may result in an axial shift of the carbon ring proper.

3. The Koppers grooved and padded face geometry has in dozens of applications proven to be far superior with respect to wear for high speed and high temperature gas operation than the customary single dam configuration. Obviously, this geometry was incorporated in the initial design.

As already mentioned, the pads, especially on the high density fluid side, generate a lifting effect (face separation) which not only results in lowering the seal torque, but reduces seal wear.

Koppers extended experience with gas seal operation has made it abundantly clear that for operation at the temperatures and speeds encountered in these tests, the specific face loading (lbs. per inch of circumference) must be kept below .5 #/In. if at all possible. A load of .5 #/In. will permit a "wobble" of the rotating shoulder or a combination of an axial excursion at shaft frequency plus wobble of .0015" TIR without causing separation.

In order to obtain minimum start up leakages, the inner pads were cut back by about .00075 ± .00025" thus insuring immediate sealing at the I.D. of the sealing dam.

It has been known for quite some time that the present bellows diaphragm design (basically nesting) employed by Koppers results in a seal face load which is greatly affected by pressure. In order to assure satisfactory face loadings, all bellows seals were and are static pressure tested at room temperature.

It is realized that at operating temperatures the Young's moduli of both AM-350 and Inco 718 are reduced by about 15% to 20% and this is taken into account in releasing the seal for shipment.

The selection of the bellows material was predicated on manufacturing experience, hence the selection of AM-350 for the initial seals. Although Inco 718 has better thermal physical characteristics than AM-350 at temperatures above about 950°F, some experimentation with preparation of the material prior to welding had to be undertaken as the oxide films on the commercially available sheets must be completely removed in order to obtain sound welds. In this respect it is worthwhile to mention that since the inception of this program Koppers has been successful in welding .006" Udimet 630 sheet, a material with much better thermal capabilities than Inco 718. It must be emphasized, however, that the preparation of Udimet 630 sheets prior to welding is extremely costly, especially if only a few pounds of material are required.

III. SEAL REDESIGN

All tests, including the final aborted endurance test, pointed out three main areas where seal performance must be improved and design changes are indicated:

1. Wear

As already mentioned, the face loading of .5 #/In. and above is too high for long term operation at the specified temperatures and speeds. Although separation will eventually occur at a rather moderate rubbing speed, the amount of separation and the speed at which lifting begins are greatly affected by load. The ideal seal bellows should therefore have a hydraulic diameter and spring scale, the latter as low as possible, not affected by pressurization. Constancy of these two variables definitely implies constancy of span (O.D. minus I.D.) hence a bellows diaphragm configuration less susceptible to pressure should be substituted for the present one.

Because of the pressure balancing difficulties encountered with bellows seals supplied over the last several years, considerable work has been expended by Koppers in this area in order to define the causes of the seating force change in function of pressure. It can be definitely shown by experiment and the data can be correlated qualitatively by theory that the spring scale of the existing diaphragms increases as an exponential function (exponent >1) with increasing pressure. Such a drastic change is incompatible with a specification of maximum face load at pressure of say .35 #/In. taking into account tolerance stackup (operating length) and wear. Assuming a total allowance of .060 for this purpose, a difference in load of 4.5 lbs. or .225 #/In. can occur, practically half of the maximum permissible face load. The balance of about .2 #/In. is generally enough to insure satisfactory seal performance.

It is therefore recommended to investigate, both from a manufacturing and empirical point of view, a sandwich type design which could utilize the existing forming dies. A second alternate is to change the diaphragm shape to either a Bellville or cantilever type, which will require new tooling.

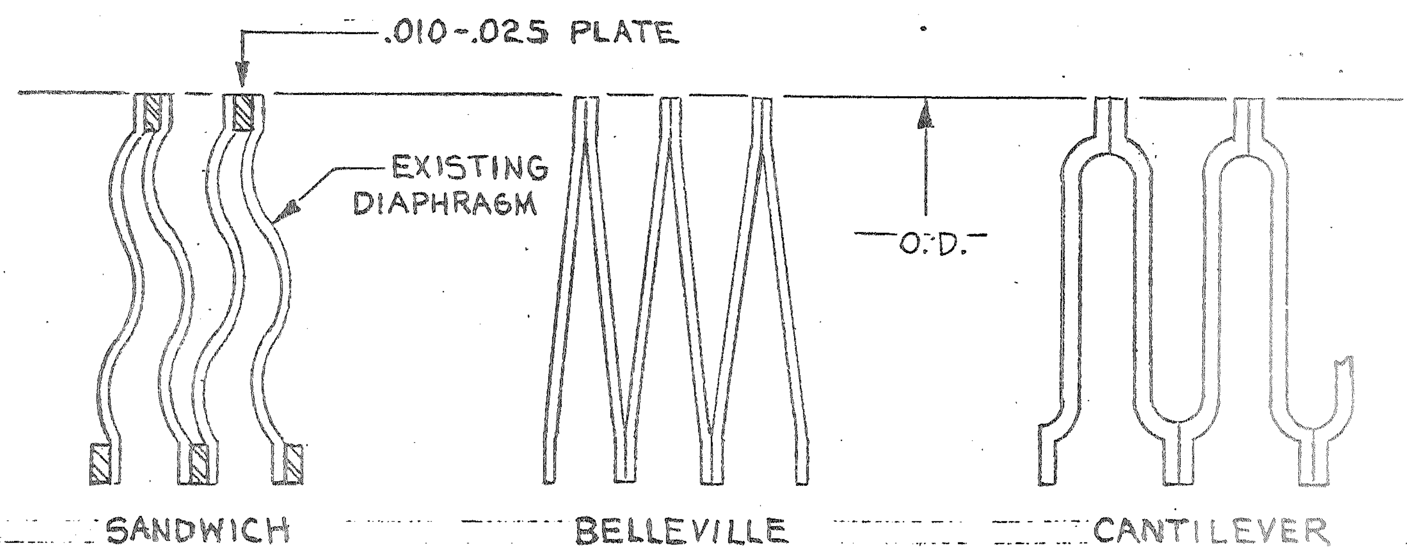


FIG. 1

Unresolved as yet (static pressure effect on spring scale of bellows) is the difference of behavior between AM-350 and Inco 718 bellows. Both diaphragms are formed with the same dies, and welding and heat treat fixtures are identical. Young's modulus and Poisson's ratio are also practically the same. Hence, any difference in the force-deflection relationship must be caused by a difference in geometry. The relaxation due to the thermal operating conditions noted with AM-350 makes it, however, imperative to change to Inco 718.

The behavior pattern of Inco 718 was such that in order to obtain proper face loading at pressure the bellows lifted off during the static tests at intermediate pressures. This behavior pattern was the reason that AM-350 had to be substituted for the initially specified Inco 718 bellows scheduled for the endurance test.

It is therefore suggested that Koppers be permitted to section one bellows each to compare the convolution shape.

2. Oil Coking and Oil Lacquering

A windback design requiring a different shoulder configuration will probably ameliorate if not necessarily eliminate the problem. Such an arrangement is considered to be necessary for all "mist-throw away" tests.

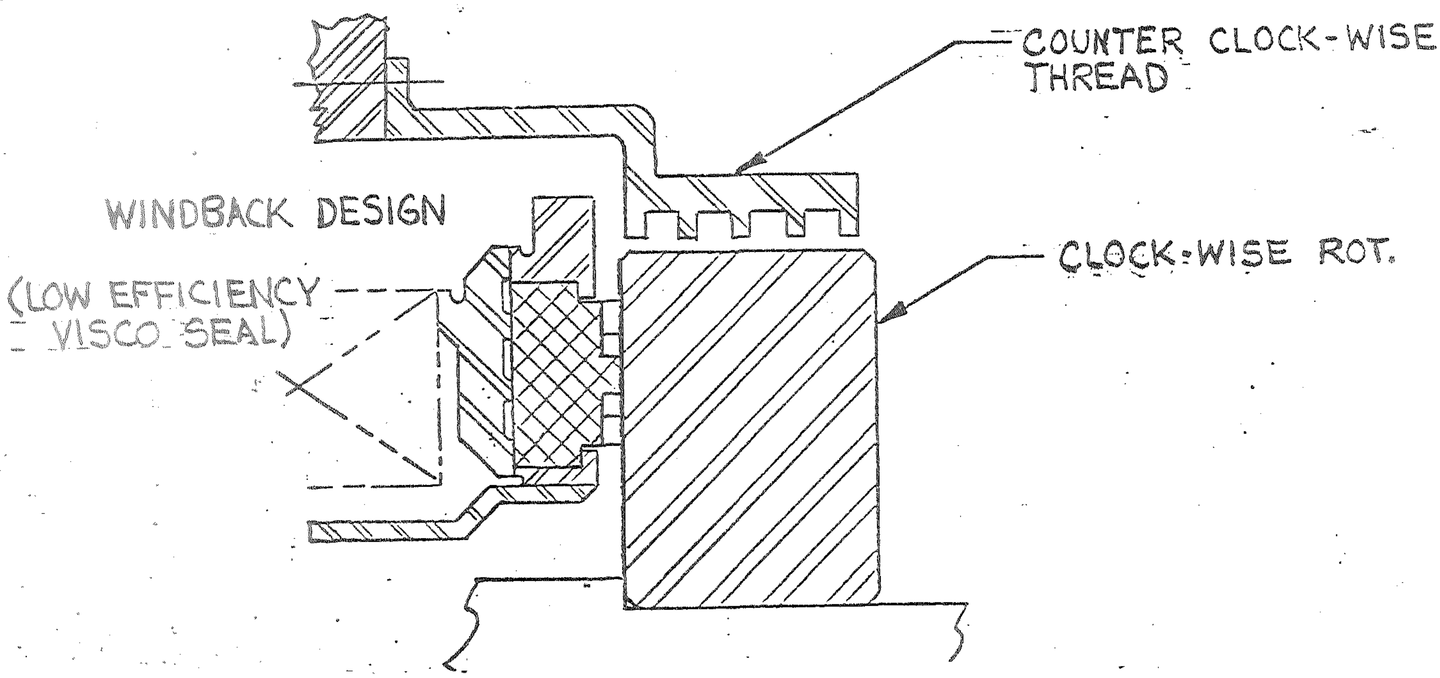


FIG. 2

3. <u>Excessive Leakage</u>

This appears to be the most serious problem; the mechanism or cause of this phenomenon has not been determined as yet.

If the sealing face is designed for a large pressure differential (balance diameter or hydraulic diameter is constant) a reduction in pressure results in a seating bias thus increasing the face load. (This conclusion is based on a nonlinear quadratic pressure profile over the sealing dam). Hence, reducing pressure will <u>not unseat</u> a seal. This fact is emphasized in case that the pressures are inadvertently reduced while the speed is increased.

It is safe to assume that during operation the mating sealing surfaces of the stationary carbon and rotating shoulder will not remain flat. The design, as previously mentioned, attempts to minimize thermally caused carbon face distortions; the shoulder, however, probably distorts thermally as shown.

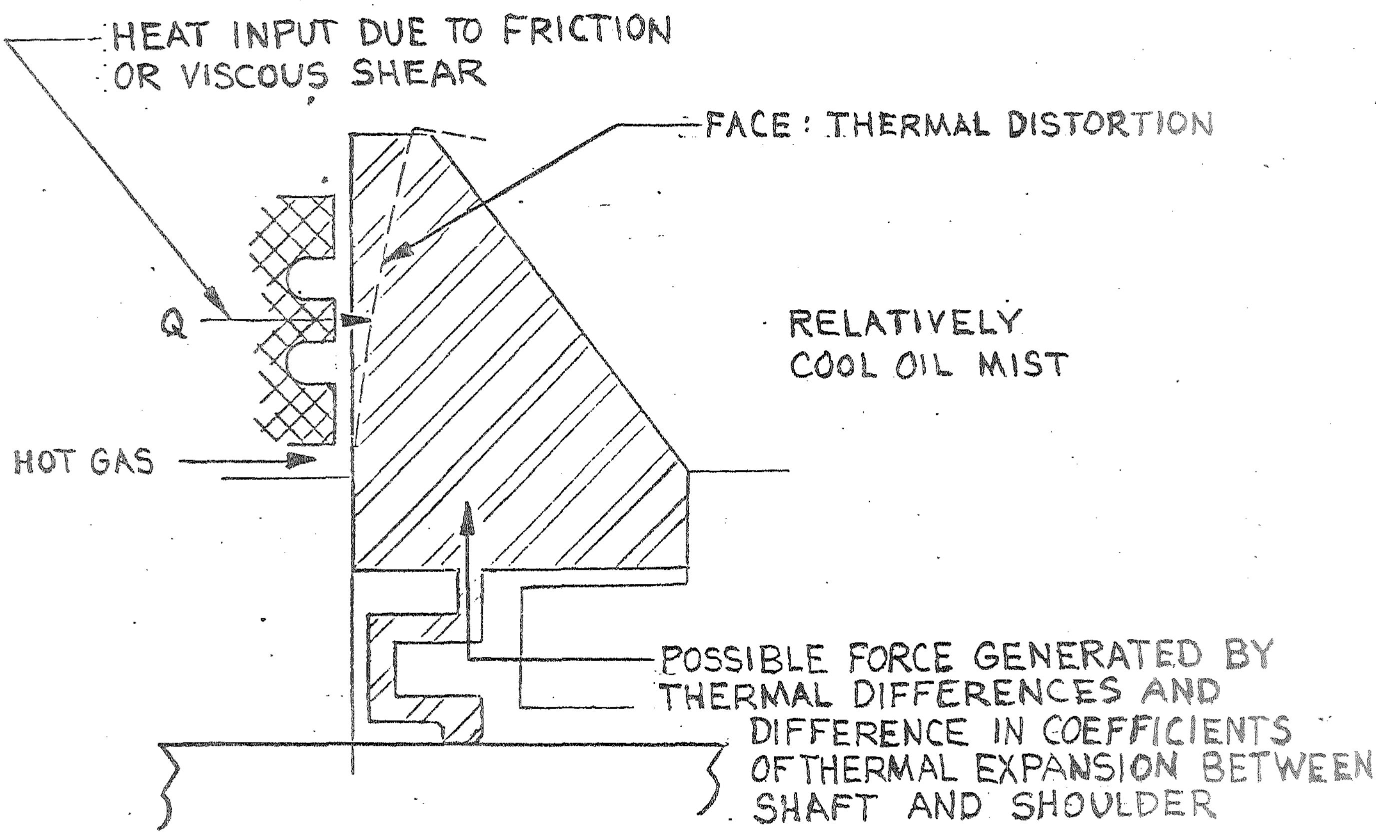


FIG. 3.

From the sketch it can be deduced that the thermal condition, at least for steady state operation, will cause initially I.D. bearing of the seal carbon and the resultant geometry of the seal face is described in Fig. 4.

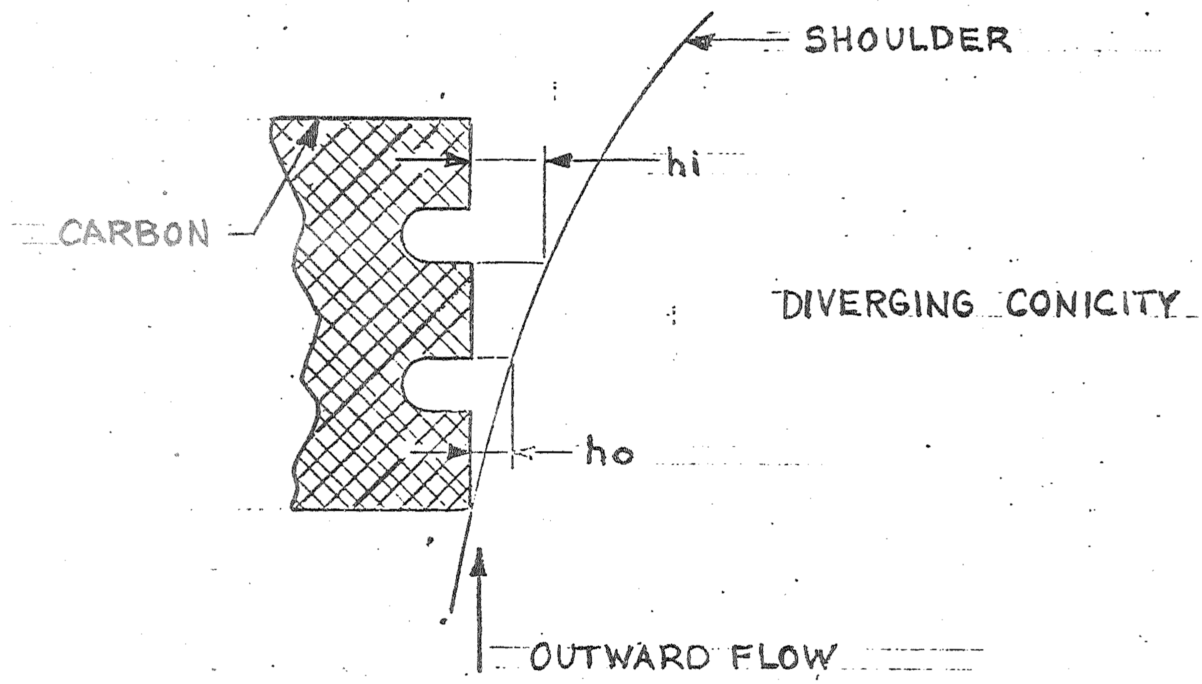
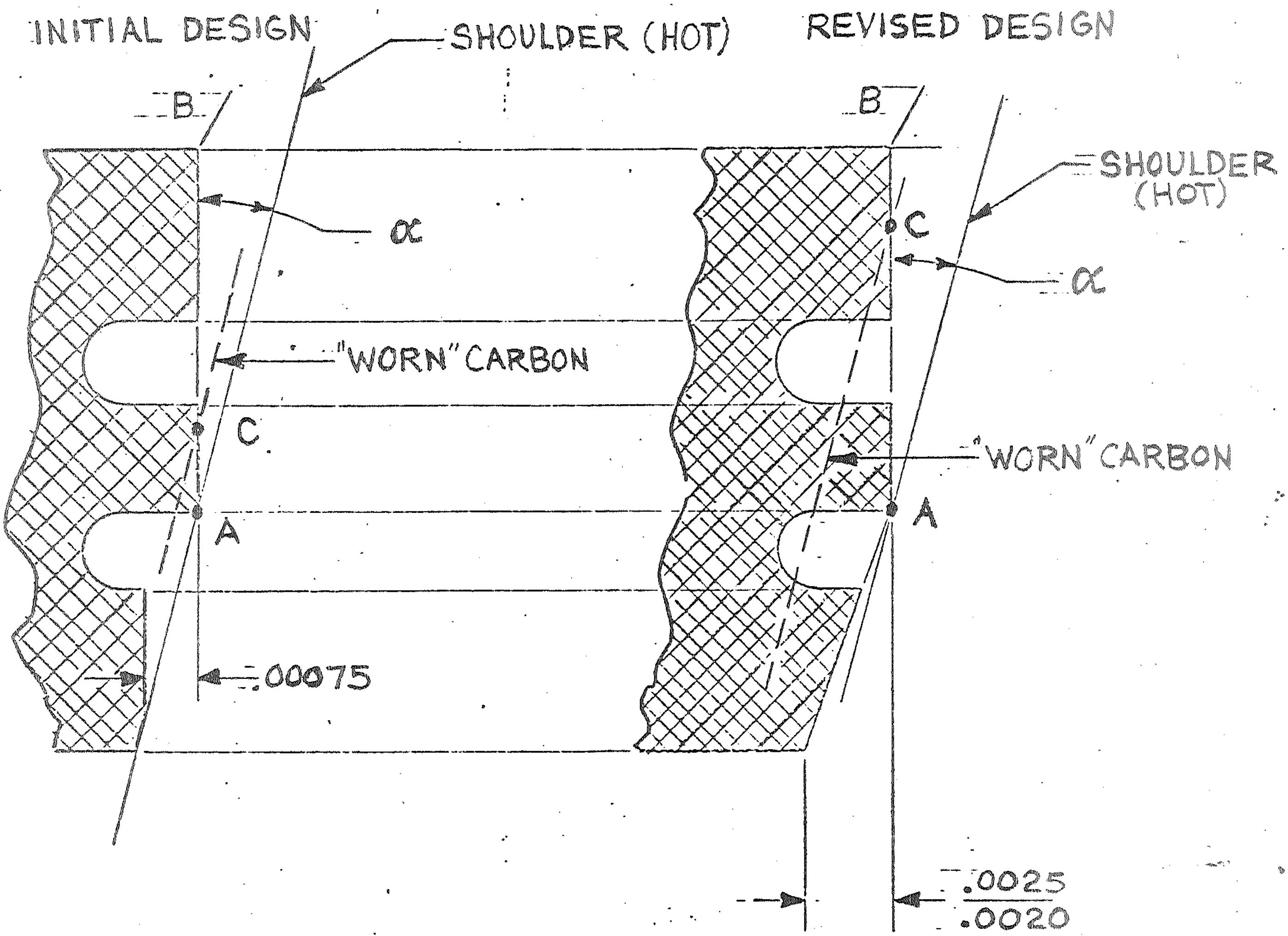


FIG. 4

It becomes obvious that diverging conicity will always increase but never decrease the face load, due to the fact that the pressure breakdown across the sealing dam becomes more rapid than would be encountered with a parallel path.

The following hypothesis describes a mechanism which will result in a converging flow path and hence tend to unseat the seal.



BOTH DESIGNS ARE IDENTICAL WITH RESPECT TO THE EFFECT OF THERMAL ROTATION ON THE FLOW PATH

FIG. 5

From Fig. 3 (heat flux and possible "expanding" force) it can be deduced that initial contact, as was intended, will take place at "A" (Fig. 5). Any wear, shown by dotted line of Fig. 5, will move intersection "C" outward, in the extreme to edge "B". If, after any wear has taken place and either force (Fs) or heat input(Q) or both reduce while reaching steady state condition, the angle α becomes smaller and point "C" represents the "pivot" for this secondary rotation. The net effect is a converging flow path, resulting in a "lifting" bias at the sealing face.

In the case "C" remains within the sealing dam (unlikely), the flow path becomes converging-diverging (venturi like cross section). If "C" moves outwardly beyond the dam, true convergence is obtained. Total wear in the order of .000020" to .000040" will move point "C" beyond the sealing dam.

A second possibility to increase separation is as follows:

If higher harmonic axial frequencies than the fundamental rig frequency are generated in the adjacent bearings, unseating of the seal could occur. A double amplitude of .0002 for the fourth harmonic of 12,000 RPM will result in an accelerating force which would cause unseating. (The weight of the carbon end equals 1.536 lbs.).

Due to the very high frequency which would be necessary to overcome the structural face load it is believed that the "squeeze" film will transmit the motion with very little damping; i.e., amplitude reduction, to the carbon face.

As can be deduced from these discussions, the cause of the somewhat erratic seal behavior has not yet been defined too clearly. The following suggested design changes will, however, have a beneficial effect.

1. Eliminate undercutting of the I.D. pads; the complete carbon sealing face to be lapped flat.

2. Since inception of this program U. S. Graphite has submitted to Koppers for test a new grade of carbon, 2866. The wear-load-temperature results show it to be superior to the presently used 2777. Although CDJ-83 is widely used (never in this program) its relatively high modulus and low coefficient of thermal expansion makes this grade sensitive with respect to deformation due to changes in the thermal level.

3. Replace steel shoulder with a sprung tungsten carbide shoulder.

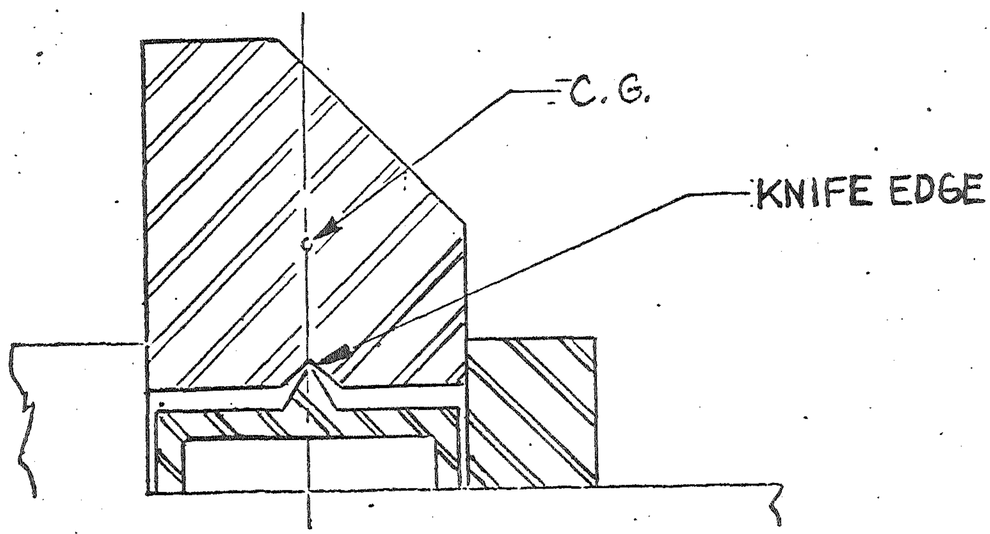


FIG. 6

Thermal coefficient of expansion of tungsten carbide (4×10^{-6}) is lower than the one for AMS-6322 (6.5×10^{-6}). New Design : zero moment. Any pressure or thermally induced deformations will be reduced because of higher modulus 90 to(30×10^{-6}) and better thermal conductivity (41 to 25).

4. Last, but maybe most importantly, all seals before shipment should be dynamically tested at ambient temperature but at pressure and speed. (Without considerable expenditures it is presently not possible to test at temperature). The basic test apparatus, instrumentation as well as air supply, is available and only seal adaptors would have to be supplied.

If, during this test, seal leakage remains substantially constant with speed, but the erratic seal behavior continues during bearing testing the two previously discussed somewhat hypothetical causes must be eliminated if at all possible.

a) Axial high frequency-low amplitude vibrations. It might be necessary to resort to a different and/or additional damping device, as shown on Fig. 7.

b) Reduce thermal shoulder distortions by means of cooling.

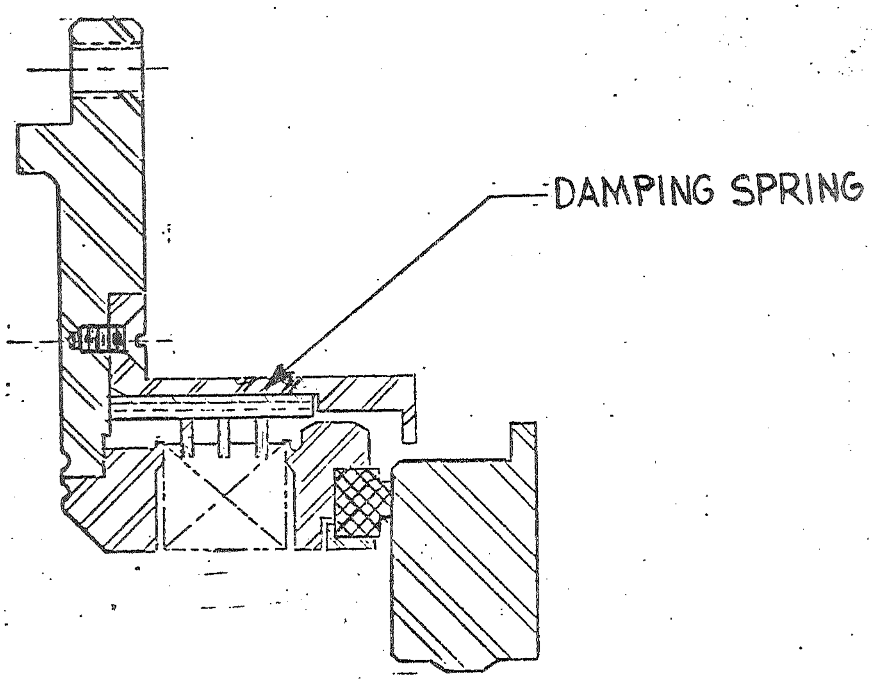


FIG. 7

IV. SUMMARY AND RECOMMENDATIONS AFFECTING SEAL DESIGN

Although the reasons for the frequent erratic and, at times, excessive seal leakage have not been completely ascertained, it is believed to be associated with either a wear problem or rig performance per se. Steps are being suggested which should substantially reduce the wear rate and should also ameliorate the existing thermal deformations and their secondary effects on seal performance. It must, however, be emphasized that in quite a few instances the seals performed very well and, therefore, it is Koppers' opinion that the basic design does not require a complete revision.

The following seven changes affecting seal design are proposed:

1. By changing the basic bellows diaphragm design dependence of bellows spring scale on pressure is reduced; at best, constancy of scale is obtained.

2. Relaxation of the AM-350 diaphragms makes it mandatory to replace this material with Inco 718. Investigate the cause of the difference (cold) in bellows behavior for these two materials.

3. To reduce seal coking incorporate a windback (low efficiency Visco seal). This, however, will require a basic geometric change of the shoulder O.D.

4. Complete carbon sealing face to be lapped flat. (No undercutting or chamfering of I.D. pads).

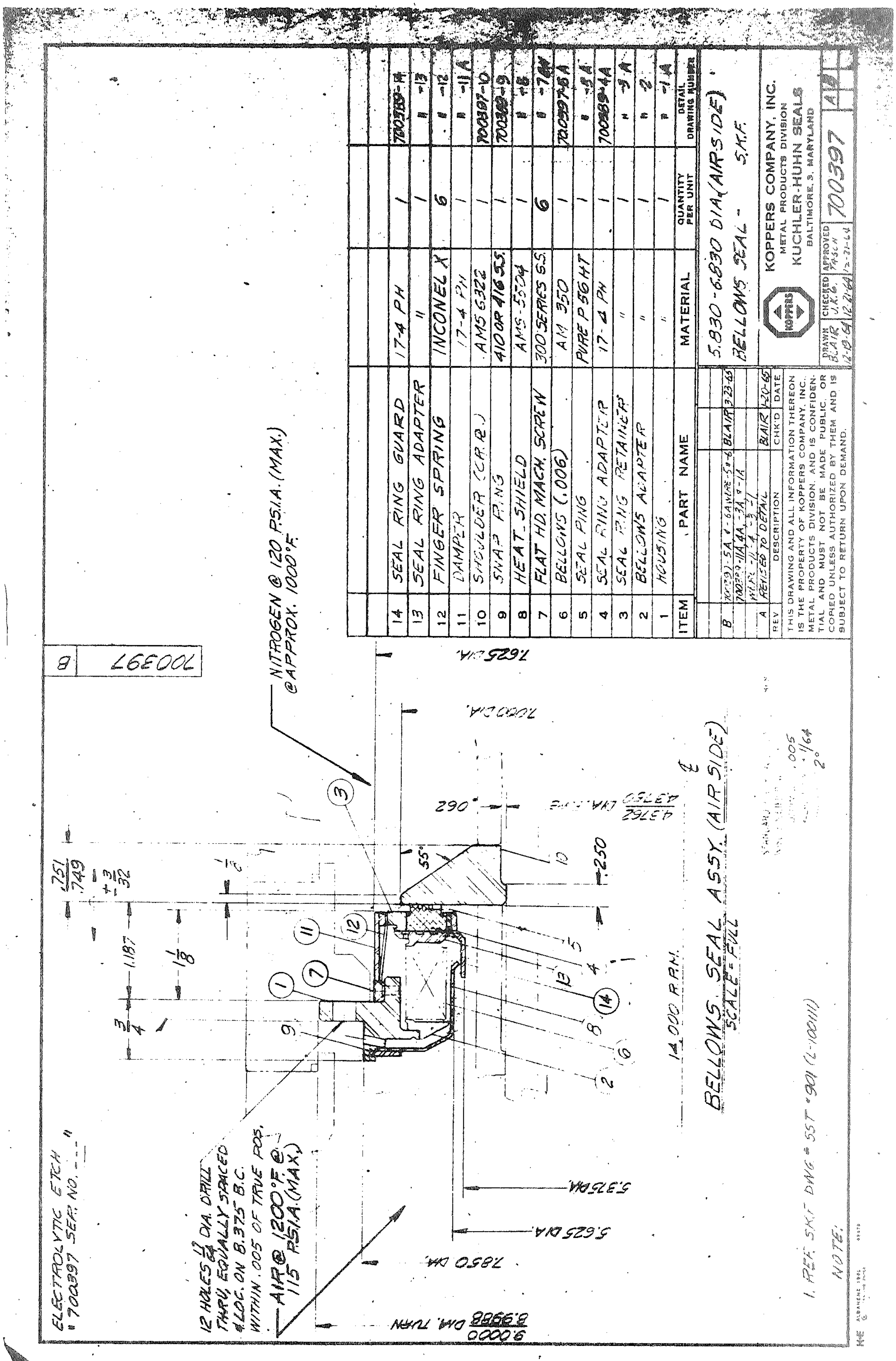
5. Replace existing carbons (USG 2777, and National CDJ-83 which was never used) with USG 2866. Koppers' data indicate this to be a superior grade to USG 2777.

6. Replace AMS-6322 oil seal shoulder with a "sprung" tungsten carbide shoulder (higher modulus and larger coefficient of thermal conductivity).

7. Oil seals to be dynamically tested (cold) at Koppers up to maximum speed and pressure.

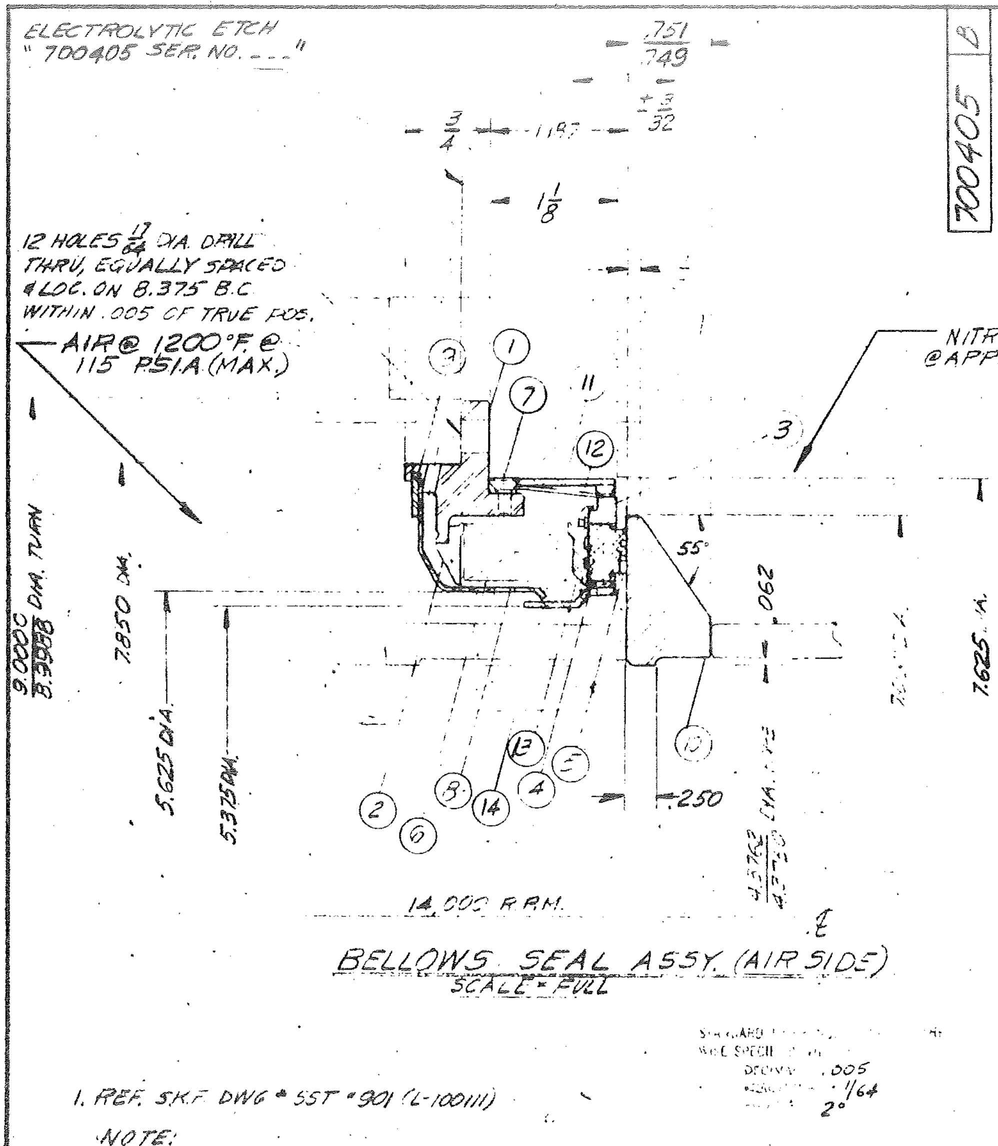
ENCLOSURE 1

AM-350 BELLOWS AIR SEAL



ENCLOSURE 2

INCO 718 BELLOWS AIR SEAL



ITEM	PART NAME	MATERIAL	QUANTITY PER UNIT	DETAIL DRAWING NUMBER
14	SEAL RING GUARD	INCONEL	1	700405-14
13	SEAL RING ADAPTER	"	1	" -13
12	FINGER SPRING	INCONEL-X	6	700389-12
11	DAMPER	"	1	700405-11 A
10	SHOULDER ~~(CAR~~ 2) LC-1C	"	1	" -10 A
9	SNAP RING	"	1	" -9
8	HEAT SHIELD	AMS-5504	1	700389-8
7	FLAT HD. MACH. SCREW	300 SERIES S.S.	6	" -7EN
6	BELLOWS (.006)	INCONEL-718	1	700405-6 A
5	SEAL RING	CDJ-83	1	" -5 A
4	SEAL RING ADAPTER	INCONEL	1	" -4 A
3	SEAL RING RETAINER	INCONEL-X	1	" -3 A
2	BELLOWS ADAPTER	INCONEL	1	" -2
1	HOUSING	"	1	" -1 A

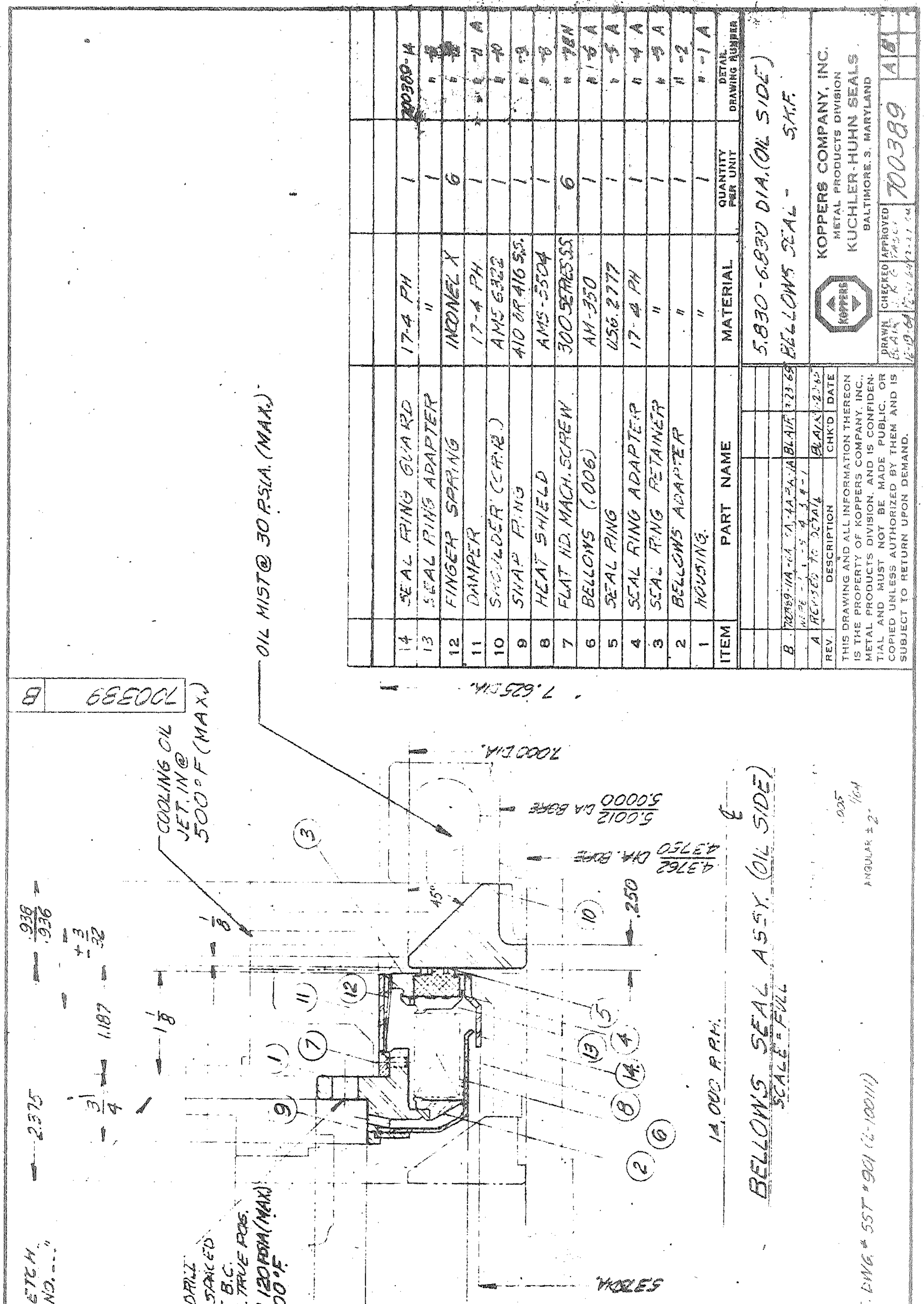
REV.	DESCRIPTION	CHK'D	DATE
B	700405-10A WAS -10	I.K.G.	5-18-65
A	700405-11A, -6A, -5A, -4A, -3A, & -1A WERE -11, -6, -5, -4, -3, & -1	BLAIR	3-23-65

5.830-6.830 DIA. (AIR SIDE) BELLOWS SEAL - S.K.F.

KOPPERS COMPANY, INC.
METAL PRODUCTS DIVISION
KUCHLER-HUHN SEALS
BALTIMORE 3, MARYLAND

DRAWN	CHECKED	APPROVED	NUMBER	
BLAIR 2-19-65	RJK 2-24-65	TASCH 2-24-65	700405	A B

TYPICAL AM-350 BELLOWS OIL SEAL



ITEM	PART NAME	MATERIAL	QUANTITY PER UNIT	DETAIL DRAWING NUMBER
14	SEAL RING GUARD	17-4 PH	1	700389-14
13	SEAL RING ADAPTER	"	1	" -13
12	FINGER SPRING	INCONEL X	6	" -12
11	DAMPER	17-4 PH.	1	" -11 A
10	SHOULDER (CR. 12)	AMS 6322	1	" -10
9	SNAP RING	410 OR 416 S.S.	1	" -9
8	HEAT SHIELD	AMS-5504	1	" -8
7	FLAT HD. MACH. SCREW	300 SERIES S.S.	6	" -7 BN
6	BELLOWS (.006)	AM-350	1	" -6 A
5	SEAL RING	U.S.G. 2777	1	" -5 A
4	SEAL RING ADAPTER	17-4 PH	1	" -4 A
3	SEAL RING RETAINER	"	1	" -3 A
2	BELLOWS ADAPTER	"	1	" -2
1	HOUSING	"	1	" -1 A

REV.	DESCRIPTION	CHK'D	DATE
B	700389-11A, -6A, -5A, -4A, -3A, -1A WERE -11, -6, -5, -4, -3, -1	BLAIR	2-23-65
A	REVISED TO DETAIL	BLAIR	1-2-65

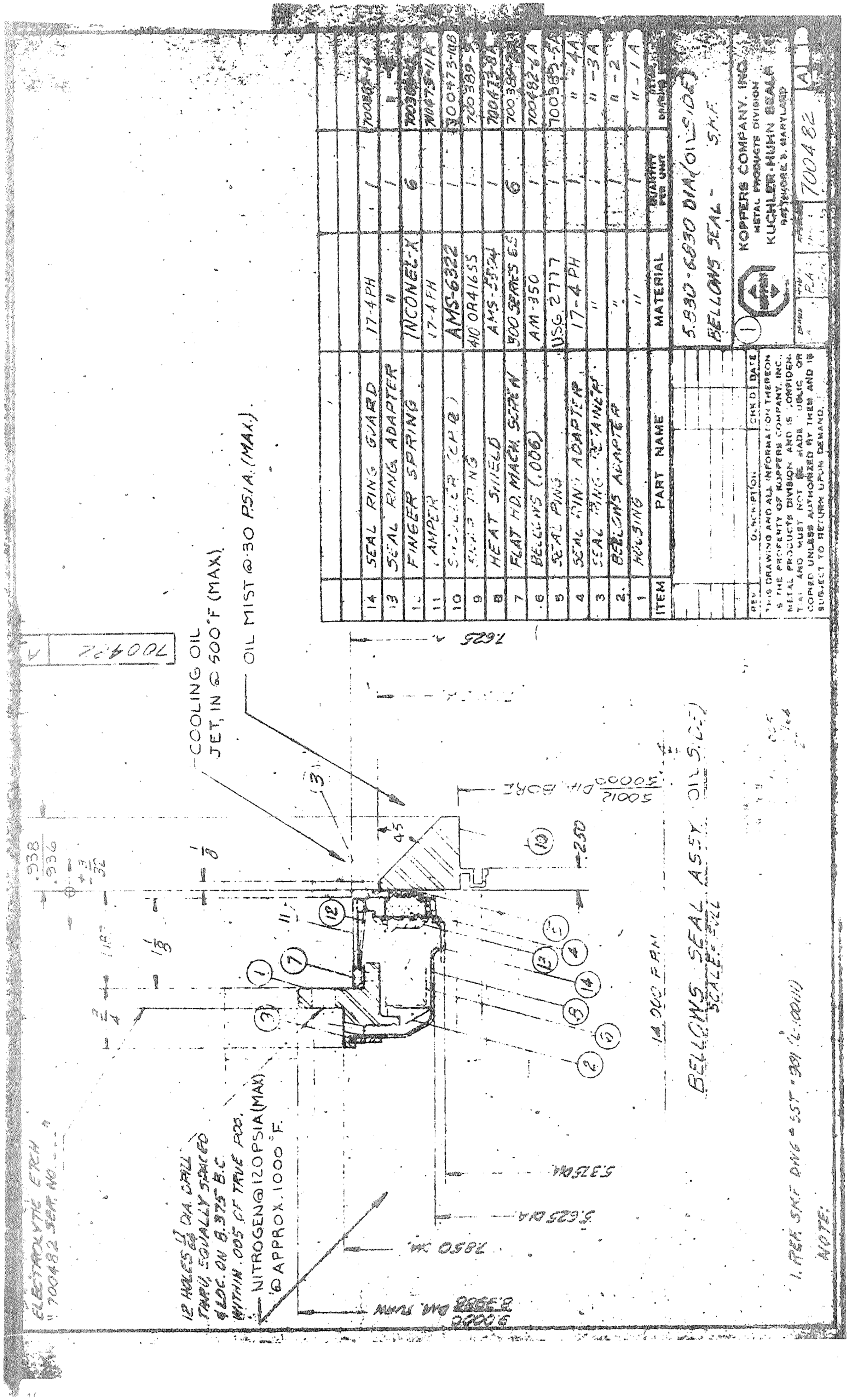
DRAWN	CHECKED	APPROVED
BLAIR 12-19-64	R. C. [illegible]	[illegible]

1 REF SKF DWG # 55T #901 (Z-100111)

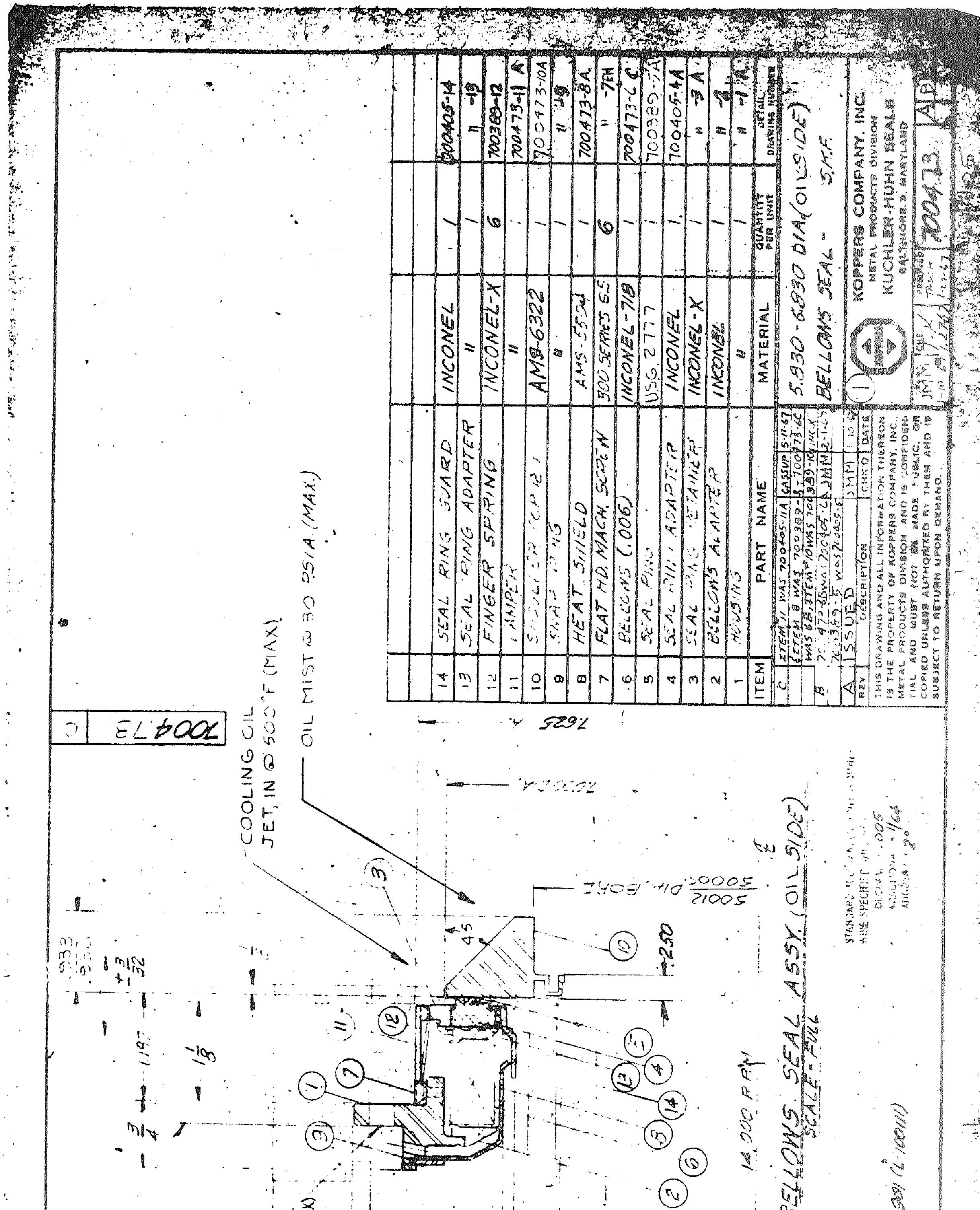
NOTE:

ENCLOSURE 4

IMPROVED AM 350 BELLOWS OIL SEAL



INCO 718 BELLOWS OIL SEAL



F4186A - R60 - 14,16 X 18.33

F4186A - R60 - 14.16 X 18.33

I-48

ENCLOSURE 6

TEST SEALS MEASUREMENTS

	Ser. No.	ORIGINAL Free Length	Spring Rate	Load at Opr. Length	Balance Dia.	Net Face Load #/In.	NOVEMBER 1966 Free Length	Spring Rate	Load at Opt. Length	Balance Dia.	Net Face Load #/In.	FEB. MARCH, APRIL 1967 Free Length	Spring Rate	Load Op.L.	Balance Dia.	Net Face Load #/In.
						(at 105 psi)										(at 90 psi)
Bellows Oil Side 700389 (AM-350)	1	1.442	65.3	16.7	6.452	.490	1.496	76/69**	23.0	Not Ck.	.48	1.355	60.0	10.1	6.374	1.33
	2	1.455	63.7	17.0	6.414	.540										
	4	1.438	66.9	16.8	6.415	.510						1.405	65.0	13.1	6.373	.91
	8	1.506	61.0	19.5	6.416	.430	1.448	62*	16.2	Not Ck.	.63***	1.440	60.0	15.3	6.382	.805
	9	1.489	67.1	20.0	6.416	.471						1.415	60.5	13.8	6.378	1.25
	10	1.457	61.5	16.6	6.416	.400										
Air Side 700397 (AM-350)						(at 5 psi)										
	3	1.358	67.0	11.5	6.287	.503										
	5	1.327	61.7	8.6	6.287	.372										
	6	1.319	59.7	7.9	6.287	.353										
	7	1.348	62.0	10.0	6.287	.469										
Air Side 700405 (Inco 718)	1	1.327	55.0	7.7	6.287	.388										
Oil Side 700473 (700405 Conv. to Oil Seal) (Inco 718)	2	1.372	54.1	10.1	6.287 (In-flow)	.467						1.335	67.5	10.1	6.350 (outflow)	.86

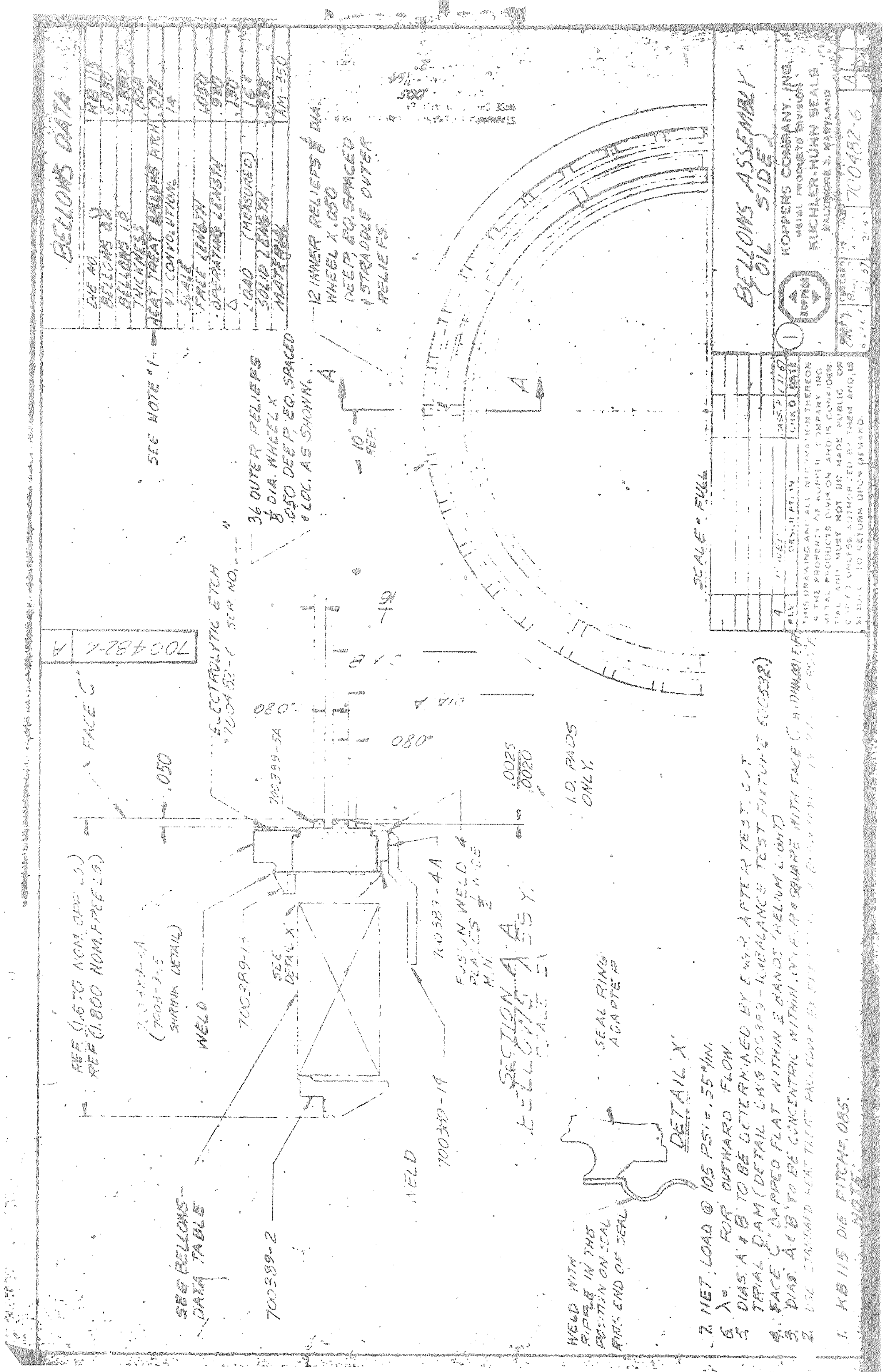
* Doubled O. D. Vents

** Cleaned

*** Almost Worn Out

ENCLOSURE 7

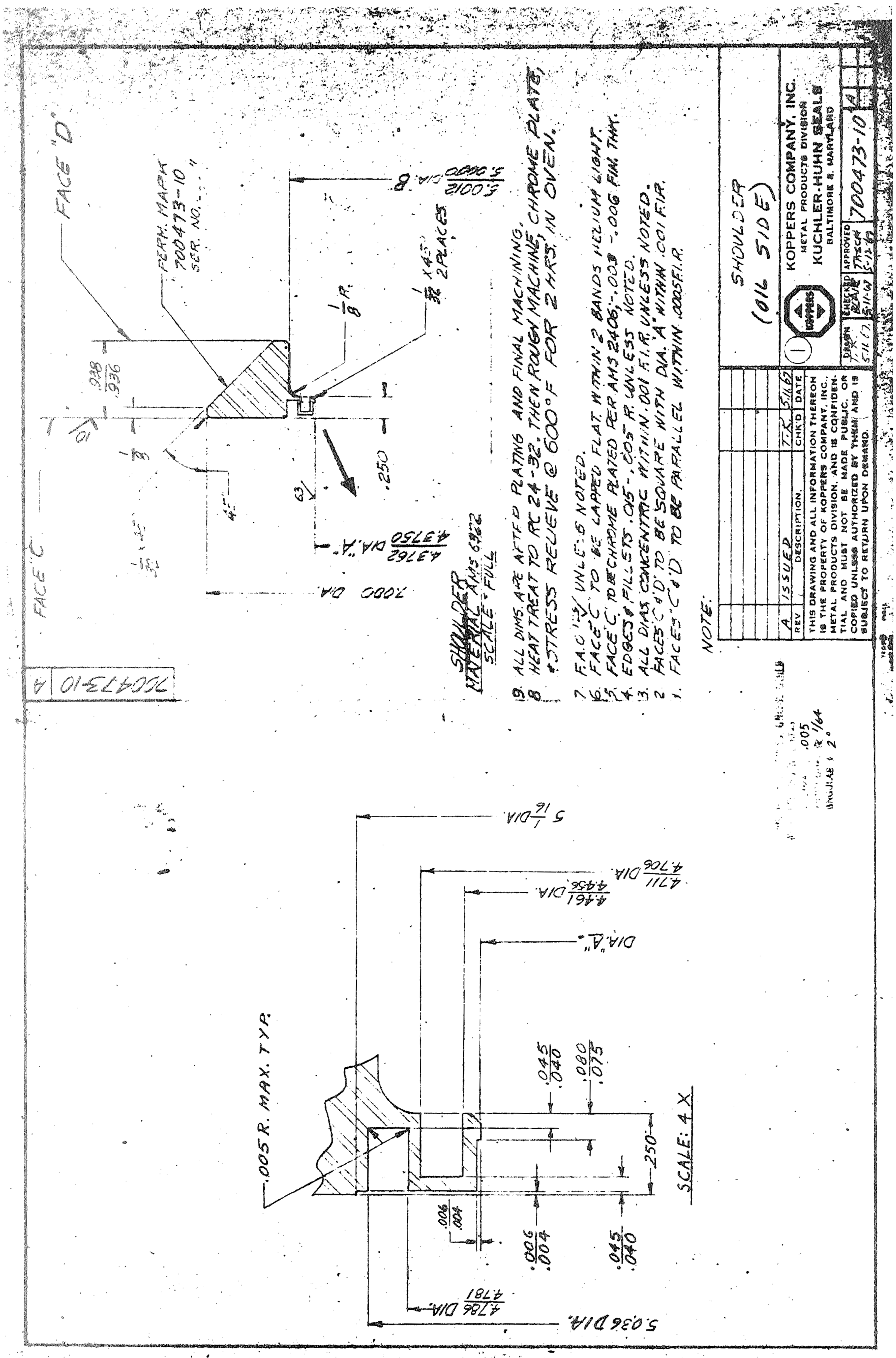
TAPERED CARBON FACE



F4186A - R60 - 14.16 X 10.33

ENCLOSURE 8

IMPROVED SEAL SHOULDER DESIGN



ATTACHMENT III

KOPPERS REPORT - EVALUATION OF HYDRODYNAMIC SEAL AFTER 100 HOURS TESTING

Metal Products Division, Koppers Company, Inc.
P. O. Box 626, Baltimore, Md. 21203
Telephone 301-727-2500

KOPPERS

August 20, 1968

SKF Industries, Inc.
Engineering & Research Center
1100 First Ave.
King of Prussia, Pa. 19406

Attention: Mr. Wm. Rhoads

Subject: Hydrodynamic Seal After 100 hrs. Test at SKF
Koppers P/N 101056
Returned for Evaluation

Gentlemen:

The "as returned" seal was examined externally and internally before reconditioning was done on this seal.

Externally, it was observed on the N_2 side of the seal that varnish or coke line existed on the area of the housing suggesting that at some time in its operation, the seal was flooded with oil and gradually "dried out" leaving the observed varnish. A fairly heavy layer of varnish and coke had developed in the windback threads. Coke was evident, approximately .005-.010 thick, on the O.D. surface of the O.D. seal face pads. No coke was evident in the face seal grooves or on the sealing pads. The seal shoulder had a thin layer of coke deposited between the track of the O.D. of the sealing dam and the I.D. of the outer pads.

It is our opinion that externally the seal appeared to be in fine condition except for small varnish deposits. The surface of the carbon had only minor score marks on the I.D. hydrodynamic pad. The seal shoulder had no more than a tiny percentage of deposits in the hydrodynamic pockets.

In detail, after disassembly, each major item of the seal is considered.

Seal Housing (Enclosure 1)

The lower 1/3 of the internal seal housing was coated rather heavily with coke and varnish. The seat face where the piston ring seats was in excellent condition except in the region believed to have been flooded by oil, which was unevenly covered with a thin tough layer of varnish.

The rotation lock bosses were heavily coated with varnish; the lower one had some coke extending into the carbon insert bore.

The spring guides were coated with coke, heaviest in the lower 1/3 where flooded with oil. The spring guides were examined for possible leakage of gas past the riveted area; none was found. The flange showed heavy marking under the flange bolt heads - the flange did not appear to be distorted however.

Springs (Enclosure 2)

Several springs were heavily covered with coke, the remainder had varnish only. Eleven of the 18 springs checked in free length with original specified in the drawing. The remaining 7 springs had varying set between 2% and 8% max.

Piston Ring (Enclosure 3)

The sealing side face of the piston ring was in excellent condition with no wear evident. The locality of the side face which was exposed to the flooded "oil level" had some minor residue. The O.D. of the piston ring showed 100% bearing contact with the seal ring bore. About 10 varying spaced areas showed "wire cutting" lines on the seal dam; this required 10X magnification to clearly define the condition. The side face on the upstream side of the piston ring had a heavy layer of varnish in the area presumed to have been flooded with oil.

Face Seal Ring (Enclosure 4)

Considerable varnish and coke was found on the areas flooded with oil. The bore of the ring in which the piston ring bears was in excellent condition except for the local varnish deposits. The burnish of the bore clearly indicated excellent piston contact with the seal ring bore.

On the face, the I.D. pads presented a glazed surface with minor line scoring. The center dam was dull with no evidence of rubbing contact with the shoulder. O.D. pads were highly burnished. Data taken for the seal face profile are tabulated on an attached sheet; the seal face had the radial profile shown by the measurements while the circumferential profile was a plane except for one spot approximately 1 1/2" long which was very slightly below the plane.

Rotation Lock Pins & Rotation Lock Bushings

These were found to be in excellent condition except for the varnish and coke residue. The rotation locks were tight indicating the torque developed did not overstress the fasteners.

Shoulder (Enclosure 5)

The surface condition of the carbide overlay is regarded as excellent. It was noted the residue accumulation in hydrodynamic pockets was no more than a few percent of the total pocket area. It was noted that burnish spots existed at each of the pressure balance bleed (caused by localized thermal deflection). The "rubbing" area between center dam and O.D. pads had a very thin deposit assumed to be a coke type residue. It was noted that the sump of the shoulder was coated with a tough, tightly adherent varnish layer (which could change heat transfer and thermal deflection greatly).

To summarize, it appears that the formation of varnish and coke residues in local areas (probably due to flooding at some time) would have certainly affected the leakage performance of the seal. It is likely that the varnish films caused local separation of the piston ring from its seat face and from the bore of the seal ring. These residues also would impede the axial freedom of movement of the seal ring.

The windback appears to be moderately effective in controlling oil reaching the interior of the seal, but it is also quite clear that the rate of deposit in the seal would severely limit the useful operational life. With respect to the "flooded" residue line, this may be a test rig condition which possibly occurred with the Nitrogen failure emergency shutdown.

The profile of the carbons (Enclosure 6) suggests that the primary thermal rotation of the seal parts sections takes place in the seal ring and only a small percentage in the shoulder. The high elastic modulus of the CDJ-83 carbon is a major factor in the thermal rotation of the seal ring.

It is not clear to us why some of the Inconel X springs took a higher set than others. In terms of face load change, the set observed in the 7 springs is estimated to represent only 5-6% of the normal design spring load.

Reconditioning of the seal consisted of:

1. Removal of the varnish and coke from all parts.

2. Touch lap side face of piston ring to remove residual varnish.

3. Relap face seal ring.

4. Burnish shoulder to remove residues (no material removal).

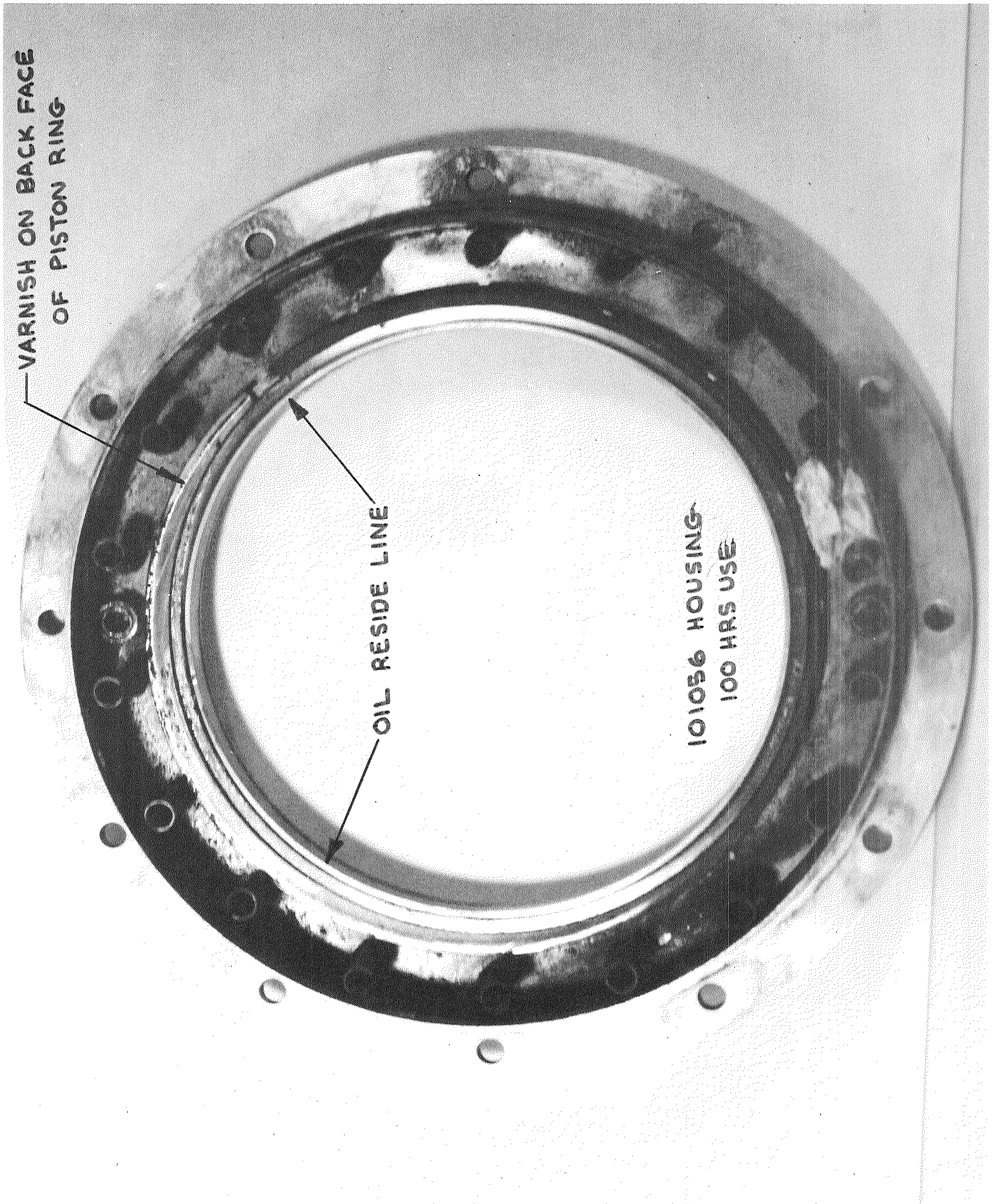
5. Replace all Inconel X springs (only parts replaced).

6. Assemble.

The only area where design change is considered involves the relative position of spring guides and rivets in the face seal ring. The springs slipped neatly over the O.D. of the rivet heads and in no way affected operation of the seal. However, a circumferential displacement of three spring guides is contemplated to assure that no problem can develop with use in this area.

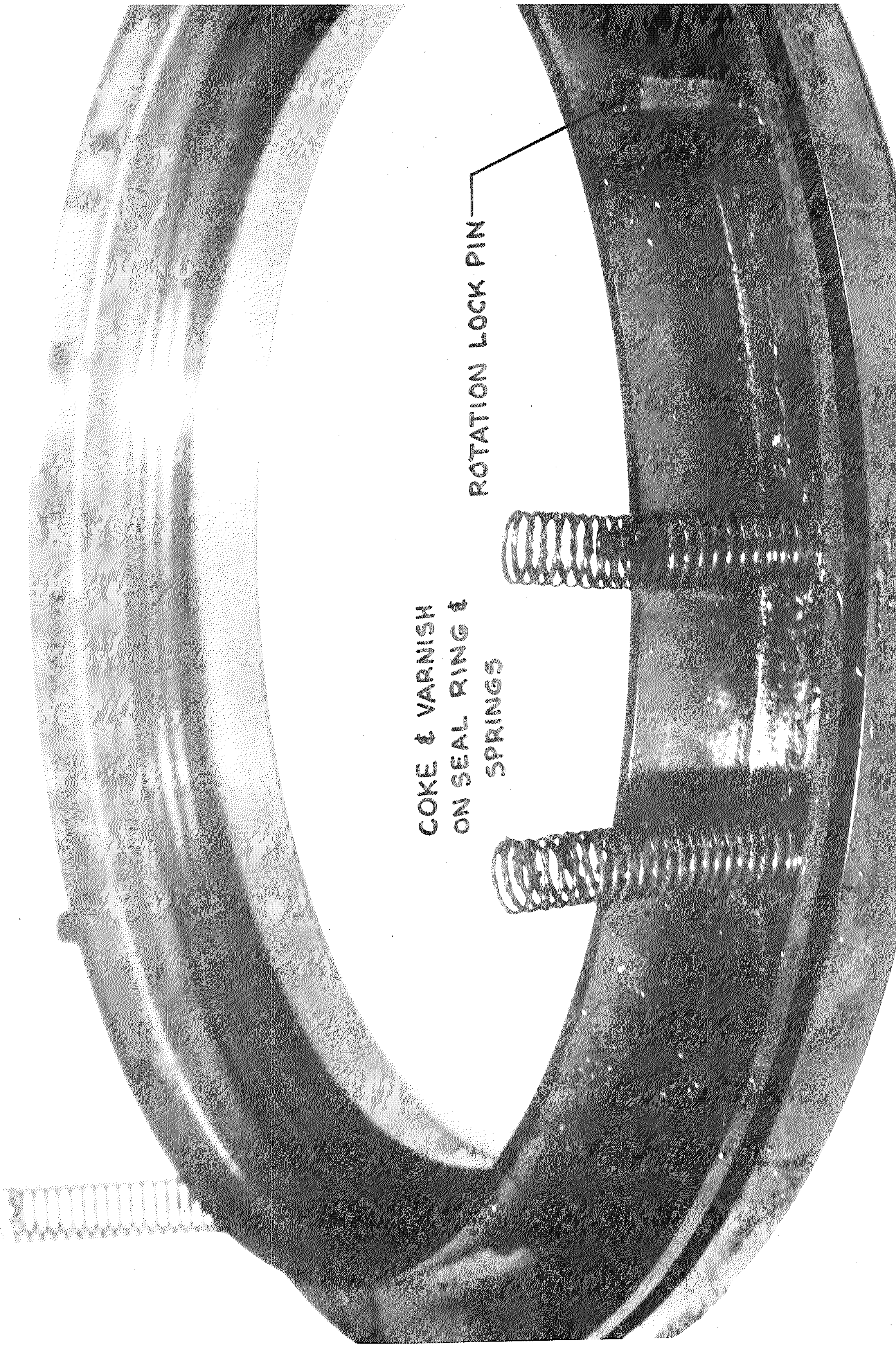
ENCLOSURE 1

INTERNAL SEAL HOUSING



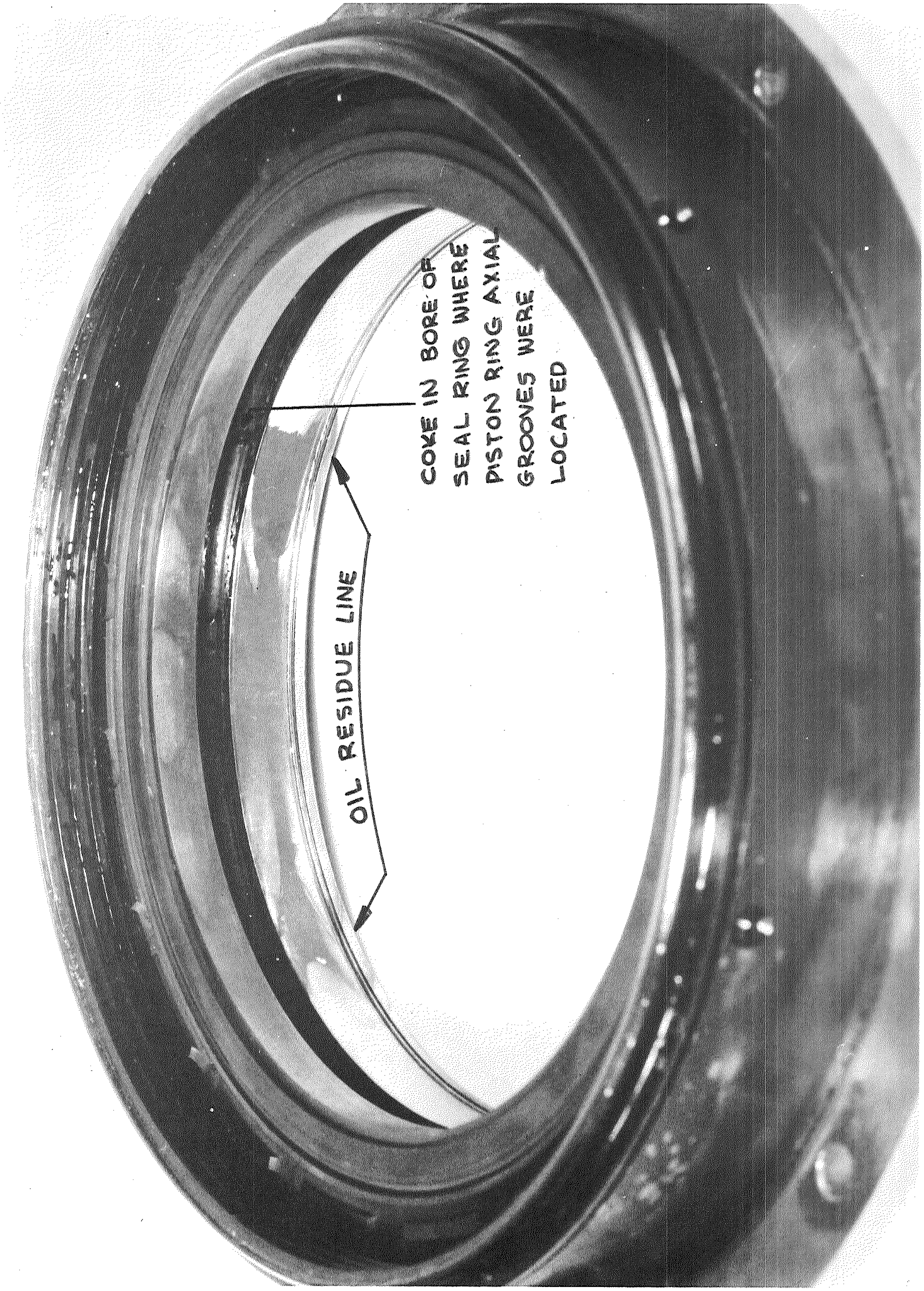
ENCLOSURE 2

SEAL RING AND SPRINGS



ENCLOSURE 3

PISTON RING SECONDARY SEAL SHOWING COKE IN BORE OF SEALING RING



ENCLOSURE 4

CARBON FACE SEAL RING

ENCLOSURE 5

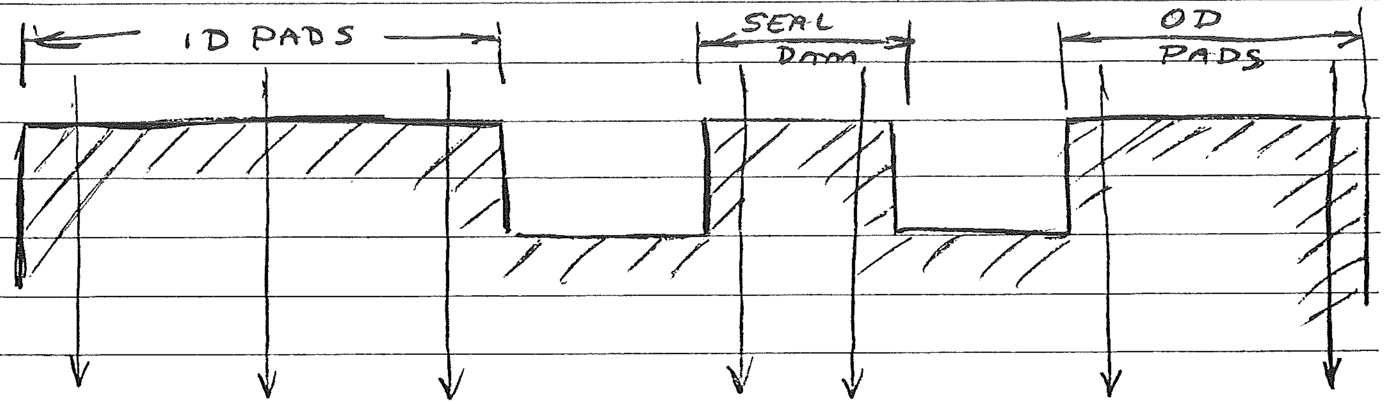
HYDRODYNAMIC LIFT DESIGN SHOULDER

ENCLOSURE 6

SEAL FACE RADIAL PROFILE

KOPPERS

101056 - SEAL FACE RADIAL PROFILE AFTER 100HRS@SKF



RADIAL POSITION

1	.00000	.00000	-.00005	-.00030	-.00025	-.00050	-.00008
2	.00000	.00000	-.00013	-.00035	-.00035	-.00063	-.00083
3	.00000	+.00008	.00000	-.00021	-.00021	-.00046	-.00040
4	.00000	.00000	-.00001	-.00026	-.00030	-.00058	-.00096
5	.00000	-.00002	-.00017	-.00033	-.00036	-.00077	-.00100
6	.00000	-.00002	-.00012	-.00032	-.00034	-.00063	-.00088

ATTACHMENT IV

KOPPERS REPORT - EVALUATION OF FACE SEALS USED IN SKF LUBRICATION INVESTIGATION - PHASE II

KOPPERS COMPANY, INC.
METAL PRODUCTS DIVISION
PISTON RING & SEAL DEPARTMENT
BALTIMORE, MD.

EVALUATION OF FACE SEALS USED IN

SKF LUBRICATION SYSTEM INVESTIGATION -- PHASE II

Prepared By: T. C. Kuchler

T. C. Kuchler, Tech.Consl't.

Meyer L. Ruthenberg

Meyer L. Ruthenberg
Seal Engineer

E. J. Taschenberg

E. J. Taschenberg
Senior Design Engineer

Date: March 27, 1970

INTRODUCTION:

After failure of the oil side bellows seal to operate satisfactorily for any extended length of time, it was decided by mutual agreement (SKF, NASA and Koppers) to replace these bellows seals with a face seal using a piston ring secondary seal. In this design the piston ring bore (balance diameter) is not affected by the operating pressures.

Since the inception of this program, dating back to 1965, Koppers did and is still doing development work in the area of hydrodynamic lift seals. The experience gained up to the end of 1967 was incorporated in the designs of the seals mentioned above.

The following remarks represent a summarization and discussion of the seal performance, general appearance, and surface conditions of the "wear" areas.

HISTORY:

The following summarized history is based on information transmitted to Koppers by SKF Industries and, to the best of our knowledge, is correct.

A. Piston Ring Seal (101056, S/N 1 Seal and Shoulder)
   Bellows Seal (700397, S/N 6 Seal and S/N 1 Shoulder)

The above seals were incorporated in five tests:

1. 50 Hr. Test with air buffer at 14,000 RPM
2. 50 Hr. Test with N_2 buffer at 14,000 RPM

   Note: Above bellows seal assembly not used in these two tests.

3. 250 Hr. Endurance Test with N_2 buffer at 14,000 RPM
4. 250 Hr. Endurance Test with N_2 buffer at 14,000 RPM
5. High Speed Test at 14,000 RPM and above, air buffer

During both 50 Hr. tests the above piston ring seal was used. The bellows seal assembly used in these two tests was 700397, S/N 2 seal and a 700405 shoulder. This particular seal assembly and shoulder were not sent to Koppers for inspection. After completion of these two 50 Hr. tests the piston ring seal and shoulder were shipped back to Koppers for inspection. At that time the seal ring face was relapped and the shoulder was burnished to remove residues. In our opinion, externally, the seals appeared to be in fine condition.[1]

[1] Report "Hydrodynamic Seal After 100 Hrs. Test", Aug. 20, 1968 by E. J. Taschenberg submitted to SKF Industries.

At this point the first 250 Hr. test had been started. The previous bellows seal and shoulder were replaced with 700397, S/N 6 seal and the S/N 1 shoulder because of extreme leakage (21-22 SCFM). The piston ring seal S/N 1 and shoulder S/N 1 had not been received by SKF, therefore the 101056, S/N 2 seal and shoulder were used. After 13 hours into the test the S/N 1 piston ring seal and shoulder were received by SKF and replaced the S/N 2 piston ring seal and shoulder. The S/N 2 seal having been fitted with the wrong carbon was sent back to Koppers and refitted with a new carbon. From this point on, the piston ring seal and shoulder 101056, S/N 1 and the bellows seal 700397, S/N 6 and shoulder S/N 1 were used throughout all the testing. Between the two 250 Hr. endurance tests the seals had been inspected. In doing so the piston ring had been broken. The piston ring seal was shipped to Koppers for repair. The seal was shipped back to SKF with no reconditioning other than replacing the piston ring.

The operating pressures during the tests were as follows:

a) Downstream side of bellows seal (air side) 106 psig.

b) Buffer gas between seals 111 psig.

c) Downstream side of piston ring seal (bearing cavity, oil side) 6 psig.

Note: Bearing cavity was not at atmospheric pressure due to thrust loading requirements.

In the 50 Hr. air test at 14,000 RPM the rig was stopped and started in approximately 10 Hr. intervals. In the beginning of the test, leakages were in the range of 10.2 to 9.3 SCFM (the 1st 20 hours).[2] In the following intervals, leakages all fell within the range of 4.2 to 6.6 SCFM. The wear encountered on the 101056, S/N 1 seal face during the first 50 Hrs. of testing with air buffer was approximately .0025". The next 50 Hr. test was run with a N_2 buffer at 14,000 RPM. During this test leakages were approximately the same as in the air buffer test. Upon inspection there was no further wear of the seal face.

(Note: Operating temperatures for the above two tests were in the same general range as in the endurance tests, except that bearing cavity temperature was approximately 450°F. in the air test.)

At the outset of the first endurance test, the leakages were high, being in the range of 8.5 to 12.7 SCFM. Leakage settled down after the first 20 hours and throughout the test ranged from 3 to 17.7 SCFM, although average leakage was approximately in the 5-7 SCFM range. The seals were inspected after the first 250 hours and the 101056, S/N 1 seal face encountered .002" wear.

[2] All leakage rates are a combination of piston ring seal and bellows seal leakage.

During the endurance test the operating temperatures were as follows:

a) Downstream side of bellows seal (air side) 1150°F. average temperature. This reading was monitored from a thermocouple immersed in the air flow near the shoulder.

b) Buffer gas between seals - temperature was not monitored.

c) Downstream side of piston ring seal (bearing cavity, oil side) 630°F. average temperature. This reading was also monitored from a thermocouple immersed in the environmental cavity.

During the endurance test, bearing race temperatures were monitored from a thermocouple buried in the outer race of the bearing. The average temperature during the first endurance test was between 640°F-670°F. Also, oil inlet temperature of the cooling oil jet for the hydrodynamic shoulder was recorded to be in the range of 500°F-515°F. at a flow of 1.5-2 gpm.

The second endurance test leakage results, operating pressures and temperatures were in the same range as the first. After external examination of the seals it was found that the 101056, S/N 1 seal face encountered an additional .003" wear. The seals were judged acceptable for the high speed test.

In the high speed test the seals ran approximately 3.1 hours at 14,000 RPM. In going to 16,000 RPM it was observed that the bearing cavity pressure had gone from 6 to 20 psig while total leakage went from 15 to 38 SCFM. At this point the rig was shut down. During this time the cooling oil inlet temperature was approximately 380°F to 410°F. and the flow went from 2 to 1 gpm. Results upon inspection are covered in another section of this report. The approximate time accumulated on each seal is as follows:

a) Piston ring seal and shoulder 101056, S/N 1 - 573.1 hours

b) Bellows seal 700397, S/N 6 and shoulder 700397, S/N 1 - 483.1 hours

B. Piston Ring Seal (101056, S/N 2 seal and shoulder)
Bellows Seal (700397, S/N 3 seal and 700405, S/N 1 shoulder)

These seals ran in one high speed test ranging in speed from 16,000 to 20,000 RPM. Upon start-up of the test, high leakage occurred. At this time the bellows air shoulder was changed from 700397, S/N 1 to 700405, S/N 1. This did not solve the leakage problem and the bellows seal 700397 was switched from S/N 6 to S/N 3. It was observed that the S/N 6 bellows had relaxed. This final set of seals, the piston ring seal and shoulder 101056, S/N 2 and the bellows seal 700397, S/N 3 and shoulder 700405, S/N 1 ran throughout this set of testing.

The operating pressures in this test were the same as in the previous set of testing. In the beginning of the test the leakage rate at 14,000 RPM was in the range of 11.9-13.2 SCFM. At 16,000 RPM the leakage range was

13.2 to 6.8 SCFM. In going to 18,000 RPM a problem arose in the rig's belt drive at which time the rig was shut down. Before shutting down a leakage measurement of 8.9 SCFM was recorded. Building back up to 18,000 RPM, the leakage rate dropped to a range of 7.6 to 5.9 SCFM. At 20,000 RPM the only recorded leakage measurement was 8.1 SCFM. The time at speeds was as follows:

a) 16,000 RPM - 2.0 hours
b) 18,000 RPM - 2.5 hours
c) 20,000 RPM - 0.7 hours

The total running time of the seals was approximately 8 hours. The balance of the running time was at intermittent intervals due to various alignment problems with the belt drive.

Operating temperatures during this test were:

a) Downstream side of bellows seal (air side) average temperature was 975°F-980°F. Measured in same manner as before.

b) Buffer gas between seals. Temperature was not monitored.

c) Downstream side of piston ring seal (bearing cavity, oil side)

14,000 RPM -	445 Avg. temp. (°F)
16,000 RPM -	485 Avg. temp. (°F)
18,000 RPM -	545 Avg. temp. (°F)
20,000 RPM -	560-630 Avg. temp. (°F)

Oil inlet temperature of the cooling oil jet was as follows:

18,000 RPM	Avg. Temp. 350°F -	.75 gpm
18,000 RPM	Avg. Temp. 450°F -	2 gpm
20,000 RPM	The oil flow was never above 1.5 gpm. No temperature readings were recorded. At shut down the oil flow was 1 gpm.	

After shut down the bearing cavity temperature was observed to be rising rapidly. Inspection revealed a fire in the bearing cavity. Upon inspection the clamping ring for the bellows shoulder was found to have taken a permanent set which increased the clamping ring by 1/16" on diameter when measured cold. (Note: This was not discovered until after the fire).

Upon completion of all testing the four assemblies were sent back to Koppers Company for inspection. Observations and comments are covered in the following sections of this report.

VISUAL EXAMINATION AND COMMENTS:

Oil Seals - Drawing 101056 Seal, S/N 1

The seal operated at test conditions in excess of 500 hours. The condition of the seal is reported by SKF prior to reuse of the seal at higher speeds. The condition of the seal as observed following termination of a high speed test is described here.

The seal face indicated wear damage had occurred; the edges of the pads and seal dam show rounding, which is to be expected in terms of the condition of the wear surface of the shoulder.

Internal examination of this seal is considered most significant since it had not been opened following completion of the endurance testing. The outer diameters and outer surfaces of the seal ring had thin layers of varnish. The internal surfaces of the seal housing also were covered with varnish excluding the area immediately adjacent to the piston ring. Springs were coated with thin varnish and a deeper accumulation was found on the outer surface of the rotation lock bosses in the housing.

The area in the bore of the face seal ring where the piston ring seats was virtually free of varnish deposits. The piston ring itself was also free of deposits.

It is rather clear that while the windback (and its housing) does not completely prevent oil from reaching the internal seal surfaces, it masks sufficiently to keep the area of the secondary seal (piston ring) virtually free of oil deposits.

The piston ring had seated on the bore of the seal ring (seating wear evident). The surfaces were in excellent condition. Very slight erosion marks were noted on the piston ring sealing dam. The adjacent bore of the seal ring showed one mark next to the piston ring where possible contact between this bore and the housing took place (the length about 20° arc). This damage was superficial and would have had negligible effect on sealing in that area.

The rotation lock pins and the bosses were in excellent condition although a thin layer of varnish was found on these pieces. Wear was not evident and it is highly unlikely that the rotation locks in any way disturbed the free operation of the seal.

Shoulder S/N 1 (101056)

This part was badly worn during the attempt to operate at the higher speeds before termination of its use. The hydrodynamic pockets were worn away and a wear track was developed on the surface which ranged in depth approximately .001" to more than .008" at a 180° to the minimum depth.

This shoulder had a gross "saddle" shape on the face away from the sealing face. One of the high points on this face was coincident with the area where the .001" depth was observed on the sealing face. It appears that clamping distortion was present during the operation of this seal.

<u>Bellows Seal</u> (700397, S/N 6)

The overall condition of this seal was good with the exception that the bellows had taken a permanent set, reflected in a short free length. The carbon face was in good condition and did not show distress due to many hours of use. Obviously, the seal operated at a reduced face load compared to the new seal; however, the net load remained sufficient to seal satisfactorily based on reported leakage rates during the endurance testing.

<u>Shoulder</u> (S/N 1) - 700397

The wear track was highly glazed with light scoring present. In one small area (possibly 3/64 dia.), a spall or pull out of the coating had taken place in the wear track. It is not obvious from its appearance what caused this material removal.

<u>Oil Seal</u> - 101056 (S/N 2)

This seal was exposed to a fire in the sump following shutdown of the high speed test. The condition of the seal reflects the residues, etc. which developed following the fire.

The outer surfaces of the seal ring were heavily coated with coke-varnish and the interior surfaces of the seal housing reflected the same condition. Again, however, the area of the piston ring on the housing and the bore of the seal ring showed only traces of varnish. The amount of coke and varnish in the seal housing was greatly in excess of that found in seal, S/N 1 discussed above.

The carbon face was visually in excellent condition and is discussed further in this report with respect to wear.

<u>Shoulder</u> - 101056 (S/N 2)

This shoulder also was found to have a gross "saddle" shape on the face opposite to the sealing face. It is interesting to note that one "low" point of the saddle showed such heavy bearing contact with the adjacent member that the letters "LSR" appear as "raised" metal. The wear track on the sealing face of the shoulder and a "burnish" pattern obtained on a lap plate indicate that this part was operating in a distorted configuration roughly oriented the same as the saddle shape on the opposite face. Two of the hydrodynamic pockets showed wear at the "high" point on the sealing face.

Some pitting was observed in the central areas of the hydrodynamic pockets. It is not clear at this time if this pitting developed due to high temperature operation alone or if the manufacturing process had some effect on adhesion in the central area of the pockets.

The area to the inside of the L feed slots in the shoulder sealing face shows evidence of rubbing; i.e., more contact than that occurring on adjacent surfaces. It is probable that this contact is due to local thermal deflection of the surface as a result of greater local heat transfer. It may be desirable in future designs to relieve this area to prevent film breakthrough.

Bellows Seals (air side) Dwg. 700397, S/N 3

This seal was found to be in generally good condition with no evidence of serious operating distress. It was noted that a metallic rub by some rotating part had marked the I.D. of the "shield" which is internal to the carbon face. This was considered minor although it may have caused some out-of-flatness in the carbon. Debris from this rub probably reached the sealing dam area causing cutting of the downstream edge of the radial grooves and left the I.D. pads a dull mat finish instead of a normal glazed surface. The free length of this bellows was in the range at which it was shipped.

Shoulder (700405) S/N 1

This shoulder operated with S/N 3 bellows and was generally good in appearance. The wear track was glazed with minor fine scoring. A mark near the I.D. of the sealing face indicated that the part which rubbed the I.D. of the seal also contacted the shoulder.

WEAR SURFACES AND COMMENTS:

The wearing surface profiles, carbon and shoulders were recorded by means of a Brush surfanalyzer, generally with a vertical setting reading .0001 per graduation. In one instance where the wear was high, an additional trace was taken with a vertical setting of .001 per graduation. Traces of the surface profiles from section-to-section of the seal parts and mating face seal rings to shoulders showed excellent relative continuity.

In comparing the radial wear markings with drawing dimensions good correlation was obtained, keeping in mind that the border delineation-wear (contact) and no wear (no contact) is not too accurately defined for low wear rates. Edge definition seems to be within about $\pm$ .005 radial, which is considered good for the very brittle materials involved.

1. Piston Ring Seal (Oil Side) Dwg. 101056, S/N 1

Carbon Grade:	Seal Ring - National CDJ 83 Piston Ring - U.S.G. 2777
Piston Ring:	Radial Force .109 lb/in. of circumference (structural)
Seal Ring Springing:	.545 lb/in. of circumference

The face design represents the typical Koppers' gas face - I.D. and O.D. pads, I.D. and O.D. collecting grooves and sealing dam. One exception had to be made. The I.D. pad operating against the shoulder lift pockets was not vented to the I.D. collecting groove.

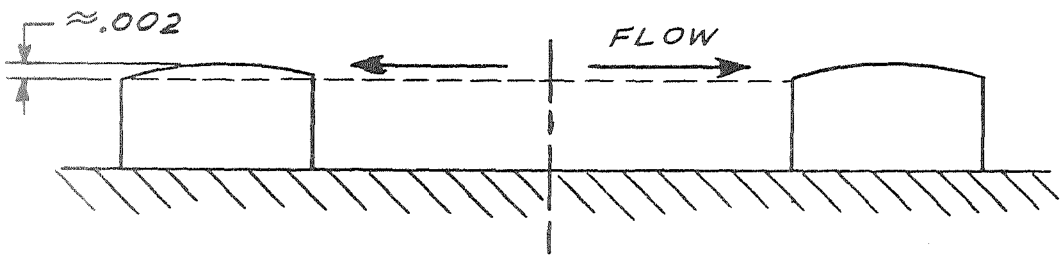
This design, in conjunction with the "pocketed" shoulder, separates the lifting from the sealing mechanism and also minimizes the effect of conicity on pressure balance in the initial stages of operation or for the life of the seal if wear progresses in parallel planes.

According to SKF (see History), the seal operated very satisfactorily for about 565 - 570 hours with an average total leakage of 5 - 7 SCFM and an approximate wear of .005 per 500 hours. Flow passages, collecting grooves and O.D. pad vents are designed to permit .030 wear. These results generally indicate practical separation; on the other hand, .001" wear per 100 hours indicates some transient short duration contact.

While increasing speed from 14,000 to 16,000 RPM, leakage was initially high and deteriorated forcing shut down. As a matter of interest, even at 20,000 RPM the seal springing was adequate if the shoulder motion (including runout at shaft frequency) is in the order of hundreds of microinches. Figure 1 summarizes the typical face appearance as well as the relative wear measurements.

The face contour strongly suggests edge breakdown at the entrance of the I.D. pad and also at the dam I.D. The data indicate "bowing" (low I.D; high middle; low O.D.). The matching shoulder (cold) is generally coned - low I.D, high O.D. Gross absolute wear measurements on the carbon indicate wear of .018".

The above geometry of the worn face of the carbon is:



It is certain that the high wear rate and resulting geometry took place when the speed was increased. However, we are at a loss to rationalize this phenomenon, unless:

a) The buffer fluid suddenly became saturated with fine particles.
b) Large axial vibrations were somehow induced.
c) Clamping distortion may have initiated high wear by film breakthrough.
d) Oxidation of carbide shoulder produced abrasive particles.

2. Shoulder for Piston Ring Seal - Dwg. 101056, S/N 1

To minimize oil mist contamination of the rubbing faces, an integral cylindrical sleeve, to accommodate a windback, was added on the O.D. The radially flexible shaft mounting used with the old bellows seal shoulder was maintained. The principle addition, however, is a series of 24 "lift" pockets.

The actual lift pocket design is based on test work performed at Koppers. It has been our opinion that the pockets should be incorporated in the shoulder rather than the carbon face because of generally lower wear rates of the shoulder material.

The pocket design used is similar to the "best" experimental design available in 1967. The following data are of interest:

.8 lb/in. of Circ.	8000 RPM (237 ft/sec.)	.000355 Separation
.75 lb/in. of Circ.	8000 RPM (237 ft/sec.)	.0002 Separation
1.5 lb/in. of Circ.	8000 RPM (237 ft/sec.)	.000135 Separation

Pocket depth h = .00063
Entering chamfer desirable
Separation started between 500-1000 RPM.

In endurance testing the seal-shoulder combination performed reasonably well at 14,000 RPM in an ambient downstream temperature of 630°F. and pressure differential of 105 psi. Rapid deterioration developed in this seal for reasons not clearly defined when an attempt was made to reach 16,000 RPM. Figure 2 lists the recorded wear.

The shoulder appeared to be in good condition after about 565-570 hours of operation. We are at a loss to rationalize shoulder wear of .005-.008" occurring in about three hours. A sudden shift (loss of clamping force) in squareness might explain the large angular difference in wear (section "B" and "E"). The possibility of dirt as well as carbon dust due to carbon edge breakdown and/or oxidation of the tungsten carbide may have been contributing factors to wear.

3. Bellows Seal (Air Side) Dwg. 700397, S/N 6

Carbon Grade:	Pure 56 HT
Bellows:	AM-350 - 6.830 O.D.- 5.830 I.D.
As Shipped:	Scale 59 lb/in. Structural Load .3 - .5 lb/in. Seating Bias (Hydraulic) .122 lb/in.
After Test:	Scale 59 lb/in. Deflection .067" Structural Load 3.95 lb; .1983 lb/in. Seating Bias (Hydraulic) .122 lb/in.

Because the seal operates with a $\Delta P = 5$ psi, the hydraulic diameter can be defined as

$$D_H = \sqrt{\frac{(O.D.)^2 + (I.D.)^2}{2}} \qquad \text{(Root Mean Square)}$$

Figure 3 lists the relative wear measurements. Unfortunately, the actual wear cannot be accurately ascertained; however, in measuring the dam height wear of approximately .003" can be assumed. Visual inspection of the seal indicated very satisfactory appearance. If wear would continue without deterioration of the surfaces, .030" would be an acceptable number resulting in a seal life of 5,000 hours plus or minus.

This result confirms Koppers initial premises; i. e., with a bellows having constant spring scale with pressure, and a weldable material with superior physicals than AM 350 at 1100°F. (now available), practical minimum leakage bellows seals (less than 5 SCFM at 105 ΔP) could be available.

This seal operates in a very demanding environment:

Air temperature 1150°F.
Buffer Gas approximately 600°F.
(Buffer gas heated by rig. With the exception of buffer gas, internal minimum temperature of rig is 510°F. (cooling oil).
Seal shoulder only cooled by buffer gas.
Final seal load: .32 lb/in.
With better diaphragm material and hydrodynamic lift this load can safely be increased to .5 -.6 lb/in.

4. Shoulder for Bellows Seal - Dwg. 700397, S/N 1

Material:	AMS 6322 - Chrome Carbide Plated

The shoulder appearance was satisfactory and as tabulated in Figure 4; the relative wear is small, but the additional wear life is not easily predicted. The effect on surface roughness is the critical criterion.

In this respect it is worth mentioning that the roughest surface was recorded in the clamping area; strangely, this roughness extends radially outward by up to .100" beyond the initial O.D. of the clamping sleeve.

Also of interest is the fact that a permanent set occurred resulting in symmetrical conicity (see Figure 4). It is our opinion that this must be a creep phenomenon, however, the stress source does not seem too well defined.

Because this shoulder is poorly cooled, the thermal gradients must be small, hence, small thermal stresses. Besides, while hot the rubbing surface is subject to a compressive stress. If yielding would take place in hot compression, the stress would be reversed to tension while cooling. This should produce the opposite curvature than noted.

5. Piston Ring Seal (Oil Side) Dwg. 101056, S/N 2

Carbon Grade:	Seal Ring - National CDJ 83 Piston Ring - U.S.G. 2777
Piston Ring:	Radial Force .109 lb/in of Circ. (Structural)
Seal Ring Springing:	.545 lb/in of Circ.

Both visual inspection and tracings of the Brush surfanalyzer of the carbon face indicated an operable surface. The relative wear measurements are listed on Figure 5. These data indicate that further operation at 20,000 RPM would have been permissible. It is our belief that if the seal was in any distress during the 8 hours test duration - .7 hours at 20,000 RPM, the wearing surface should show it.

Parenthetically it is interesting to note that the seal springing of .545 lb/in. should accommodate a total axial travel of .0002" (vibration plus out-of- squareness) at 333 CPS. The recorded leakage of 8.1 SCFM at 20,000 RPM indicates that the seal follows the axial shaft motion.

The seal wearing face represents a practically symmetrical cone, low by roughly .00015" on the O.D.

6. Shoulder for Piston Ring Seal - Dwg. 101056, S/N 2

Material:	AMS-6322 Tungsten Carbide Flame Plate .002-.004 thick

All mating (wearing) surfaces show as good a finish as the "no contact" areas. It is again our opinion that the shoulder was not in any distress during the test. The traces indicate a slight slope, low on the O.D. for all eight sections investigated. A saddle of approximately .0004" also seems to be present. (See Figure 6).

7. Bellows Seal (Air Side) Dwg. 700397, S/N 3

Carbon Grade:	Pure 56 HT
Bellows:	AM-350 - 6.830 O.D., 5.830 I.D.
As Shipped:	Scale 59 lb/in. Structural Load .65-.75 lb/in. Seating Bias (Hydraulic) .122 lb/in.
After Test:	Scale 59 lb/in. Deflection .281" Structural Load 16.58 lb; .832 lb/in. Seating Bias (Hydraulic) .122 lb/in.

It is noted in "Visual Examination and Comments" that some member of the test rig contacted the shoulder. The traces confirmed this observation and showed that the I.D. carbon pads and about a 45° sector of the dam I.D. were sufficiently damaged to be worthless with respect to their sealing functions. Otherwise, relative wear is minimal. It is interesting to note that the O.D. pads are "crowned". No explanation for this phenomenon can be given. (See Figure 7).

It is our belief that this seal could have continued to operate for quite some time, satisfactorily. The fact that all sealing areas (carbon and shoulders) appeared to be in excellent condition was contradictory to our experience for a room temperature load of .954 lb/in. Based on years of experience with gas seals of similar face designs, and operating at much lower ambient temperatures and rubbing speeds (to 300 ft/sec), a maximum load of .4 to .5 lb/in was experimentally established. The inability to operate the original bellows "oil seal" for the full pressure range did confirm our experience. It is our opinion that the chrome carbide plate does not improve performance to such an extent. We are at a loss to explain this deviation from past performance.

8. Shoulder of Bellows Seal - Dwg. 700405, S/N 1

Material:	Inconel-X Chrome Carbide Plated

This shoulder remained essentially flat although it was contacted while rotating, by some metallic material. (See: Visual Examination and Comments). Figure 8 summarizes the wear data; wear increases towards shoulder O.D. (O.D. carbon pads). This matches the carbon face slope and wear data. The surface finish of the areas where wear occurred is roughly the same as for the noncontacting areas. Hence, it is our belief that the shoulder could have continued satisfactory operation for quite some time.

SUMMARY AND CONCLUSIONS:

1. Air Side

Incorporation of hydrodynamic lift pockets should make current bellows seals (different diaphragm material) practical. We define "practical" as over 5,000 hours of operation with an air ambient temperature of 1200°F. and a buffer gas (preferably N_2) temperature in the 550-700°F. range. A pressure differential of 4 to 7 psi and a rubbing speed of 550 ft/sec. are acceptable.

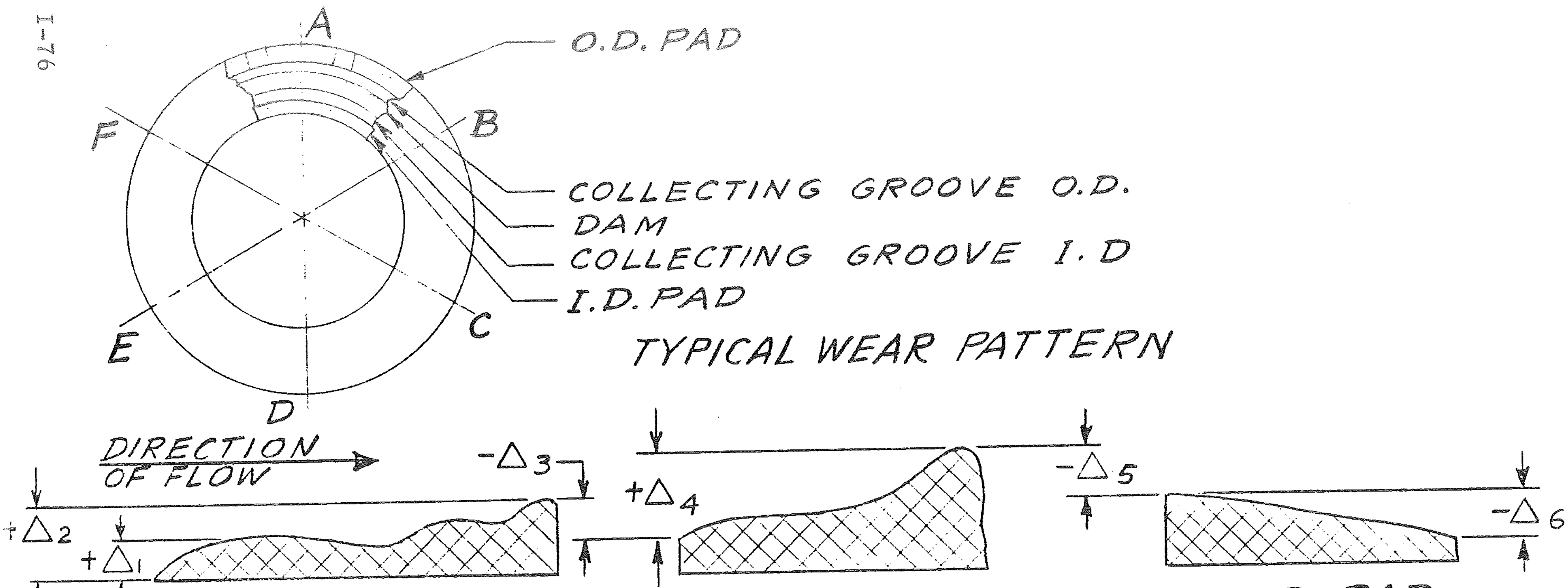
Bellows Seals are minimum leakage seals and therefore preferred.

2. Oil Side

The seal-shoulder combination which operated at 14,000 RPM should perform satisfactorily (5-10 SCFM) for several thousand hours with ambient thermal and pressure conditions as tested.

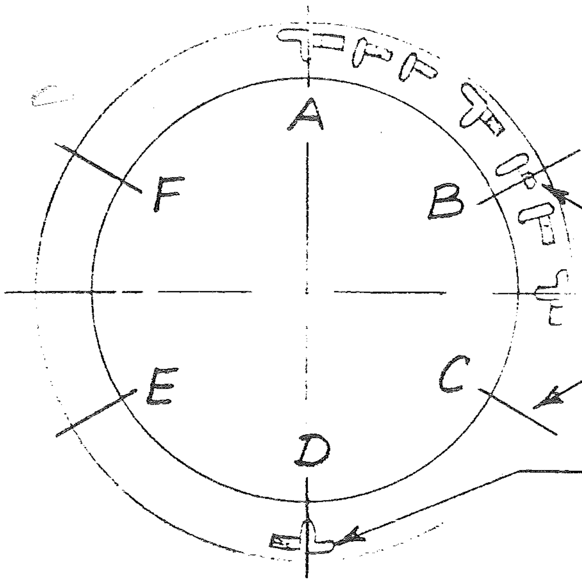
The present design will perform at test conditions (downstream ambient temperature 630°F; pressure differential 105 psi) at 20,000 RPM. Leakages should be in the 5-10 SCFM range. The life of the seal cannot be predicted but must be experimentally evaluated. Catastrophic failure while reaching speed is not likely.

Improvements may be possible in changing to shoulder materials of better thermal conductivity. It is also possible that the lift pocket design is not the optimum one. Further analysis and experimentation will resolve this problem.



	I.D. PAD		DAM		O.D. PAD	
	Δ_1	Δ_2	Δ_3	Δ_4	Δ_5	Δ_6
A	.00065	.00155	-.0007	.00175	-.0006	-.00075
B	.00095	.00185	-.0006	.00185	-.00045	-.00065
C	.00045	.00115	-.00075	.00185	-.0005	-.00065
D	.00075	.0015	-.0006	.00185	-.00045	-.00065
E	.00065	.00110	-.0010	.00195	-.00055	-.00055
F	.00065	.00115	-.00085	.00185	-.0004	-.00065

CARBON FACE 101056 SN1
FIG. 1



B HIGHEST WEAR
F LOWEST WEAR

B-C HIGH WEAR SECTOR
E-F LOW WEAR SECTOR

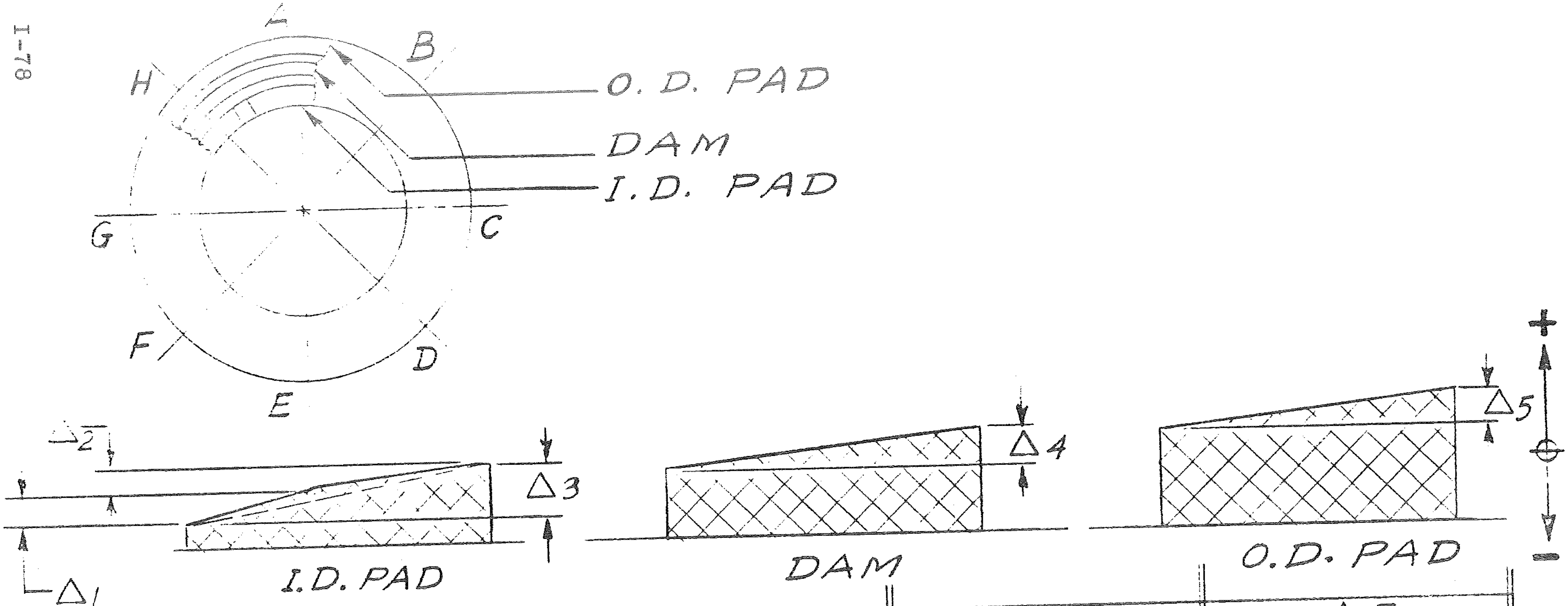
△ .0001 SCALE
○ .001 SCALE

* RADIAL WIDTH

		CARBON I.D. PAD	DAM	CARBON O.D. PAD	TOTAL CONE HIGH O.Y O.D.
A	△	.00155 – .0019	——	——	.000725
	○	.001 – .002	.00225 – .00425	.0045	.001
B	△	——	——	——	.00085
	○	.00525 – .0065	.00625 – .00825	.008 – .00825	.001
C	△	——	——	——	.0008
	○	.00375 – .005	.0045 – .00675	.00675 – .007	.001
D	△	.000575 – .000675	.001 –>.003	——	.00105
	○	.0005 – .00075	.001 – .003	.0025 – .003	.00125
E	△	.0002 – .00045 BOTTOM LIFT POCKET PARTIALLY RECORDED	.00015 – .0007 NOTE LARGE DIFFERENCE	.0009	.00035 O.D. SLOPE .0002/.105*
	○	——	——	——	——
F	△	.0002 – .0004 BOTTOM OF LIFT POCKET RECORDED	.00035 – .001 NOTE LARGE DIFFERENCE	.001025	.0006 O.D. SLOPE .0003/.105*
	○	——	——	——	——

SHOULDER FACE 101056 SN1

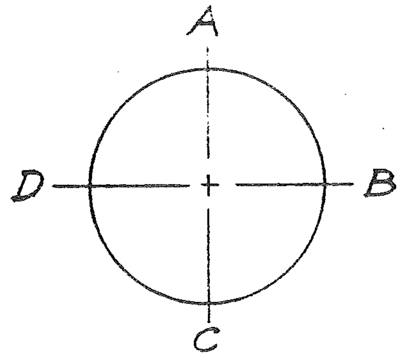
FIG. 2

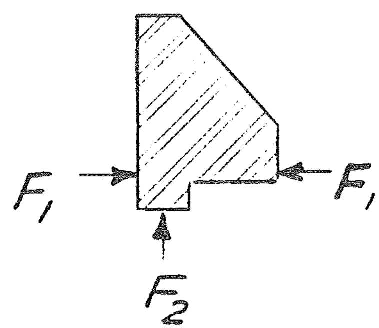


	Δ1	Δ2	Δ3	Δ4	Δ5
A	———	———	.0003	.00005	0
B	.00025	.0002	———	.00015	.0002
C	.000475	.0002	———	.00010	.0001
D	.000325	0	———	0	.000050
E	———	———	.000325	.000050	0
F	———	———	.00030	0	-.000050
G	———	———	.000225	-.000075	-.0001
H	———	———	.00025	0	-.000075

CARBON FACE 700397 SN 6

FIG. 3





F_2 WILL PRODUCE  MOMENT

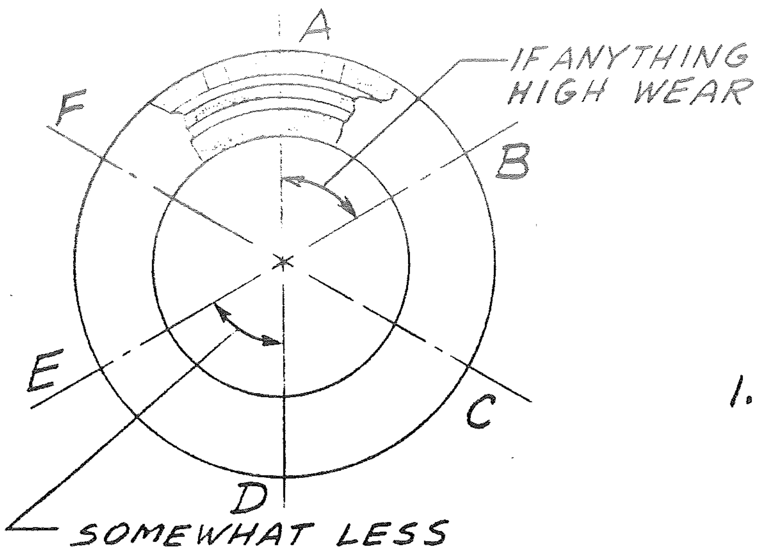
F_1 CAN PRODUCE EITHER MOMENT 

	SLOPE (NOT NECESSARILY CONSTANT) HIGH ON O.D.	RELATIVE WEAR		
		I.D. PAD	DAM	O.D. PAD
A	.0006/1.250 *	NEGLIGIBLE	.00009	.00005/.00015
B	.0005/1.250	NEGLIGIBLE	.000125	.00010/.00015
C	.00055/1.250	.00010/.00015	.00025	.00020/.00025
D	.0004/1.250	.00010/.00015	.00025	.00003

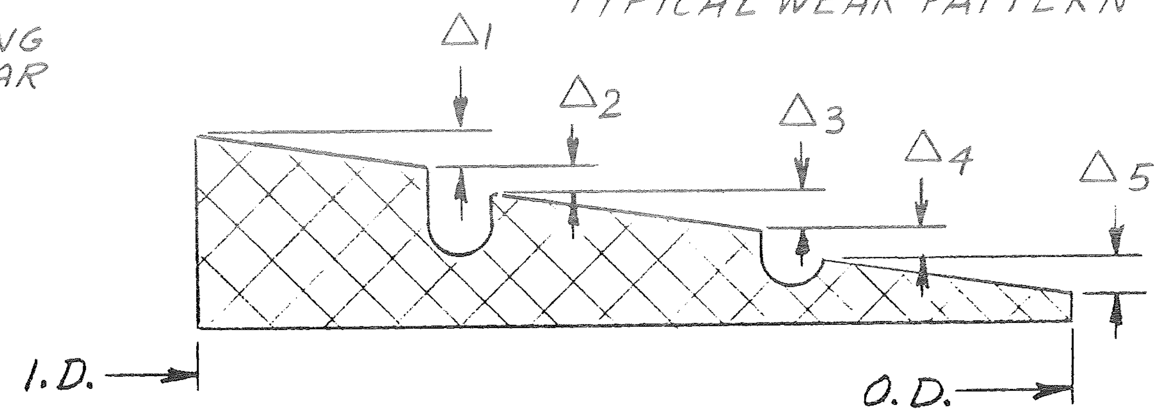
*RADIAL FACE WIDTH

SHOULDER FACE 700397 SNI

FIG. 4

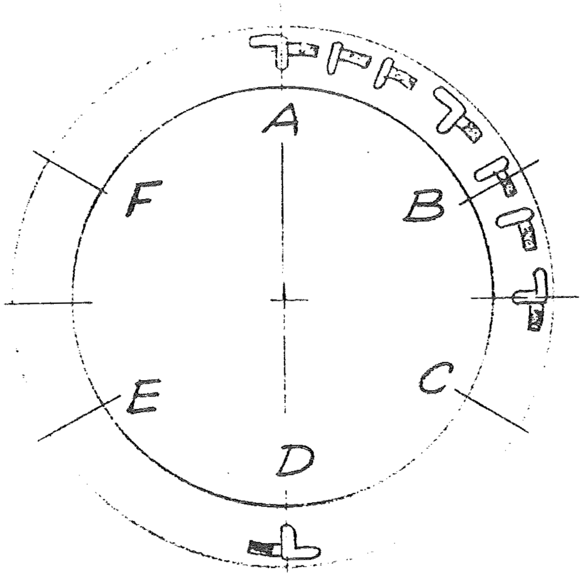


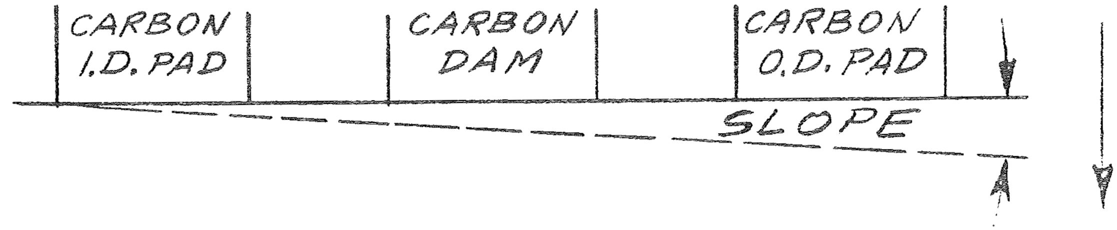
TYPICAL WEAR PATTERN



	Δ1	Δ2	Δ3	Δ4	Δ5
	WEAR	STEP	WEAR	STEP	WEAR
A	.00065	.00025	0	.0003	.000525
B	.0006	.0004	.000050	.0004	.00045
C	.00075	.0004	.000050	.00035	.000325
D	.0006	.0005	.000050	.0003	.00035
E	.00065	.0003	0	.0003	.00035
F	.00075	.00025	0	.00025	.00035

CARBON FACE SEAL 101056 SN 2
FIG. 5



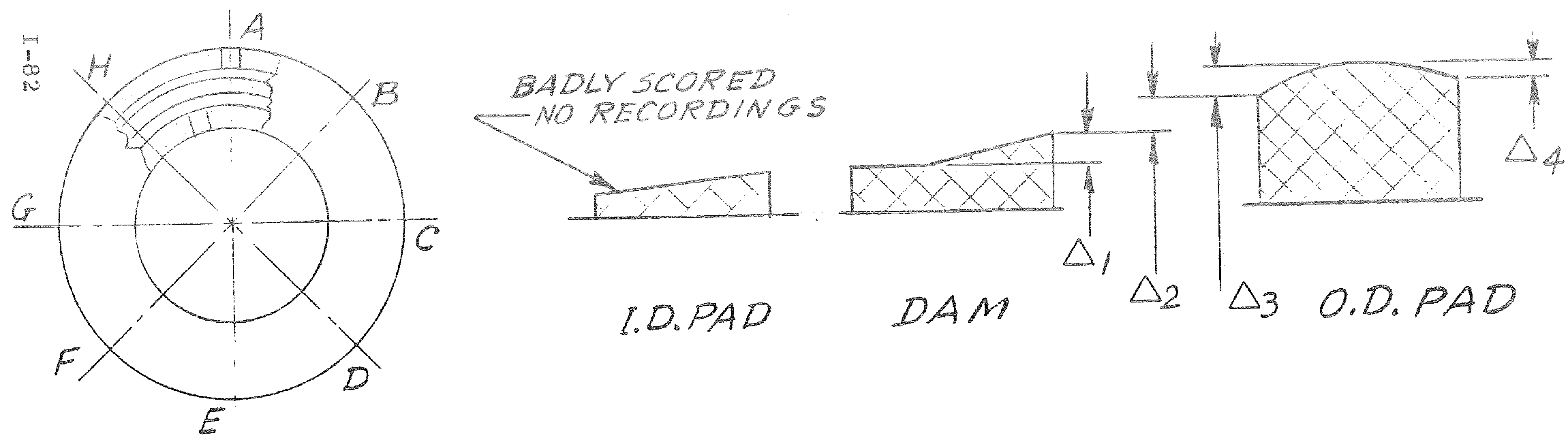


*RADIAL FACE WIDTH

	I.D. PAD	DAM	O.D. PAD	SLOPE
A	POSSIBLY .0001	0	POSSIBLY .000050	.000050 /.930*
B	POSSIBLY .000050	0	POSSIBLY .0001	.00015 /.930*
C	0	0	0	.000525/.930*
D	.000275	.0002	.00015	.00055 /.930*
E	0	0	0	.00105 /.930*
F	0	0	0	.00065 /.930*

SHOULDER FACE 101056 SN 2

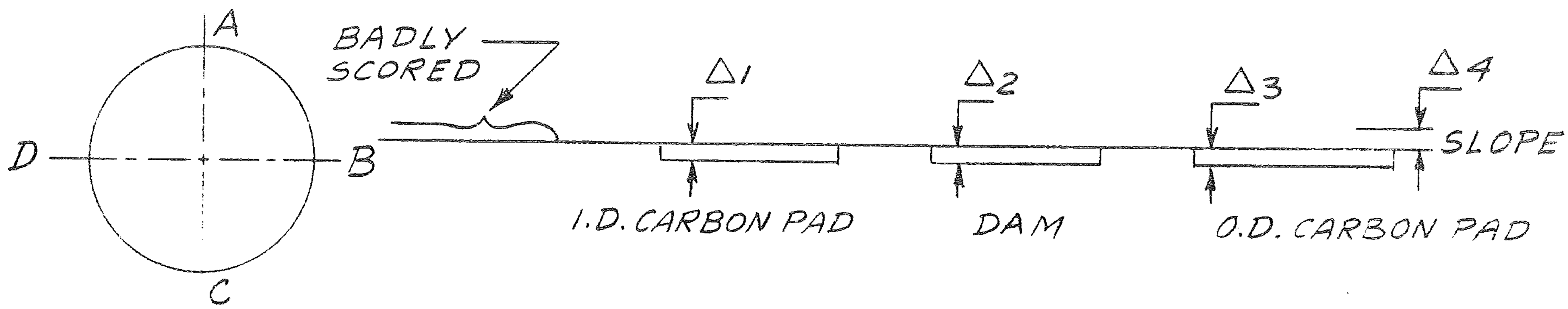
FIG. 6



	Δ1	Δ2	Δ3	Δ4
A	——	.0002	.00045	-.00015
B	.00025	.000175	.00045	-.00025
C	.0001	.00005	.000125	-.000325
D	0	0	0	-.000475
E	.000125	.00005	.0002	-.00035
F	——	.00015	.0005	-.0002
G	——	——	.00035	-.0002
H	.00025	.000175	.000375	-.000175

CARBON FACE 700397 SN 3

FIG. 7



* RADIAL FACE WIDTH

	Δ1	Δ2	Δ3	Δ4
A	.0001	.00005	.00015	0
B	.00015	.0001	.000275	0
C	.00025	.000175	.000325	.00005/1.250*
D	.0001	.000050	.00025	0

SHOULDER FACE 700405 SN 1

FIG. 8

APPENDIX II

A MASS SPECTROSCOPIC STUDY OF BLENDED MOBIL XRM 109F AND 10% KENDALL HEAVY RESIN 0839 IN A 250-HOUR HIGH TEMPERATURE LUBRICATION SYSTEM ENDURANCE RUN

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II-3	Mass Spectrum of Mobil XRM 109F and 10% Kendall Heavy Resin 0839 After 56.6 Hours
II-4	Mass Spectrum of Mobil XRM 109F and 10% Kendall Heavy Resin 0839 After 72.2 Hours
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A MASS SPECTROSCOPIC STUDY OF BLENDED MOBIL XRM 109F AND 10% KENDALL HEAVY RESIN 0839 IN HIGH SPEED HIGH TEMPERATURE BEARING TESTS

SUMMARY

As part of the program on NASA Contract NAS3-6267, Phase II, a blend of Mobil XRM-109F and 10% by weight of Kendall Heavy Resin 0839 was evaluated for its performance as a lubricant under simulated advanced turbine engine conditions. Since a mass spectrometer was used for controlling gas purity and for determining seal leakage rates, an opportunity was also afforded for observing the behavior of the lubricant during these tests by recording mass distribution data of the lubricant vapor from the bearing test chamber while the bearing test was underway.

The present report comprises a discussion of the data obtained, its interpretation in terms of lubricant stability and a tentative correlation with other lubricant parameters, such as viscosity, acidity, environmental conditions and others.

CONCLUSIONS

1) Reaction products of blended Mobil XRM 109F and 10% by weight of Kendall Heavy Resin 0839, formed by a thermal degradation mechanism and/or oxidative degradation mechanism, were observed to become more significant when oxygen values exceeded 300 ppm in the inerting gas during a 250-hour endurance test in a 125 mm-bore bearing rig at conditions of 14,000 rpm shaft speed, 3280 lbs. thrust load, and 650°F outer bearing ring and housing temperature, and 500°F oil inlet temperature.

2) There is evidence that degradation occurs by depolymerization of the lubricant molecule with evaporation of the more volatile fragments. Degradation products were observed in the gas from the bearing test chamber during the test and as residual constituents in the lubricant after the test.

APPLICATION OF RESULTS

These observations can provide a method of continuous monitoring of a high temperature unit for the rate of degradation product development which will serve as an immediate forwarning of lubricant failure or as an indication of probable behavior in more extended operation.

DETAILS

In order to shed some light on the behavior of the lubricant as well as the structural changes that occur during use, mass spectra were obtained of the lubricant in the unused and used condition by introducing the vapor of the sample at room temperature into the mass spectrometer. Spectra were also recorded of vapor products from the bearing test chamber while the test was in progress.

A Bendix Model 12-101A Time of Flight Mass Spectrometer with Model 12-107 source was used for this work. The mass spectrometer and manner in which mass indications are generated have been described previously in (1).*

Enclosure II-1 contains a photograph of the spectrum obtained from a unused sample of the blended XRM 109F and 10% by weight of Kendall Heavy Resin 0839 with the sample at room temperature.

Enclosures II-2, II-3, II-4 and II-5 contain photographs of spectra obtained from room temperature samples of blended XRM 109F and 10% Kendall Heavy Resin 0839 after undergoing test conditions of 14,000 rpm, 3280 pound load and outer ring and housing temperature of 650°F for 21.8 hours, 56.6 hours, 72.2 hours and 251.5 hours respectively. Each spectrum was recorded at the same mass spectrometer condition relevant to mass peak production.

Enclosure II-6 contains a table which lists the mass numbers and peak heights in arbitrary units that appeared in spectra of the unused and used oil samples at room temperature with corresponding values for viscosity at 100°F, contamination level and neutralization number.

Enclosure II-7 contains graphical representations for observing the mass numbers present in the room temperature lubricant spectra as a function of their peak height over the total range of running time. Enclosure II-8 contains viscosity, contamination level,

* Numbers in parentheses refer to references at end of Part I.

neutralization number of the tested lubricant, and oxygen content in the test bearing cavity as measured continuously by the mass spectrometer during test, over the total range of running time.

DISCUSSION OF RESULTS

According to available information, Mobil XRM 109F is a synthetic hydrocarbon lubricant prepared by the catalytic polymerization of an α-olefin, and Kendall Heavy Resin 0839 is a highly refined, high molecular weight mineral oil. A blend of XRM 109F and 10% by weight of Kendall Heavy Resin 0839 was used as the test lubricant for the 250 hour endurance run at 125 mm bore bearing test conditions of 14,000 rpm shaft speed, 3280 lbs. thrust load, and 650°F outer ring and housing temperature. Total test time was accumulated in segments of 10 hours at test conditions. After each test segment the lubricant was evaluated for viscosity, contamination level and neutralization number, and subjected to mass spectroscopic examination.

The mass spectrum obtained from the unused blend with the sample at room temperature (Enclosure II-1) consists of peaks at atomic mass units which are not descriptive of the molecular structure of the lubricant. This seems to indicate that the high molecular weight of the fluid precludes room temperature volatilization and these mass indications only represent dissolved atmospheric contaminants. Individual samples of XRM 109F and Kendall Heavy Resin 0839 produced similar spectra which gives supporting evidence that only dissolved contaminants compose these spectra. For this reason, the structure of the lubricant could not be determined and the spectrum was used as a baseline for the formation of additional mass peaks in the used lubricant.

Enclosure II-2, II-3, II-4 and II-5 illustrate spectra of used lubricant and permit some observations to be made on the effect of operating conditions, since variations occurring in peak heights and production of new mass peaks can be attributed to the degradation or rearrangement of the lubricant molecule. Since it would not be of any advantage to display all of the spectra, more of a direct peak comparison can be obtained from Enclosure II-6, which consists of a table listing the mass numbers and corresponding peak heights in arbitrary units that appeared in each of the used lubricant spectra. Each lubricant sample is listed in the vertical columns, designated by the total accumulated hours of test running time, in order of increasing amount of time. Also listed with each lubricant sample is viscosity at 100°F, (centistoke value) contamination level (grams per 100 mls. of test lubricant) and neutralization number (milligrams of potassium hydroxide per gram of lubricant).

Nearly all of the peak heights vary significantly and new peaks have appeared in addition to those observed with new oil indicating that changes have occurred in the composition of the molecules which volatilize from the sample into the spectrometer. This, in turn, indicates changes in the bulk fluid which have occurred as a result of exposure to operating conditions. The variations observed in viscosity, contamination level, and neutralization number are also indicative of changes in the bulk fluid.

In order to utilize the spectra for determining lubricant degradation products, it was first necessary to separate the mass indications into associated groups, each of which would represent only one particular product, since decomposition or thermal degradation of any large polymeric structure probably results in more than one compound. Without any preliminary separation technique, such as gas chromatography, a mass spectrum would include parent molecules and positive ion fragments from all species comprising a gas. It must be understood that the relative peak height patterns cited in tables of "Mass Spectral Data" are indicative of only pure constituents, therefore, differentiation between positive ion fragments from different parent molecules is required to make use of the literature and verify the correctness of any predicted ionic structure.

Some distinction between mass indications was obtained graphically and illustrated in Enclosure II-7. Observing any mass number as a function of its' peak height over the total range of running time of the lubricant showed trends developing at intervals of time whereby a group of masses displayed similar variations. When viscosity, contamination level, neutralization number, and oxygen concentration in the bearing test chamber, as measured continuously by the mass spectrometer during the course of the test, and also observed in a similar manner, (Enclosure II-8) a correlation becomes apparent between increasing amount of oxygen in the bearing test cavity and the occurrence of certain masses in the tested lubricant spectra. The appearance of these mass numbers coincide with variations in viscosity, contamination level and neutralization number.

At 72.2 hours, 125 hours, and 170 hours of running time, the mass spectrometer gave values for the oxygen content in the test bearing cavity as 0.3%, 0.6% and 0.5% respectively, which exceeded, in each case, the normal operating value of 0.03% (300 ppm). Correspondingly, mass peaks 43, 41, 29, 42, 27, 57, 56, 86, 55, 84 and 85 appeared in significant amounts in the spectra of used lubricant after these test segments. Apparently, the oxygen atmosphere was capable of causing a degradation process which formed more volatile reaction products in the base fluid.

A literature search showed that the abundance pattern listed did not conform to any of the pure constituents in "Compilation of Mass Spectral Data" (14), but rather fragmentation species associated with parent hydrocarbons ranging from six to ten carbon atoms. Further separation and identification of individual degradation products would not be possible unless additional instrumental techniques were used prior to introduction of the gas into the mass spectrometer.

One identifiable residual degradation product is water, represented by mass peaks 18, 17 and 16 in the proper peak height ratios for water, in the bulk fluid. The amount of water varied with the concentration of oxygen in the gas phase.

Other observations on peak performance lead to speculation on the mechanism of their production with regard to viscosity, contamination and neutralization number. Mass peak 32 which is normally associated with diatomic oxygen is observed to vary in the test lubricant inversely with the appearance of mass peaks 44, 18, 17, 43, 29, 16, 42, 27, 57, 56, 86, 55, 84 and 85, and with neutralization number, contamination level, and the amount of oxygen measured in the bearing test cavity during the test. It seems reasonable to hypothesize that as long as the oxygen concentration in the bearing test chamber remains at 0.03%, no reaction occurs with the lubricant except a physical process of oxygen absorption into the lubricant bulk (high mass peak 32). When the oxygen level exceeds 0.03%, it initiates a chemical reaction which degrades the lubricant molecule resulting in smaller hydrocarbon residues as well as high polymer sludges and oxygenated compounds as verified by the increasing values for contamination level and neutralization number. Oxygen, at these times, becomes a reactant and its supply decreases in the bulk fluid (lower values for mass peak 32).

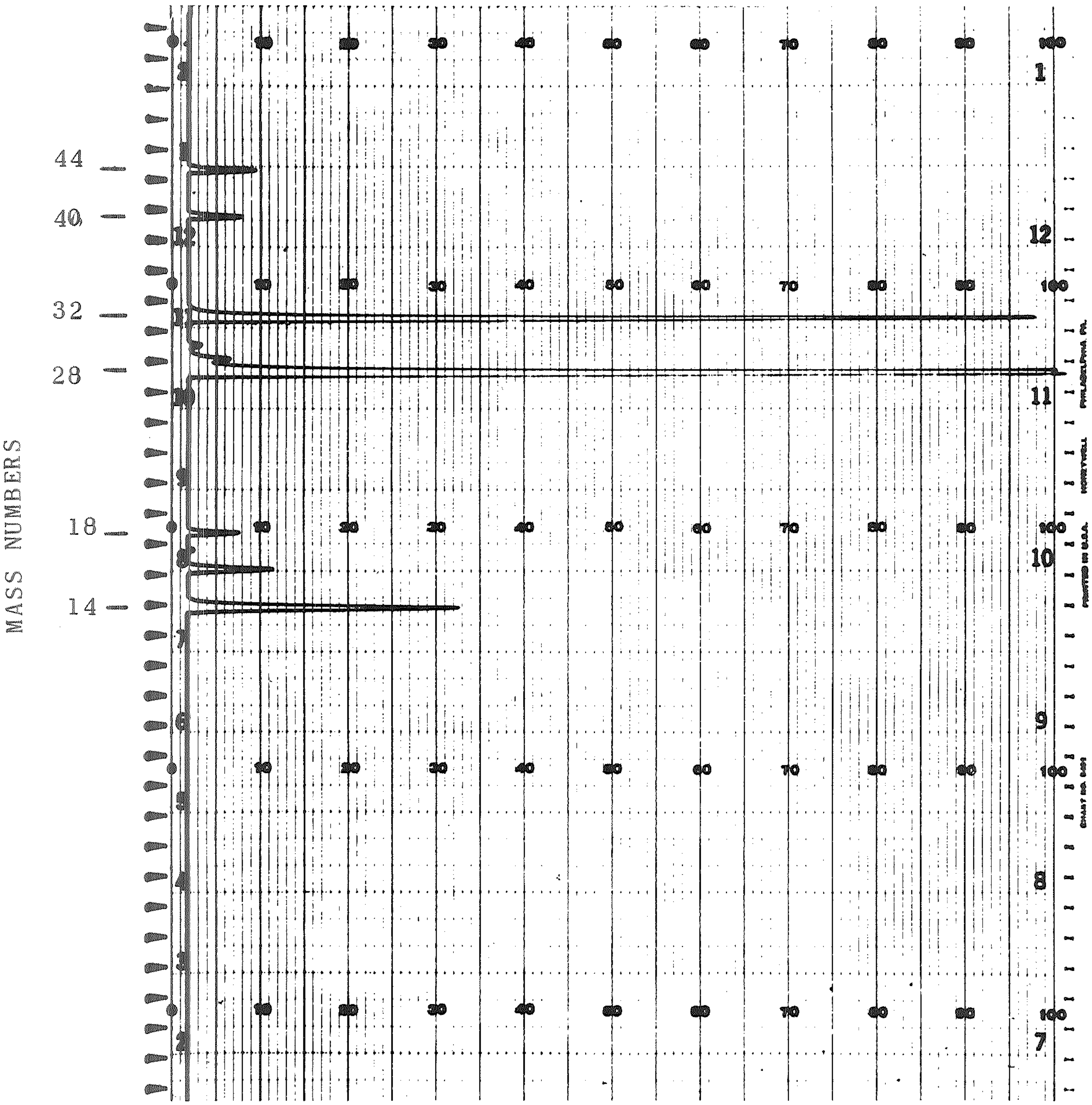
The 0.03% oxygen concentration stated is a value for normal system operation. Values of 0.3% to 0.6% are abnormally high and indicate a system leak. However, how much the 0.03% oxygen concentration level can be exceeded before the beginning of lubricant degradation can only be found by further testing, since prolonged testing at engine conditions with 0.03% oxygen in nitrogen atmosphere shows no detrimental effect to the lubricant structure. Enclosure II -5 consists of photograph of the spectrum of the lubricant blend after undergoing bearing test conditions for 251.5 hours, and shows very little difference when compared to a spectra of the unusued or used lubricant after 10.9 hours of testing where the oxygen level remained at 0.03%. There is still some distillation of smaller fractions from the lubricant even at this low oxygen concentration, since the viscosity of the bulk fluid increases with time, however, this is not a result of molecular decomposition. There is a correlation between viscosity and addition of make-up fluid, i.e. each addition of make-up fluid is followed by a decrease in viscosity and a subsequent rise.

It follows that the use of this type of lubricant blend at these high test temperatures in an excessive oxygen atmosphere is susceptible to oxidative as well as thermal degradation with the formation of residual decomposition products which can effect the viscosity, contamination level and neutralization number of the bulk fluid.

While the endurance test was in progress, spectra were recorded of the gas from the test bearing cavity at various intervals during the test program. The make-up of this gas is mainly nitrogen with a small percentage of helium tracer gas for the detection of seal leakage and any vaporized decomposition products from the lubricant. Spectra of the gas from the bearing test chamber contained, in addition to the high nitrogen peaks (28, 14 and 29), mass peaks, identical to the mass indications that appeared in the spectra of used lubricant after each test segment. In other words, the same light distillation fragments of the blended lubricant appear as a vapor during the test and as residual products after the test.

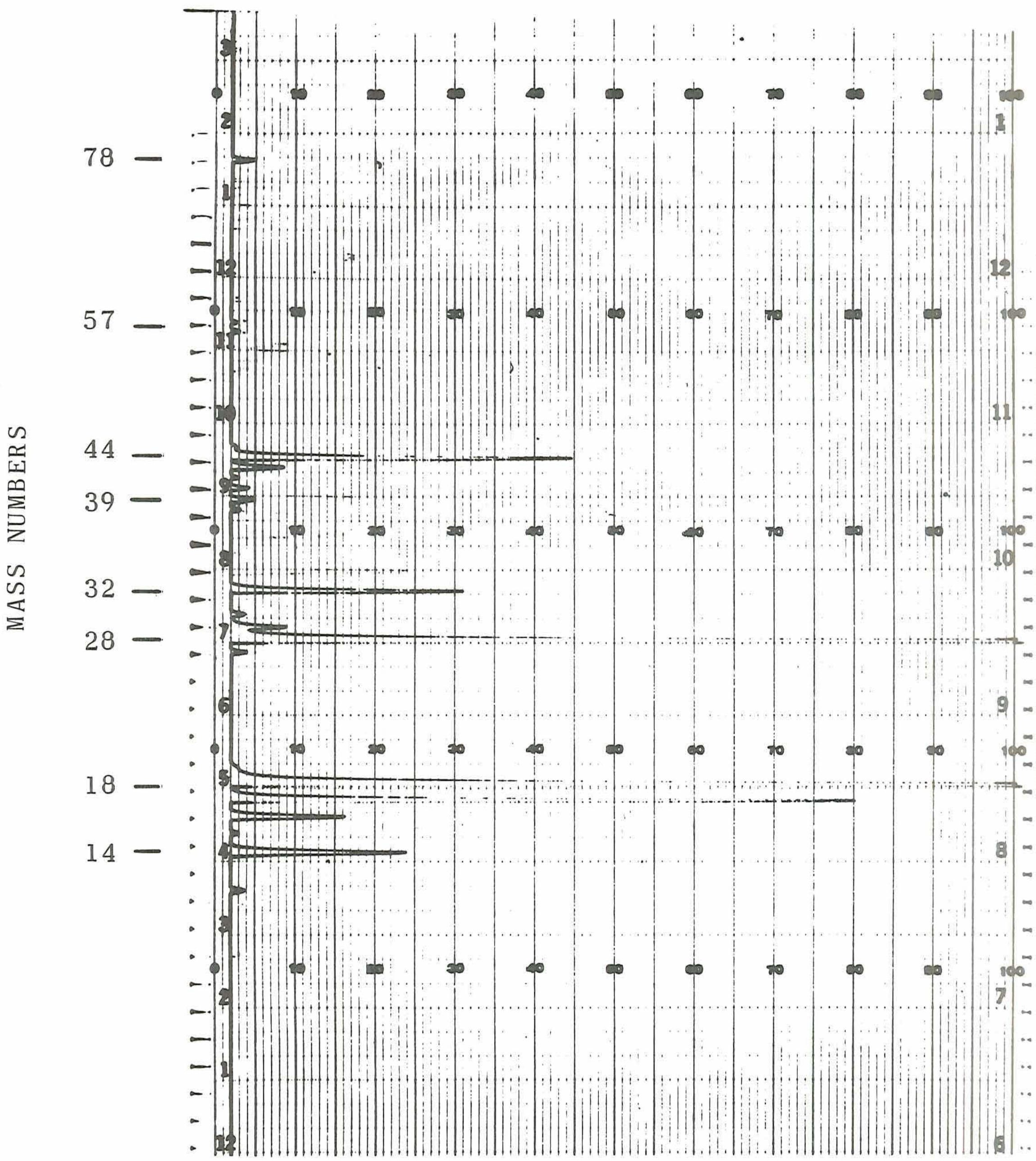
ENCLOSURE II-1

Mass Spectrum of Unused
Mobil XRM 109F and
10% Kendall Heavy Resin 0839



ENCLOSURE II-2

Mass Spectrum of Mobil XRM 109F and
10% Kendall Heavy Resin 0839 after 21.8 Hours



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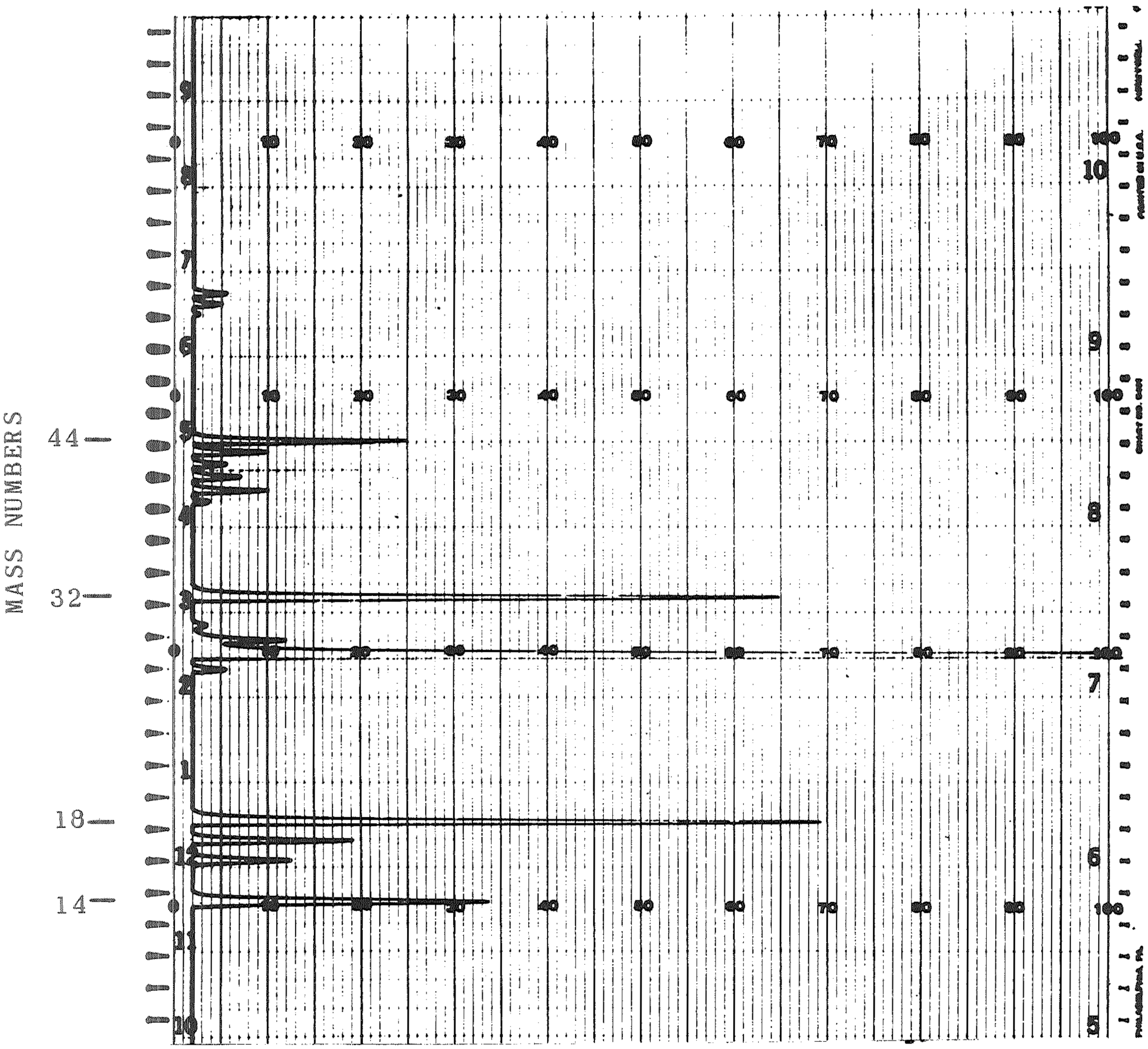
ENCLOSURE II-3

Mass Spectrun of Mobil XRM 109F and
10% Kendall Heavy Resin 0839 after 56.6 Hours



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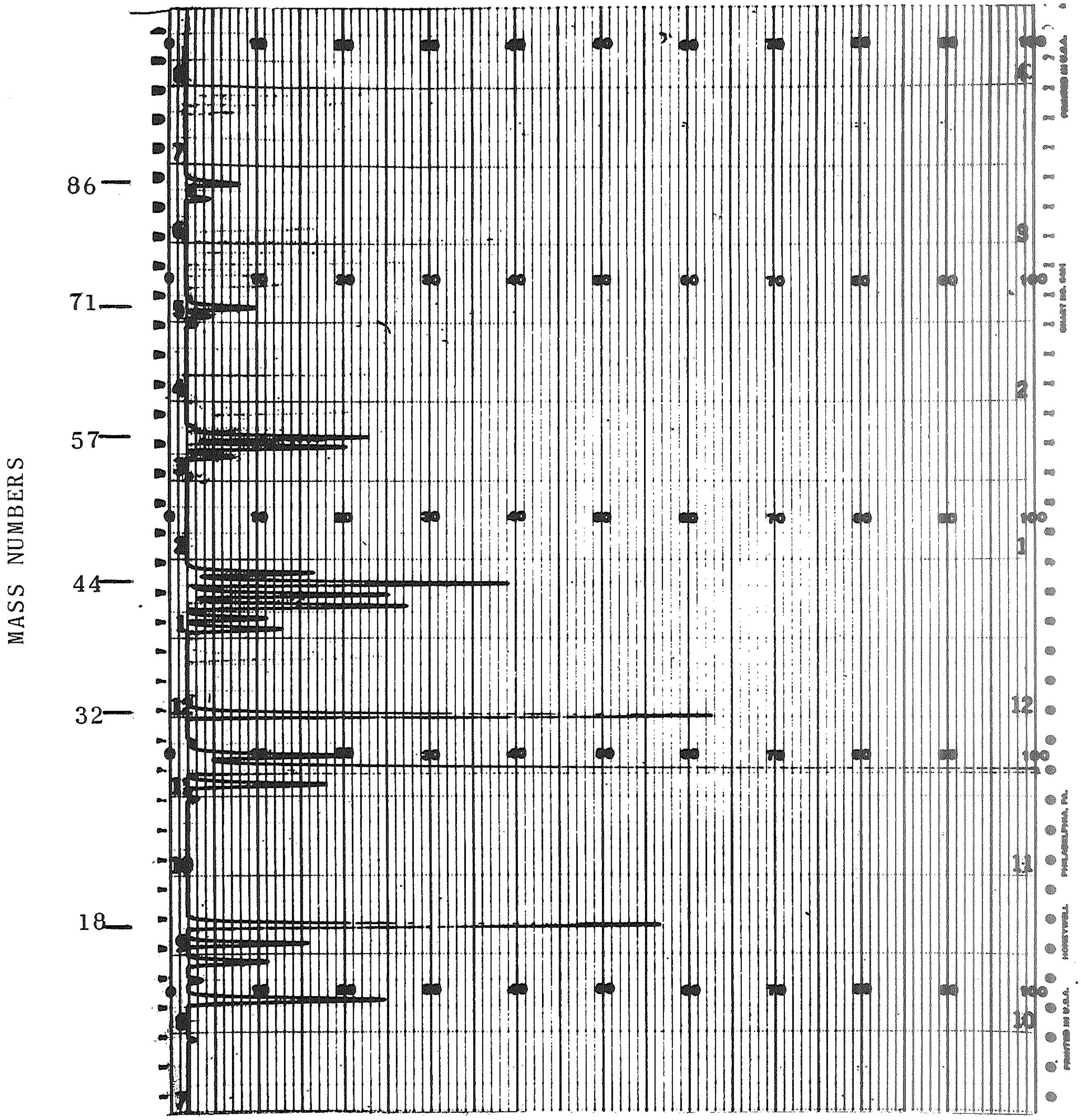
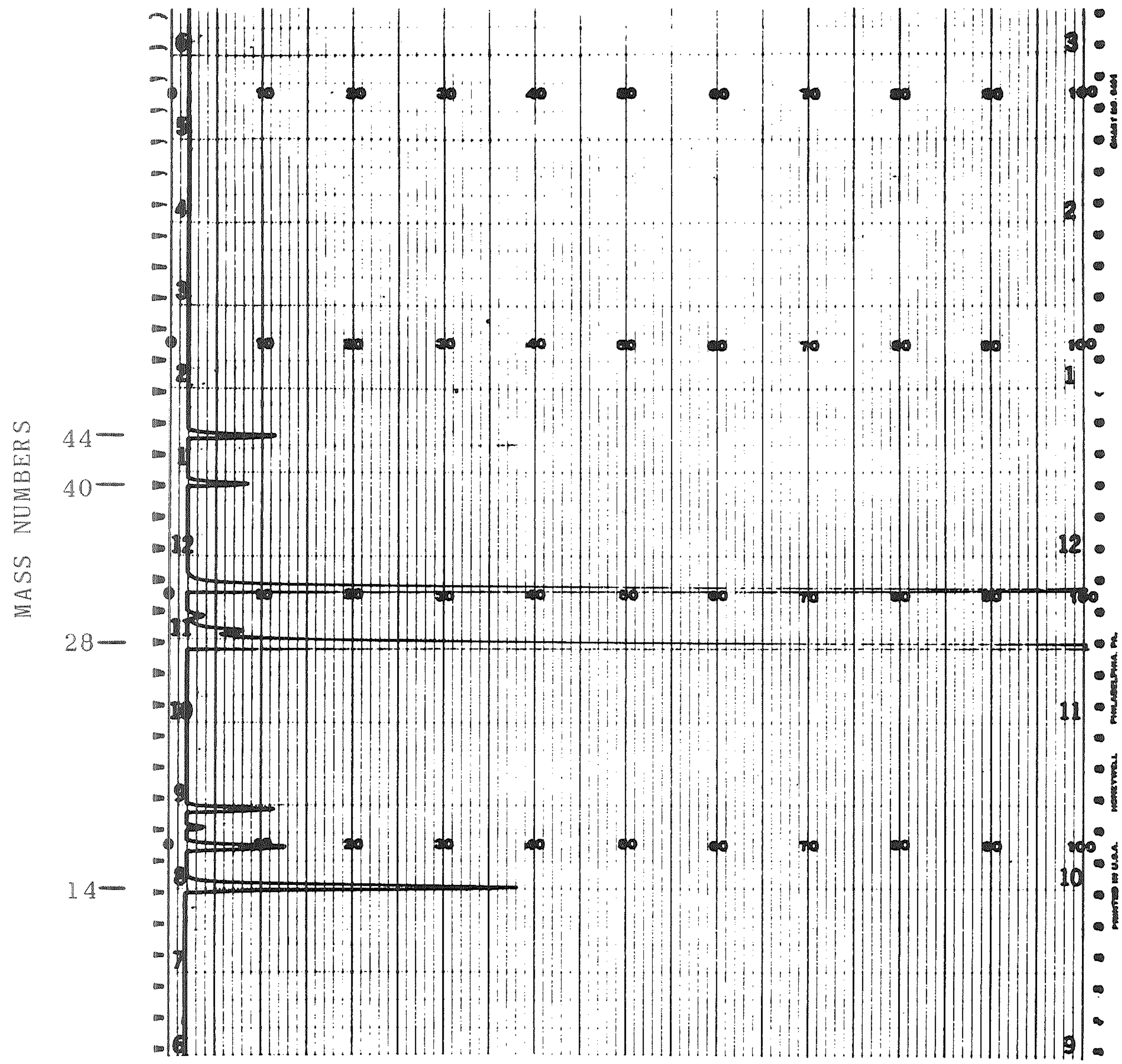
ENCLOSURE II-4

Mass Spectrum of Mobil XRM 109F and 10% Kendall Heavy Resin 0839 after 72.2 Hours



ENCLOSURE II -5

Mass Spectrum of Mobil XRM 109F and 10% Kendall Heavy Resin 0839 after 251.5 Hours



ENCLOSURE II-6

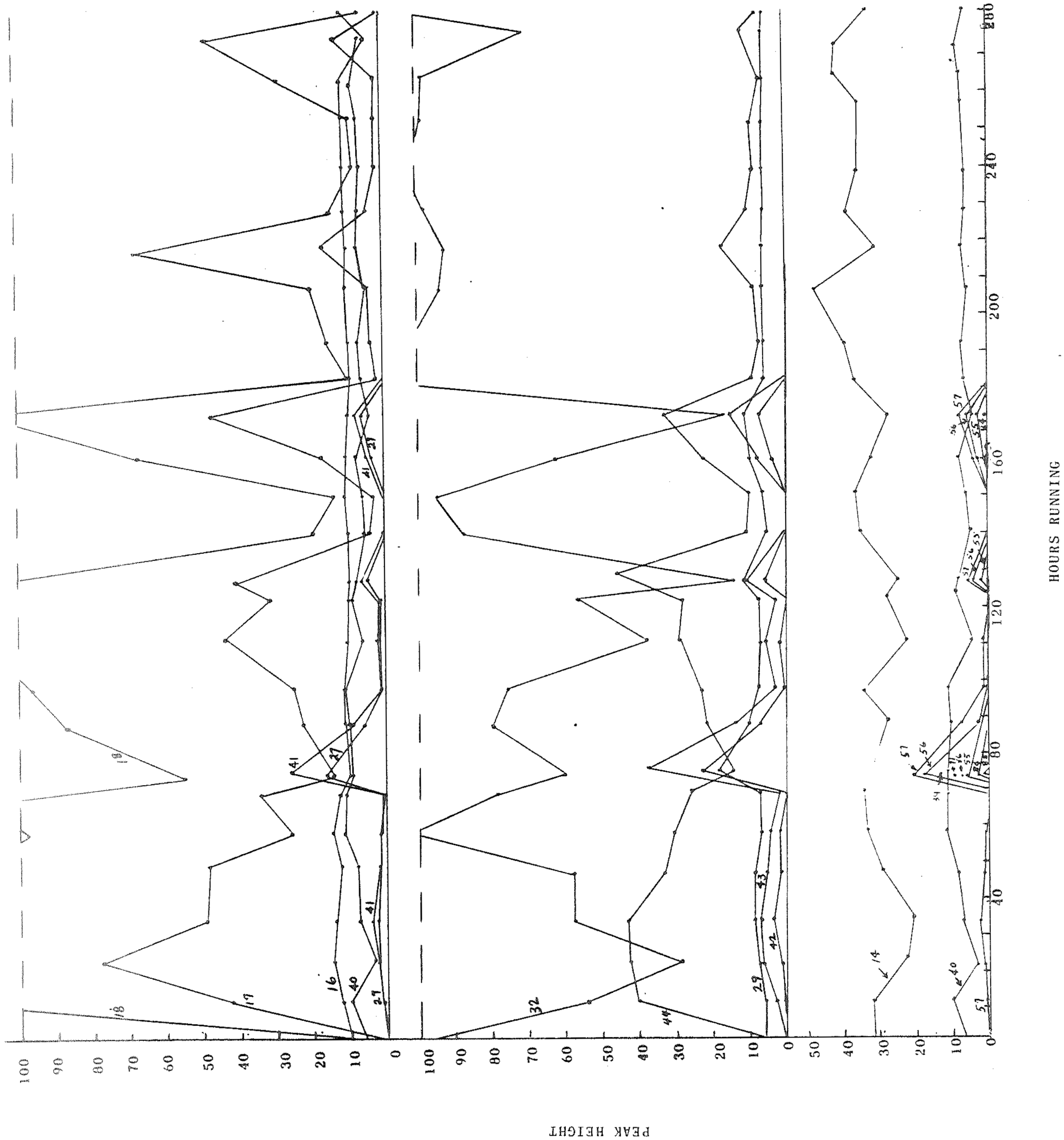
TABLE OF MASS NUMBERS AND CORRESPONDING PEAK HEIGHT IN ARBITRARY UNITS THAT APPEARED IN EACH OF THE USED LUBRICANT SPECTRA

TOTAL RUNNING TIME FOR OIL (HOURS)

MASS NO.	UNUSED OIL	10.9	21.8	32.5	45.7	56.6	67.1	72.2	86.4	96.6	109.3	120.2	125.4	138.1	148.4	158.9	170.0	180.4	190.0	205.4	216.0	226.9	237.5	251.5	262.3	273.0	280.6
12	--	1.5	1.5	1.5	1.0	1.0	--	1.0	--	--	1.0	1.0	1.5	--	--	--	1.5	--	--	--	--	--	--	--	--	--	--
13	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
14	31.0	31.5	22.0	21.0	29.5	33.5	34.0	23.0	27.0	34.0	22.5	28.0	25.0	35.5	36.5	32.0	28.0	36.5	39.5	47.5	31.0	39.0	36.5	35.0	41.5	41.5	33.0
15	--	--	1.0	--	--	--	--	1.5	0.5	--	0.5	--	1.0	--	--	--	1.5	--	--	--	--	--	--	--	--	--	--
16	9.5	13.0	14.5	14.0	13.5	15.0	13.0	9.5	11.5	12.5	10.5	10.0	9.0	10.0	11.0	10.5	9.5	11.0	10.0	10.5	12.0	11.0	10.5	11.0	12.5	6.0	9.5
17	--	42.0	78.0	49.5	48.5	26.0	34.5	14.0	22.5	25.0	44.0	32.0	41.0	4.5	3.0	17.5	47.5	2.0	3.5	4.5	16.5	4.0	1.5	1.5	1.5	13.0	1.0
18	6.0	Off Scale	Off Scale	Off Scale	Off Scale	98.0	Off Scale	55.0	87.5	96.5	Off Scale	Off Scale	Off Scale	20.5	14.0	67.5	Off Scale	9.5	15.5	19.0	68.0	15.5	7.5	8.0	8.0	49.5	6.0
26	--	--	--	--	--	--	--	1.5	--	--	--	--	--	--	--	--	0.5	--	--	--	--	--	--	--	--	--	--
27	--	1.0	2.0	2.5	1.5	1.5	0.5	16.0	6.0	1.0	1.5	1.0	5.0	--	--	3.5	6.5	--	--	--	--	--	--	--	--	--	--
28	Off Scale																										
29		6.5	7.0	7.5	9.0	7.5	7.5	19.0	10.5	7.5	7.0	8.0	11.5	5.5	6.5	10.0	11.5	6.0	6.5	5.5	6.0	6.0	6.0	5.5	5.5	5.5	6.5
30	1.5	1.5	2.0	2.0	2.0	2.0	1.5	1.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2.0	1.5	1.5	2.0	1.5	2.0	1.5	1.5	2.0	1.5
31	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
32	96.0	54.5	29.0	58.0	58.0	off scale	79.5	61.0	80.0	76.5	38.5	57.0	14.5	88.5	95.0	63.0	16.0	off scale	off scale	94.5	93.0	98.0	off scale	98.0	98.0	71.0	off scale
39	--	--	1.0	1.5	1.0	--	--	11.0	4.0	--	1.0	--	3.0	--	--	2.0	4.5	--	--	--	--	--	--	--	--	--	--
40	6.0	10.0	3.0	7.5	8.0	11.5	11.0	9.5	10.0	11.0	6.5	9.0	8.0	5.5	6.0	8.0	4.5	6.5	7.0	5.5	7.0	6.5	6.0	6.5	6.5	8.5	6.0
41	--	1.0	2.5	4.0	2.5	2.0	0.5	25.5	9.0	1.5	2.0	1.0	7.0	--	--	5.0	9.5	--	--	--	--	--	--	--	--	--	--
42	--	--	1.0	3.0	1.5	1.5	--	23.5	7.0	0.5	1.0	--	5.5	--	--	3.5	7.0	--	--	--	--	--	--	--	--	--	--
43	--	3.0	6.5	7.0	5.5	4.5	2.0	37.5	13.5	2.5	5.5	3.0	11.5	--	--	8.0	16.0	--	--	--	--	--	--	--	--	--	--
44	7.5	41.0	43.0	43.5	33.5	31.0	26.0	14.5	21.5	23.5	29.0	28.5	46.5	11.0	10.5	23.0	33.5	9.5	7.0	8.5	17.0	10.0	8.5	9.0	6.5	11.5	7.5
53	--	--	--	--	--	--	--	0.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
54	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
55	--	--	--	--	--	--	--	5.5	2.0	--	--	--	1.5	--	--	1.0	2.5	--	--	--	--	--	--	--	--	--	--
56	--	--	--	--	--	--	--	18.5	7.0	0.5	1.0	--	4.5	--	--	3.0	6.0	--	--	--	--	--	--	--	--	--	--
57	--	--	1.0	2.0	1.0	0.5	--	21.0	7.5	1.0	1.5	--	5.5	--	--	4.0	8.0	--	--	--	--	--	--	--	--	--	--
58	--	--	0.5	2.5	1.5	1.5	--	--	--	--	--	--	--	--	--	--	1.5	--	--	--	--	--	--	--	--	--	--
69	--	--	--	--	--	--	--	1.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
70	--	--	--	--	--	--	--	3.0	0.5	--	--	--	--	--	--	--	1.0	--	--	--	--	--	--	--	--	--	--
71	--	--	--	--	--	--	--	8.0	2.0	--	--	--	1.0	--	--	--	1.5	--	--	--	--	--	--	--	--	--	--
78	--	--	3.0	--	1.0	--	--	--	--	--	1.5	--	--	--	--	--	4.0	--	--	--	--	--	--	--	--	--	--
84	--	--	--	--	--	--	--	2.5	1.0	--	--	--	--	--	--	--	1.0	--	--	--	--	--	--	--	--	--	--
85	--	--	--	--	--	--	--	1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
86	--	--	--	--	--	--	--	6.0	1.5	--	--	--	0.5	--	--	--	1.0	--	--	--	--	--	--	--	--	--	--
Viscosity @ 100°F	565.2	595.2	676.2	718.1	657.4	721.7	731.2	742.4	748.9	773.0	808.5	817.9	803.1	841.2	667.8	846.3	920.2	852.0	814.6	740.2	817.5	824.7	773.9	793.3	780.9	776.9	774.4
Dirt Content gms/100mk		.012	.014	.0108	.0104	.0092	.0104	.0168	.0084	.0224	.0128	.0088	.0456	.0180	.006	.0108	.0108	.0124	.0076	.006	.0052	.004	.004	.0072	.0044	.0044	.0136
Neutralization No.		0.09	0.07	0.08	0.08	0.10	0.09	0.09	0.07	0.07	0.08	0.07	0.10	0.07	0.07	0.08	0.12	0.13	0.09	0.14	0.07	0.08	0.08	0.06	0.08	0.06	0.09

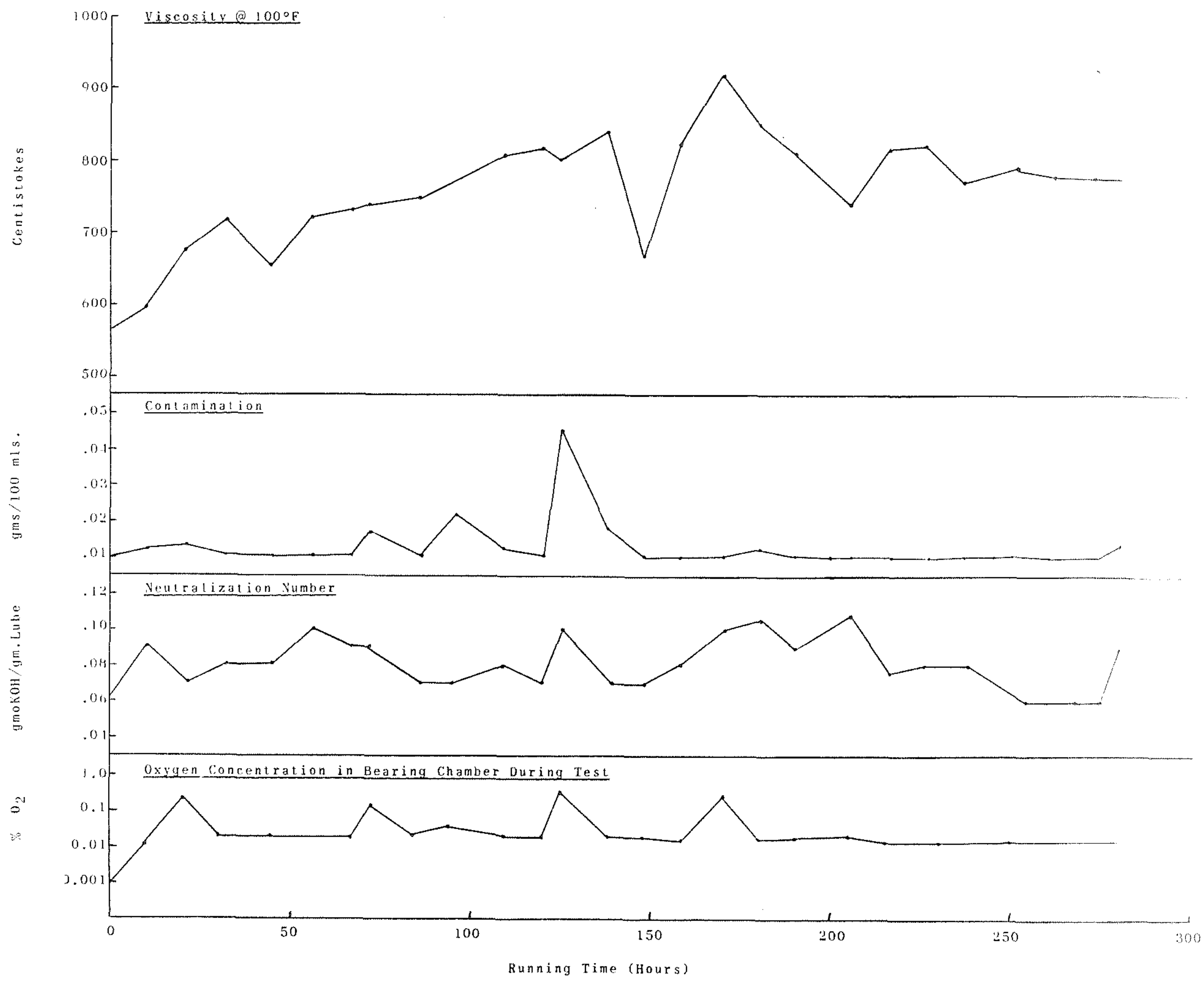
ENCLOSURE II-7

GRAPH OF THE MASS NUMBERS PRESENT IN ROOM TEMPERATURE LUBRICANT SPECTRA AS A FUNCTION OF THEIR PEAK HEIGHT OVER THE TOTAL RANGE OF RUNNING TIME



ENCLOSURE II-8

GRAPH OF OXYGEN CONTENT IN BEARING CHAMBER, VISCOSITY, CONTAMINATION AND NEUTRALIZATION NUMBER DURING TOTAL RUNNING TIME OF TEST



APPENDIX III

SUMMARY DATA SHEETS FOR TASKS II, III AND IV

ADVANCED TURBINE ENGINE MAINSHAFT LUBRICATION SYSTEM TEST RUNS

WB49 459980H (II)

TEST BEARING # 267101

OIL USED MOBIL JET II

DATE 11-2-67

RUNNING TIME, HOURS	0.7	0.5	1.7	2.2	2.7	2.9						
SPEED, RPM	14	14	14	14	14	14						
MOTOR POWER, VOLT X AMPS												
AIR MANIFOLD PRESS. (PSI)	106	106	107	106	106							
BEARING CAVITY PRESS. (PSI)	6	6	6	6	6							
SEAL CAVITY PRESS. (PSI)	110	111	110	111	111							
HOT AIR FLOW (SCFM)	35	44	42	42	50							
TEST OIL FLOW (GPM)	1.2	1	1	1	0.9							
TOTAL SEAL LEAKAGE (SCFM)	14.4	14.4	13.5	16.4	20.0							
TEST BEARING OUTER RING (°F)	515	540	545	540	540							
TEST BEARING INNER RING (°F)	—	—	—	—	—							
ROLLER BEARING OUTER RING (°F)	450	490	500	500	510							
OIL SEAL HOUSING (°F)	490	505	515	475	470							
AIR SEAL HOUSING (°F)	700	790	815	780	790							
TEST BEARING HOUSING (°F)	500	545	540	535	550							
ROLLER BEARING HOUSING (°F)	530	550	555	540	560							
AIR SEAL BELLOWS (°F)	—	—	—	—	—							
HOT AIR IN MANIFOLD (°F)	1140	1195	1200	1200	1205							
OIL INLET (°F)	435	450	455	445	460							
OIL OUTLET (°F)	450	—	430	425	445							

BEARING: FAILURE

OIL SEAL LIFT OFF: OIL BLOWN OUT OF VENT

The majority of the total seal leakage was across the air seal.
The oxygen content in the test bearing chamber was .023 - .030%.

APPENDIX II

AL69T016

WB49 80H (II)

TEST BEARING # 267102

OIL USED MOBIL JET II

DATE 11-16-67

Running Time, Hours	START	0.7	0.8	STOP: RESTART	0.8	1.0	STOP: HIGH OIL SEAL LEAKAGE					
Speed, RPM		14	14									
Motor Power, Volt x Amps												
Air Manifold Press. (psi)	106	106	106			106						
Bearing Cavity Press. (psi)	6	6	6			20-25						
Seal Cavity Press. (psi)	111	111	111			111						
Hot Air Flow (scfm)	—	—	—		—	—						
Test Oil Flow (gpm)	1.75	1.5	1.0		1.75	—						
Total Seal Leakage (scfm)												
Test Bearing Outer Ring (°F)	390	560	740+		550	550						
Test Bearing Inner Ring (°F)	380	550	740+		540	540						
Roller Bearing Outer Ring (°F)	410	505	505		—	—						
Oil Seal Housing (°F)	370	600	600		—	—						
Air Seal Housing (°F)	615	860	860		—	—						
Test Bearing Housing (°F)	555	620	620		—	—						
Roller Bearing Housing (°F)	505	550	550		—	—						
Air Seal Bellows (°F)	—	—	—		—	—						
Hot Air in Manifold (°F)	760	1080	1010		—	—						
Oil Inlet (°F)	—	—	—		—	—						
Oil Outlet (°F)	360	—	—		—	—						

↑ TEST BEARING TEMPERATURE EXCURSION

III-4

WB49 80H (II)

TEST BEARING # 267103

OIL USED MOBIL JET II

DATE 12-19-67

RUNNING TIME, HOURS	0.3	1.0	1.4	1.5								
SPEED, RPM	4	12	14	14								
MOTOR POWER, VOLT X AMPS												
AIR MANIFOLD PRESS. (PSI)	106	106	106	106								
BEARING CAVITY PRESS. (PSI)	6	6	6	6								
SEAL CAVITY PRESS. (PSI)	111	111	111	111								
HOT AIR FLOW (SCFM)	—	—	40	—								
TEST OIL FLOW (GPM)	1.5	0.8	1	1								
TOTAL SEAL LEAKAGE (SCFM)	4.6	—	—	—								
TEST BEARING OUTER RING (°F)	490	530	590	600								
TEST BEARING INNER RING (°F)	510	590	610	650								
ROLLER BEARING OUTER RING (°F)	450	505	540	540								
OIL SEAL HOUSING (°F)	390	630	650	645								
AIR SEAL HOUSING (°F)	580	865	765	765								
TEST BEARING HOUSING (°F)	595	580	505	600								
ROLLER BEARING HOUSING (°F)	490	520	600	525								
AIR SEAL BELLOWS (°F)	—	—	—	—								
HOT AIR IN MANIFOLD (°F)	665	970	850	840								
OIL INLET (°F)	—	—	500	—								
OIL OUTLET (°F)	—	—	485	—								

The oxygen content in the test bearing chamber was .036 - .05%.

AL69T016

WB49 459980H (Series II)

TEST BEARING # 267104

OIL USED MOBIL XRM 154D

DATE 1-16-68

Running Time, Hours	START	1.2	STOP: RESTART	1.2	2.3	STOP: TEMPERATURE EXCURSION						
Speed, RPM	2	14		1	14							
Motor Power, Volt x Amps	—											
Air Manifold Press. (PSI)	106	106		106	106							
Bearing Cavity Press. (PSI)	6	6		6	6							
Seal Cavity Press. (PSI)	111	111		111	111							
Hot Air Flow (SCFM)												
Test Oil Flow (GPM)	1.5	1.5		1.0	0.7							
Total Seal Leakage (SCFM)	2-3											
Test Bearing Outer Ring (°F)	400	465		400	500							
Test Bearing Inner Ring (°F)	420	505		420	510							
Roller Bearing Outer Ring (°F)	460	490		415	520							
Oil Seal Housing (°F)	400	595		460	615							
Air Seal Housing (°F)	590	910		600	870							
Test Bearing Housing (°F)	565	570		460	630							
Roller Bearing Housing (°F)	480	455		410	485							
Air Seal Bellows (°F)	—	—		—	—							
Hot Air in Manifold (°F)	800	1090		785	1095							
Oil Inlet (°F)	—	—		400	440							
Oil Outlet (°F)	—	—		—	—							

↑ REPLACED SLIP RING

The oxygen content in the test bearing chamber was ≈ 1%.

WB49 80H (Series II)

TEST BEARING # 267108

OIL USED MOBIL XRM154D

DATE 4-9-68

Running Time, Hours	1.0	1.15	1.3	1.75	2.0	2.45	3.45	4.45	4.95	5.2		
Speed, RPM	14	14		14		14	14	14	14	14		
Motor Power, Volt x Amps												
Air Manifold Press. (psi)	106	106		106		106	106	106	106	106		
Bearing Cavity Press. (psi)	6	6		6		6	6	6	6	23		
Seal Cavity Press. (psi)	111	111		111		111	111	111	111	111		
Hot Air Flow (scfm)	—	50		50		50	50	50	50	50		
Test Oil Flow (gpm)	2.0	2.0		2.0		2.0	2.0	2.0	2.0	1.5		
Total Seal Leakage (scfm)	—	—		—		1.7	1.7	1.4	4.4	—		
Test Bearing Outer Ring (°F)	630	640	RESTART	650	RESTART	630	640	640	645	650		
Test Bearing Inner Ring (°F)	630	620		610		610	620	625	630	640	STOP: OIL SEAL LIFT OFF	
Roller Bearing Outer Ring (°F)	580	580		505		500	500	490	490	500		
Oil Seal Housing (°F)	520	685		720		725	720	755	715	550		
Air Seal Housing (°F)	890	930		970		975	987	990	985	940		
Test Bearing Housing (°F)	560	555		540		515	505	515	515	515		
Roller Bearing Housing (°F)	470	490	STOP:	480	STOP:	460	440	455	450	450		
Air Seal Bellows (°F)	830	860		925		920	935	940	920	915		
Hot Air in Manifold (°F)	—	—		—		—	—	—	—	—		
Oil Inlet (°F)	—	480		490		490	495	480	485	—		
Oil Outlet (°F)	—	—		—		—	—	—	—	—		

↑ (1.3, 2.0) SHEAR PINS BROKE

The majority of the total seal leakage was across the oil seal for the first two hours and then splitting equally for the final hour.
The oxygen content in the test bearing chamber was 0.009 - 0.02%.

WB49 80H (Series II)

TEST BEARING # 267/06

OIL USED BLENDED MOBIL XRM 109F + 10 o/o KENDALL HEAVY RESIN 0839 DATE 2-20-68

RUNNING TIME, HOURS	0.9	1.5	2.3	3.0	3.9	TRANSITION PERIOD	4.9	5.3	6.4	7.4	8.0	QUIT TIME
SPEED, RPM	14	14	14	14	14		14	14	14	14	14	
MOTOR POWER, VOLT X AMPS												
AIR MANIFOLD PRESS. (PSI)	106	106	106	106	106		106	106	106	106	106	
BEARING CAVITY PRESS. (PSI)	6.5	6.5	6.5	6.5	6.5		6.5	6-25	6-8	6-8		
SEAL CAVITY PRESS. (PSI)	111	111	111	111	111		111	111	111	111	111	
HOT AIR FLOW (SCFM)	48	33	34	34	34		49	43	43	48	—	
TEST OIL FLOW (GPM)	1.25	1.25	1.25	1.5	1.5		1.5	—	1.25	1.25	1.25	
TOTAL SEAL LEAKAGE (SCFM)				1.6	1.6		1.8	+11.4		7.4	<2	
TEST BEARING OUTER RING (°F)	618	590	580	580	575		690	725	680	695	700	
TEST BEARING INNER RING (°F)	622	590	580	575	575		690	695	680	680	700	
ROLLER BEARING OUTER RING (°F)	565	500	470	465	440		580	550	530	540	540	
OIL SEAL HOUSING (°F)	802	777	745	744	727		852	700	685	795	800	
AIR SEAL HOUSING (°F)	982	970	935	927	920		1020	940	935	970	980	
TEST BEARING HOUSING (°F)	605	523	485	467	460		737	675	657	665	670	
ROLLER BEARING HOUSING (°F)	525	460	435	415	410		580	575	560	550	560	
AIR SEAL BELLOWS (°F)	930	925	885	880	870		955	810	815	870	885	
HOT AIR IN MANIFOLD (°F)	810	—	—	—	—		—	—	—	—	—	
OIL INLET (°F)	470	430	420	430	430		520	—	490	500	—	
OIL OUTLET (°F)	—	—	—	—	—		—	—	—	—	—	

↑ MOMENTARY OIL SEAL LIFT OFF (at 5.3 hours)

The majority of the total seal leakage was across the air seal.
The oxygen content in the test bearing chamber was 0.041 - 0.078%.

TEST BEARING # 267/09 [M-50 Steel Bearing, 459981G (Series I Design)]

OIL USED MOBIL JET II (OPEN ATMOSPHERE) DATE 5/20-22/68

Running Time, Hours	0.8	1.2	1.9	2.7	3.4	4.2	5.2	6.2	7.2	8.2	9.2	10.2
Speed, RPM	14	STOP: RESTART SHEAR PINS	STOP: RESTART OIL LEAK	14	STOP: RESTART SHEAR PINS	14	14	14	14	14	14	14
Air Manifold Press. (psi)	106			106		106	106	106	106	106	106	106
Bearing Cavity Press. (psi)	6			6		6	6	6	6	6	6	6
Seal Cavity Press. (psi)	111			111		111	111	111	111	111	111	111
Hot Air Flow (scfm)	50			40		42	53	54	49	49	49	52
Test Oil Flow (gpm)	2			2		2	2	2	2	2	2	2
Total Seal Leakage (scfm)	10.2			9.3		4.6	4.8	5.3	4.2	5.9	4.2	3.8
Test Bearing Outer Ring (°F)	520			520		518	530	545	535	525	520	510
Test Bearing Inner Ring (°F)	500			505		500	525	545	525	515	510	500
Roller Bearing Outer Ring (°F)	430			435		425	445	455	425	410	405	400
Oil Seal Housing (°F)	—			—		—	—	—	—	—	—	—
Air Seal Housing (°F)	840			810		800	865	890	860	845	850	870
Test Bearing Housing (°F)	500			525		500	495	490	400	390	370	380
Roller Bearing Housing (°F)	465			510		500	490	480	410	390	390	360
Air Seal Bellows (°F)	—			—		—	—	—	—	—	—	—
Hot Air in Manifold (°F)	1200			1160		1060	1130	1160	1150	1150	1160	1180
Oil Inlet (°F)	410			400		400	420	435	420	410	400	390
Oil Outlet (°F)	435			415		410	430	440	415	400	400	390

TEST CONDITIONS

TEST BEARING # 267109

OIL USED MOBIL JET II (OPEN ATMOSPHERE) DATE 5/22-24/68

Running Time, Hours	11.2	12.2	13.2	13.8	14.6	15.6	16.8	17.6	18.6	19.6	20.8	21.7
Speed, RPM	14	14	14	STOP: RESTART RG NOISE	14	14	14	14	14	14	14	14
Air Manifold Press. (psi)	106	106	106		106	106	106	106	106	106	106	106
Bearing Cavity Press. (psi)	6	6	6		6	6	6	6	6	6	6	6
Seal Cavity Press. (psi)	111	111	111		111	111	111	111	111	111	111	111
Hot Air Flow (SCFM)	52	52	52		35	48	48	46	55	52	52	52
Test Oil Flow (GPM)	2	2	2		2	2	2	2	2	2	2	2
Total Seal Leakage (SCFM)	4.6	5.9	5.5		4.9	—	5.0	4.7	5.0	5.0	4.9	6.6
Test Bearing Outer Ring (°F)	510	520	520		500	520	470	500	500	500	500	500
Test Bearing Inner Ring (°F)	510	510	510		490	520	480	500	500	500	500	500
Roller Bearing Outer Ring (°F)	400	400	410		420	410	390	420	420	420	420	420
Oil Seal Housing (°F)	—	—	—		—	—	—	—	—	—	—	—
Air Seal Housing (°F)	860	860	870		780	825	860	855	855	855	855	870
Test Bearing Housing (°F)	380	380	380		495	495	485	490	490	490	500	505
Roller Bearing Housing (°F)	360	360	350		495	495	485	490	490	490	490	490
Air Seal Bellows (°F)	—	—	—		—	—	—	—	—	—	—	—
Hot Air in Manifold (°F)	1180	1180	1190		1020	1080	1090	1100	1120	1120	1120	1150
Oil Inlet (°F)	390	390	390		490	420	390	390	390	390	390	390
Oil Outlet (°F)	390	390	400		400	430	380	400	405	405	410	400

→ TEST CONDITIONS

TEST BEARING # 267109

OIL USED MOBIL JET II (OPEN ATMOSPHERE) DATE 5/24-27/68

Running Time, Hours	22.6	23.7	24.4	24.6	25.3	26.3	27.3	28.3	29.3	30.3	31.3	32.4
Speed, RPM	14	14	14		14	14	14	14	14	14	14	14
Air Manifold Press. (psi)	106	106	106		106	106	106	106	106	106	106	106
Bearing Cavity Press. (psi)	6	6	6		6	6	6	6	6	6	6	6
Seal Cavity Press. (psi)	111	111	111		111	111	111	111	111	111	111	111
Hot Air Flow (scfm)	52	52	52	STOP: RESTART END OF TEST PERIOD	50	—	48	46	46	.46	46	46
Test Oil Flow (gpm)	2	2	2		2	2	2	2	2	2	2	2
Total Seal Leakage (scfm)	6.8	5.6	6.6		—	4.9	5.7	5.5	6.6	5.8	5.7	5.1
Test Bearing Outer Ring (°F)	500	500	500		510	525	520	520	520	525	515	515
Test Bearing Inner Ring (°F)	500	500	500		500	525	520	520	520	525	515	515
Roller Bearing Outer Ring (°F)	420	420	420		430	450	440	440	450	450	430	420
Oil Seal Housing (°F)	—	—	—		—	—	—	—	—	—	—	—
Air Seal Housing (°F)	870	870	870		785	850	870	880	880	920	920	920
Test Bearing Housing (°F)	500	500	500		500	495	495	495	490	490	—	—
Roller Bearing Housing (°F)	490	490	500		490	490	495	495	490	490	—	—
Air Seal Bellows (°F)	—	—	—		—	—	—	—	—	—	—	—
Hot Air in Manifold (°F)	1150	1150	1150		1150	1110	1130	1130	1140	1200	1170	1200
Oil Inlet (°F)	390	390	390		390	420	410	410	410	410	410	410
Oil Outlet (°F)	400	400	390		—	—	—	—	—	—	—	—

└→ TEST CONDITIONS

TEST BEARING # 267109

OIL USED MOBIL JET II (OPEN ATMOSPHERE) DATE 5/27-28/68

RUNNING TIME, HOURS	32.9	33.3	33.9	34.9	35.3	35.4	35.7	36.7	37.7	38.7	39.7	40.7
SPEED, RPM		14	14	14	14		14	14	14	14	14	14
AIR MANIFOLD PRESS. (PSI)		106	106	106	106		106	106	106	106	106	106
BEARING CAVITY PRESS. (PSI)		6	6	6	6		6	6	6	6	6	6
SEAL CAVITY PRESS. (PSI)		111	111	111	111		111	111	111	111	111	111
HOT AIR FLOW (SCFM)		54	50	50	49		45	50	50	48	48	48
TEST OIL FLOW (GPM)	STOP: RESTART SHEAR PINS.	2	2	2	2	STOP: RESTART END of TEST PERIOD	2	2	2	2	2	2
TOTAL SEAL LEAKAGE (SCFM)		4.5	5.8	5.3	5.1		5.5	5.5	—	6.5	6.8	6.3
TEST BEARING OUTER RING (°F)		500	512	502	520		515	510	520	525	530	525
TEST BEARING INNER RING (°F)		485	505	500	520		500	510	520	525	525	525
ROLLER BEARING OUTER RING (°F)		410	420	400	420		440	420	435	440	445	440
OIL SEAL HOUSING (°F)		—	—	—	—		—	—	—	—	—	—
AIR SEAL HOUSING (°F)		740	880	880	880		760	860	860	865	865	860
TEST BEARING HOUSING (°F)		380	370	390	390		415	420	470	480	485	485
ROLLER BEARING HOUSING (°F)		380	390	405	405		415	410	465	475	475	465
AIR SEAL BELLOWS (°F)	—	—	—	—	—		—	—	—	—	—	—
HOT AIR IN MANIFOLD (°F)		1000	1150	1170	1145		1030	1110	1110	1110	1110	1115
OIL INLET (°F)		390	395	395	405		415	400	410	410	415	410
OIL OUTLET (°F)		—	—	—	—		—	—	—	—	—	—

→ TEST CONDITIONS (arrows pointing to 33.3 and 35.7 columns)

AL69T016

TEST BEARING # 267109

OIL USED MOBIL JET II (OPEN ATMOSPHERE) DATE 5/28-29/68

Running Time, Hours	41.8	42.8	43.8	44.8	45.8	46.6	47.4	47.9	48.3	49.3	50.3	51.3
Speed, RPM	14	14	14	14	STOP: RESTART END OF TEST PERIOD	14	14	STOP: RESTART: COMPRESSOR SHUT DOWN:	14	14	14	14
Air Manifold Press. (psi)	106	106	106	106		106	106		106	106	106	106
Bearing Cavity Press. (psi)	6	6	6	6		6	6		6	6	6	6
Seal Cavity Press. (psi)	111	111	111	111		111	111		111	111	111	111
Hot Air Flow (scfm)	48	48	48	48		46	48		44	48	45	45
Test Oil Flow (gpm)	2	2	2	2		2	2		2	2	2	2
Total Seal Leakage (scfm)	5.1	5.2	6.2	6.5		6.2	6.9		4.9	5.4	5.1	5.4
Test Bearing Outer Ring (°F)	520	520	520	525		520	530		515	512	500	500
Test Bearing Inner Ring (°F)	520	520	520	525		500	525		500	520	510	505
Roller Bearing Outer Ring (°F)	445	440	440	450		430	450		430	430	440	420
Oil Seal Housing (°F)	—	—	—	—		—	—		—	—	—	—
Air Seal Housing (°F)	865	865	860	860		855	880		860	870	875	870
Test Bearing Housing (°F)	470	465	475	500		430	490		490	430	485	460
Roller Bearing Housing (°F)	480	465	470	480		430	480		480	440	475	450
Air Seal Bellows (°F)	—	—	—	—		—	—		—	—	—	—
Hot Air in Manifold (°F)	1110	110	1110	1110		1130	1160		1145	1150	1160	1150
Oil Inlet (°F)	415	415	410	420		410	425		400	405	390	380
Oil Outlet (°F)	—	—	—	—		—	—		—	—	—	—

(Columns 46.6 and 48.3) → TEST CONDITIONS

TEST BEARING # 267109

OIL USED MOBIL JET II (OPEN ATMOSPHERE) DATE 5/29/68

RUNNING TIME, HOURS	52.3	53.3	54.3	55.3	55.9	56.5						
SPEED, RPM	14	14	14	14	14							
AIR MANIFOLD PRESS. (PSI)	106	106	106	106	106	STOP: TEST COMPLETED						
BEARING CAVITY PRESS. (PSI)	6	6	6	6	6							
SEAL CAVITY PRESS. (PSI)	111	111	111	111	111							
HOT AIR FLOW (SCFM)	45	45	45	45	45							
TEST OIL FLOW (GPM)	2	2	2	2	2							
TOTAL SEAL LEAKAGE (SCFM)	6.0	6.1	6.0	6.4	5.5							
TEST BEARING OUTER RING (°F)	505	500	500	500	500							
TEST BEARING INNER RING (°F)	510	500	500	495	495							
ROLLER BEARING OUTER RING (°F)	415	410	410	410	410							
OIL SEAL HOUSING (°F)	—	—	—	—	—							
AIR SEAL HOUSING (°F)	880	885	890	885	885							
TEST BEARING HOUSING (°F)	425	415	430	430	430							
ROLLER BEARING HOUSING (°F)	425	415	420	420	420							
AIR SEAL BELLOWS (°F)	—	—	—	—	—							
HOT AIR IN MANIFOLD (°F)	1150	1150	1155	1155	1155							
OIL INLET (°F)	390	385	390	39	390							
OIL OUTLET (°F)	—	—	—	—	—							

WB49 459980H (II)

TEST BEARING # 267/07

OIL USED MOBIL XRM 109F + 10 o/o BY WGT. KENDALL HEAVY RESIN 0839 DATE 3-7-68

Running Time, Hours	2.6	2.8	3.2	3.7	4.2	5.0	5.8	6.6	7.6	8.6	9.6	10.6
Speed, RPM		14			14	14	14	14	14	14	14	14
Air Manifold Press. (psi)		106			106	106	106	106	106	106	106	106
Bearing Cavity Press. (psi)		6			6	6	6	6	6-7	6-7	6-7	6-7
Seal Cavity Press. (psi)		111			111	111	111	111	111	111	111	111
Hot Air Flow (SCFM)		30			33	36	36	36	36	36	36	36
Test Oil Flow (GPM)		1			1	1	1	1	1	1	1	1
Total Seal Leakage (SCFM)		—			2.8	2.0	—	2	2	2	2	2
Test Bearing Outer Ring (°F)	TEST CONDITIONS:	640	STOP: RESTART	TEST CONDITIONS	640	640	640	640	640	640	645	645
Test Bearing Inner Ring (°F)		665			660	660	660	650	660	660	665	665
Roller Bearing Outer Ring (°F)		560			625	605	600	560	500	485	495	490
Oil Seal Housing (°F)		825			845	865	840	740	780	780	780	780
Air Seal Housing (°F)		955			865	890	850	740	925	950	960	950
Test Bearing Housing (°F)		720			610	630	560	420	480	480	480	480
Roller Bearing Housing (°F)		705			610	630	570	500	490	480	480	480
Air Seal Bellows (°F)		935			840	890	830	730	910	930	93	920
Hot Air in Manifold (°F)		—			—	—	—	—	—	—	—	—
Oil Inlet (°F)		500			500	510	500	470	500	490	500	500
Oil Outlet (°F)		505			540	535	520	570	470	460	470	470

← MALFUNCTION OF I.R. HIGH TEMPERATURE SHUT DOWN

During the first test period the majority of the total seal leakage was across the oil seal.

The oxygen content in the test bearing chamber was 0.014-0.02%.

TEST BEARING # 267107

OIL USED MOBILXRM109F + 10 o/o BY WGT. KENDALL HEAVY RESIN 0839 DATE 3/7-8/68

Running Time, Hours	11.4	12.9	13.1	14.5	14.6	15.4	16.4	17.4	18.9	20.7	21.7	22.7
Speed, RPM	14	14	STOP : RESTART	TEST CONDITIONS	14	14	14	14	14	14	14	14
Air Manifold Press. (psi)	106	106			106	106	106	106	106	106	106	106
Bearing Cavity Press. (psi)	6-7	6-7			6-8	6-8	6-8	6-8	6-8	6-8	6-8	6-8
Seal Cavity Press. (psi)	111	111			111	111	111	111	111	111	111	111
Hot Air Flow (scfm)	36	36			24	24	24	44	44	40	40	40
Test Oil Flow (gpm)	1	1			1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Total Seal Leakage (scfm)	2	2			2.8	2.8	2.7	2.5	2.7	2.5	2.6	2.5
Test Bearing Outer Ring (°F)	640	640			650	650	650	655	650	640	630	650
Test Bearing Inner Ring (°F)	660	660			660	690	655	690	675	670	670	675
Roller Bearing Outer Ring (°F)	490	490			525	520	500	528	525	525	520	510
Oil Seal Housing (°F)	780	770			690	715	715	760	760	770	760	770
Air Seal Housing (°F)	945	940			820	870	860	945	950	950	945	950
Test Bearing Housing (°F)	480	480			480	480	480	480	480	490	480	490
Roller Bearing Housing (°F)	480	480			475	475	480	480	510	510	500	510
Air Seal Bellows (°F)	930	920			820	860	855	920	925	920	900	910
Hot Air in Manifold (°F)	—	—			—	—	—	—	—	—	—	—
Oil Inlet (°F)	500	500			500	490	490	490	490	500	490	500
Oil Outlet (°F)	470	470			470	465	470	470	470	480	470	475

↳ END OF FIRST TEST PERIOD

During the 2nd 10-hour test period the majority of the total seal leakage for the first 5 hours was across the oil seal and approximately equal between the oil and the air seal for the last 5 hours.
The oxygen content in the test bearing chamber was 0.015-0.054%.

TEST BEARING # 267107

OIL USED MOBIL XRM109F 10 % BY WGT. KENDALL HEAVY RESIN 0839 DATE 3/8-12/68

RUNNING TIME, HOURS	24.2	24.5	25.2	25.5	26.2	27.2	28.2	28.7	29.2	30.2	31.2	32.2
SPEED, RPM	14	STOP: RESTART	TEST CONDITIONS:	14	14	14	14	MOMENTARY INCREASE IN TOTAL SEAL LEAKAGE	14	14	14	14
AIR MANIFOLD PRESS. (PSI)	106			106	106	106	106		106	106	106	106
BEARING CAVITY PRESS. (PSI)	6-8			6	6	6	6		6	6	6	6
SEAL CAVITY PRESS. (PSI)	111			111	111	111	111		111	111	111	111
HOT AIR FLOW (SCFM)	40			50	45	48	48		48	48	48	48
TEST OIL FLOW (GPM)	1.25			1.25	1.25	1.25	1.25		1.25	1.25	1.25	1.25
TOTAL SEAL LEAKAGE (SCFM)	2.5			2.4	2.5	2	2		2	1.7	1.8	1.8
TEST BEARING OUTER RING (°F)	640			650	650	650	650		650	650	655	660
TEST BEARING INNER RING (°F)	660			680	680	672	680		670	670	670	680
ROLLER BEARING OUTER RING (°F)	480			565	560	585	605		585	610	620	620
OIL SEAL HOUSING (°F)	755			830	840	830	835		820	825	825	820
AIR SEAL HOUSING (°F)	940			1000	1000	1005	1010		1005	1005	1010	1010
TEST BEARING HOUSING (°F)	480			675	690	670	675		665	670	670	645
ROLLER BEARING HOUSING (°F)	500			615	640	640	645		650	650	650	640
AIR SEAL BELLOWS (°F)	910			980	990	985	990		980	980	985	985
HOT AIR IN MANIFOLD (°F)	—			—	—	—	—		—	—	—	—
OIL INLET (°F)	500			515	500	500	500		500	500	500	500
OIL OUTLET (°F)	465			500	490	490	495		495	495	500	490

↳ END OF SECOND TEST PERIOD

During the third 10-hour test period the majority of the total seal leakage was across the oil seal.

The oxygen content in the test bearing chamber was 0.01%.

TEST BEARING # 267107 [WB49 Bearing, 459980H (Series II)]

OIL USED **MOBIL XRM109F + 10 o/o BY WGT. KENDALL HEAVY RESIN 0839** DATE 3/12-26/68

RUNNING TIME, HOURS	33.2	34.2	34.9	35.2	38.1	39.1	39.9	41.2				
SPEED, RPM	14	14	14				14					
AIR MANIFOLD PRESS. (PSI)	106	106	106				106					
BEARING CAVITY PRESS. (PSI)	6	6	6				6					
SEAL CAVITY PRESS. (PSI)	111	111	111				111					
HOT AIR FLOW (SCFM)	49	50	50				55					
TEST OIL FLOW (GPM)	1.25	1.25	1.25				1.25					
TOTAL SEAL LEAKAGE (SCFM)	1.8.	1.8	1.9				9					
TEST BEARING OUTER RING (°F)	650	650	650	STOP: RESTART	TEST CONDITIONS	STOP: RESART	655	TEST TERMINATED				
TEST BEARING INNER RING (°F)	670	670	670				655					
ROLLER BEARING OUTER RING (°F)	550	550	550				530					
OIL SEAL HOUSING (°F)	820	820	810				685					
AIR SEAL HOUSING (°F)	1010	1005	990				935					
TEST BEARING HOUSING (°F)	640	650	650				595					
ROLLER BEARING HOUSING (°F)	640	640	640				580					
AIR SEAL BELLOWS (°F)	980	980	980				820					
HOT AIR IN MANIFOLD (°F)	—	—	—				—					
OIL INLET (°F)	500	500	500				500					
OIL OUTLET (°F)	480	480	480				475					

→ OIL SEAL LIFT OFF (41.2)

→ TEST CONDITIONS (39.9)

→ I HSG. HEATERS AND AIR SEAL REPLACED (39.1)

→ END OF THIRD TEST PERIOD (35.2)

AL67T016

TEST BEARING # 267110 [WB49 Bearing, 459980H (Series II)]

OIL USED MOBIL XRM 109F, MOBIL XRM 127B + 10 % BY WGT. KENDALL HEAVY RESIN 0839 DATE 6/10-13/68

Running Time, Hours	3.7	4.8	5.8	6.8	7.8	8.8	9.8	10.8	11.8	12.8	13.8	14.8
Speed, RPM		14	14	14	14	14	14	14	14	14	14	—
Air Manifold Press. (psi)	STOP: RESTART I HSG HEATERS BLEW	106	106	106	106	106	106	106	106	106	106	STOP: RESTART END OF TEST PERIOD
Bearing Cavity Press. (psi)		6-7	6-7	6-7	6-7	6-7	6-7	6-7	6-7	6-7	6-7	
Seal Cavity Press. (psi)		111	111	111	111	111	111	111	111	111	111	
Hot Air Flow (SCFM)		46	46	46	41	43	43	43	43	43	43	
Test Oil Flow (GPM)		2	2	2	2	2	2	2	2	2	2	
Total Seal Leakage (SCFM)		11.3	10.2	10.2	9.7	9.4	11.3	9.3	11.7	10	9.3	
Test Bearing Outer Ring (°F)		630	640	650	650	650	650	650	650	650	650	
Test Bearing Inner Ring (°F)		630	640	640	650	650	650	650	640	650	650	
Roller Bearing Outer Ring (°F)		540	570	570	570	560	570	570	570	560	560	
Oil Seal Housing (°F)		—	—	—	—	—	—	—	—	—	—	
Air Seal Housing (°F)		1000	980	970	975	980	980	980	980	980	980	
Test Bearing Housing (°F)		670	720	725	735	730	730	720	700	690	690	
Roller Bearing Housing (°F)		625	680	690	700	700	700	700	690	685	690	
Air Seal Bellows (°F)		835	800	790	800	800	800	800	800	800	800	
Hot Air in Manifold (°F)		1190	1200	1200	1200	1200	1200	1200	1190	1200	1195	
Oil Inlet (°F)		500	510	515	530	530	530	530	525	525	530	
Oil Outlet (°F)		530	520	520	550	555	550	550	550	550	545	

↳ TEST CONDITIONS

TEST BEARING # 267110

OIL USED MOBIL XRM 109F, MOBIL XRM127B + 10% BY WGT. KENDALL HEAVY RESIN 0839 DATE 6/14/68

Running Time, Hours	15.6	16.6	17.7	18.7	19.7	20.7	21.7	22.7	23.7	24.7	25.7	26.6
Speed, RPM	14	14	14	14	14	14	14	14	14	14	STOP: RESTART END OF TEST PERIOD	14
Air Manifold Press. (psi)	106	106	106	106	106	106	106	106	106	106		106
Bearing Cavity Press. (psi)	6-7	6-7	6-7	6-7	6-7	6-7	6-7	6-7	6-7	6-7		6-7
Seal Cavity Press. (psi)	111	111	111	111	111	111	111	111	111	111		111
Hot Air Flow (SCFM)	40	40	40	40	40	48	48	48	48	48		46
Test Oil Flow (GPM)	2	2	2	2	2	2	2	2	2	2		2
Total Seal Leakage (SCFM)	10.2	9.2	9.9	9.3	8.9	10.6	10.6	9.5	10.6	10.4		12.2
Test Bearing Outer Ring (°F)	640	650	645	645	630	640	640	640	640	640		640
Test Bearing Inner Ring (°F)	620	640	645	650	640	640	650	650	640	640		630
Roller Bearing Outer Ring (°F)	545	555	565	565	555	560	555	560	560	560		530
Oil Seal Housing (°F)	—	—	—	—	—	—	—	—	—	—		—
Air Seal Housing (°F)	950	970	975	975	875	990	990	995	995	995		965
Test Bearing Housing (°F)	670	715	715	705	700	700	705	705	705	690		620
Roller Bearing Housing (°F)	620	—	—	—	—	—	—	—	—	—		—
Air Seal Bellows (°F)	770	800	800	800	800	815	820	820	820	820		790
Hot Air in Manifold (°F)	1180	1190	1190	1190	1190	1200	1200	1200	1200	1200		1190
Oil Inlet (°F)	530	530	530	530	530	525	520	520	520	520		515
Oil Outlet (°F)	520	560	550	555	535	545	545	545	545	545		520

TEST CONDITIONS

The majority of the total seal leakage was across the oil seal.

The oxygen content in the test bearing chamber was 0.011%.

TEST BEARING # 267110

OIL USED MOBIL XRM109F, MOBIL XRM127B + 10 o/o BY WGT. KENDALL HEAVY RESIN 0839

DATE 6/14-17/68

RUNNING TIME, HOURS	27.6	28.6	29.6	30.6	31.6	32.6	33.6	34.6	35.6	36.6	36.7	37.5
SPEED, RPM	14	14	14	14	14	14	14	14	14	14		14
AIR MANIFOLD PRESS. (PSI)	106	106	106	106	106	106	106	106	106	106		106
BEARING CAVITY PRESS. (PSI)	6-7	6-7	6-7	6-7	6-7	6-7	6-7	6-7	6-7	6-7		6-7
SEAL CAVITY PRESS. (PSI)	111	111	111	111	111	111	111	111	111	111		111
HOT AIR FLOW (SCFM)	46	46	46	46	46	46	46	42	44	45		52
TEST OIL FLOW (GPM)	2	2	2	2	2	2	2	2	2	2		2
TOTAL SEAL LEAKAGE (SCFM)	12.5	11.5	10.6	11.9	10.8	12.8	13.6	10.6	11.1	12.3		8.5
TEST BEARING OUTER RING (°F)	640	640	640	640	650	650	650	650	650	660		640
TEST BEARING INNER RING (°F)	640	630	630	640	650	640	640	650	650	650	STOP: END OF TEST PERIOD RESTART	620
ROLLER BEARING OUTER RING (°F)	550	550	550	550	560	555	560	560	560	560		540
OIL SEAL HOUSING (°F)	—	—	—	—	—	—	—	—	—	—		—
AIR SEAL HOUSING (°F)	985	970	970	970	980	985	975	970	970	830		1010
TEST BEARING HOUSING (°F)	690	690	690	690	700	700	705	710	700	710		685
ROLLER BEARING HOUSING (°F)	560	570	570	565	560	560	560	565	570	560		540
AIR SEAL BELLOWS (°F)	800	790	790	790	790	790	790	780	790	670		840
HOT AIR IN MANIFOLD (°F)	1210	1200	1190	1200	1200	1205	1200	1200	1200	1150		1200
OIL INLET (°F)	515	520	520	520	525	520	520	520	530	530		520
OIL OUTLET (°F)	540	540	540	540	545	540	545	545	550	550		530

TEST CONDITIONS

The majority of the total seal leakage was across the oil seal.

The oxygen content in the test bearing chamber was 0.011%.

TEST BEARING # 267110

OIL USED MOBIL XRM 109F, MOBIL XRM 127B + 10 % BY WGT. KENDALL HEAVY RESIN 0839 DATE 6/17-18/68

RUNNING TIME, HOURS	38.5	39.5	40.5	41.5	42.5	43.4	43.8	44.8	45.8	46.8	47.8	48.8
SPEED, RPM	14	14	14	14	14	STOP: RESTART — BROKEN N_2 LINE	14	14	14	14	14	14
AIR MANIFOLD PRESS. (PSI)	106	106	106	106	106		106	106	106	106	106	106
BEARING CAVITY PRESS. (PSI)	6-7	6-7	6-7	6-7	6-7		6-7	6-7	6-7	6-7	6-7	6-7
SEAL CAVITY PRESS. (PSI)	111	111	111	111	111		111	111	111	111	111	111
HOT AIR FLOW (SCFM)	46	46	46	46	46		45	45	45	45	45	45
TEST OIL FLOW (GPM)	2	2	2	2	2		2	1.75	1.75	1.75	1.75	1.75
TOTAL SEAL LEAKAGE (SCFM)	11.9	11.9	10.6	11.4	10		23	24	23	23	30	30
TEST BEARING OUTER RING (°F)	645	650	650	650	650		650	660	650	650	650	640
TEST BEARING INNER RING (°F)	645	650	650	650	650		640	640	635	635	640	640
ROLLER BEARING OUTER RING (°F)	550	550	550	555	550		515	550	570	545	555	540
OIL SEAL HOUSING (°F)	—	—	—	—	—		—	—	—	—	—	—
AIR SEAL HOUSING (°F)	1000	995	1000	1000	1000		870	910	915	910	925	905
TEST BEARING HOUSING (°F)	680	685	690	690	690		600	620	630	610	620	610
ROLLER BEARING HOUSING (°F)	560	565	565	565	565		530	590	610	590	600	530
AIR SEAL BELLOWS (°F)	815	810	810	815	810		650	685	705	690	705	680
HOT AIR IN MANIFOLD (°F)	1200	1200	1200	1200	1200		1130	1170	1170	1180	1170	1170
OIL INLET (°F)	520	520	520	520	520		514	540	515	525	525	500
OIL OUTLET (°F)	540	540	540	540	540		490	530	545	525	535	515

↳ TEST CONDITIONS

TEST BEARING # 267110

OIL USED . MOBIL XRM109F, MOBIL XRM127B, +10 % BY WGT KENDALL HEAVY RESIN 0839 DATE 6/18/68

Running Time, Hours	49.8	50.8	51.8	52.8	53.8	54.7	55.7	56.7	57.7	58.6	58.7	
Speed, RPM	14	14	14	14	STOP: RESTART END OF TEST PERIOD	14	14	14	14	14	TEST COMPLETED	
Air Manifold Press. (psi)	106	106	106	106		106	106	106	106	106		
Bearing Cavity Press. (psi)	6-8	6-8	6-8	6-8		6-7	6-7	6-7	6-7	6-7		
Seal Cavity Press. (psi)	111	111	126	111		111	111	111	111	111		
Hot Air Flow (SCFM)	52	46	46	46		48	46	46	46	46		
Test Oil Flow (GPM)	1.75	1.75	1.75	1.75		1.75	1.75	1.75	1.75	1.75		
Total Seal Leakage (SCFM)	19.1	24.2	19.5	22.9		22.5	21.6	21.4	21.6	19.2		
Test Bearing Outer Ring (°F)	650	650	650	650		650	650	650	650	650		
Test Bearing Inner Ring (°F)	645	660	650	660		650	650	650	650	650		
Roller Bearing Outer Ring (°F)	560	560	560	560		510	515	520	530	500		
Oil Seal Housing (°F)	—	—	—	—		—	—	—	—	—		
Air Seal Housing (°F)	980	930	1005	970		950	960	960	960	960		
Test Bearing Housing (°F)	645	660	675	680		640	655	660	660	660		
Roller Bearing Housing (°F)	560	570	585	565		535	550	550	550	550		
Air Seal Bellows (°F)	755	705	790	755		730	740	740	740	740		
Hot Air in Manifold (°F)	1200	1180	1200	1200		1195	1200	1200	1200	1200		
Oil Inlet (°F)	520	520	520	520		505	505	505	505	505		
Oil Outlet (°F)	540	540	540	545		520	520	525	525	530		

↳ TEST CONDITIONS

The majority of the total seal leakage was across the oil seal.

The oxygen content in the test bearing chamber was 0.01%.

WB49 80H (II)

TEST BEARING # 267105

OIL USED MOBIL XRM-177F

DATE 2/6/68

Running Time, Hours	0.3	1.3	1.4	1.6	2.2	2.7	3.2	3.8	4.7	5.8	7.0	7.9
Speed, RPM	STOP: OIL LEAK AT OUTER RACE THERMOCOUPLE FITTING	TEST CONDITIONS	14	STOP: MALFUNCTION IN THE AUTOMATIC TORQUE SHUT DOWN	14	14	14	14	14	14	14	STOP: PULLEY LOCK RING FAILED
Air Manifold Press. (psi)			106		106	106	106	106	106	106	106	
Bearing Cavity Press. (psi)			6-7		6-7	6-7	6-7	6-7	6-7	6-7	6-7	
Seal Cavity Press. (psi)			111		111	111	111	111	111	111	111	
Hot Air Flow (SCFM)			40		39	39	39	39	39	39	39	
Test Oil Flow (GPM)			2.0		2.0	2.0	2.0	2.0	2.0	2.0	2.0	
Total Seal Leakage (SCFM)			2.8		—	—	1.9	2.4	—	1.7	1.7	
Test Bearing Outer Ring (°F)			600		590	590	595	590	590	600	600	
Test Bearing Inner Ring (°F)			—		600	603	603	610	610	610	620	
Roller Bearing Outer Ring (°F)			—			545	550	556	540	555	550	
Oil Seal Housing (°F)			675		740	740	748	755	750	750	750	
Air Seal Housing (°F)			825		867	867	900	922	915	915	915	
Test Bearing Housing (°F)			620		630	640	640	640	640	640	645	
Roller Bearing Housing (°F)			590		605	615	615	620	620	600	615	
Air Seal Bellows (°F)			—		—	—	—	—	—	—	—	
Hot Air in Manifold (°F)			1160		1160	1160	1150	1150	1150	1140	1140	
Oil Inlet (°F)			510		520	525	525	520	520	530	525	
Oil Outlet (°F)			—		—	—	—	—	—	—	—	

↑ TEST CONDITIONS

The majority of the total seal leakage was across the air seal.
The oxygen content in the test bearing chamber was .034-.076%.

TEST BEARING # 267105

OIL USED MOBIL XRM-177F

DATE 2/7-8/68

RUNNING TIME, HOURS	8.6	8.9	9.7	10.5	11.5	12.5	13.5	14.0	15.0	16.0	17.0	17.5
SPEED, RPM	14	14	14	14	14	14	14	14	14	14	14	14
AIR MANIFOLD PRESS. (PSI)	106	106	106	106	106	106	106	106	106	106	106	106
BEARING CAVITY PRESS. (PSI)	6-7	6-7	6-7	6-7	6-7	6-7	6-7	6-7	6-7	6-7	6-7	6-7
SEAL CAVITY PRESS. (PSI)	111	111	111	111	111	111	111	111	111	111	111	111
HOT AIR FLOW (SCFM)	37	36	36	36	36	33	33	35	33	33	33	33
TEST OIL FLOW (GPM)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
TOTAL SEAL LEAKAGE (SCFM)	1.3	2.1	1.8	1.7	2.1	2.5	1.8	2.4	2.2	6.4	7.2	7.7
TEST BEARING OUTER RING (°F)	580	590	600	600	600	600	590	600	600	600	610	610
TEST BEARING INNER RING (°F)	600	610	620	620	620	620	605	620	620	620	620	620
ROLLER BEARING OUTER RING (°F)	525	540	550	550	550	550	530	540	540	520	515	510
OIL SEAL HOUSING (°F)	720	715	720	725	730	730	720	730	700	675	670	665
AIR SEAL HOUSING (°F)	900	915	910	910	920	910	880	910	875	870	865	860
TEST BEARING HOUSING (°F)	630	650	660	655	655	650	635	640	625	620	620	620
ROLLER BEARING HOUSING (°F)	590	610	620	625	630	620	610	610	590	585	580	580
AIR SEAL BELLOWS (°F)	—	—	—	—	—	—	—	—	—	—	—	—
HOT AIR IN MANIFOLD (°F)	1080	1080	1080	1080	1090	1090	1080	1080	1050	1060	1055	1050
OIL INLET (°F)	515	520	530	530	530	530	530	525	540	540	545	545
OIL OUTLET (°F)	490	500	510	510	510	510	500	510	470	490	480	480

TEST BEARING # 267105

OIL USED MOBIL XRM-177F

DATE 2/8/68

RUNNING TIME, HOURS	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	21.55			
SPEED, RPM	14	14	14	14	14	14	14	14	STOP: OIL SEAL LIFT OFF BLEW / TEST OIL OUT VENT. ROLLER BRG. FAIL-ED			
AIR MANIFOLD PRESS. (PSI)	107	107	107	107	107	107	107	106				
BEARING CAVITY PRESS. (PSI)	6-7	6-7	6-7	6-7	6-7	6-7	6-7	11				
SEAL CAVITY PRESS. (PSI)	111	111	111	111	112	111	111	111				
HOT AIR FLOW (SCFM)	33	33	38	39	37	38	37	39				
TEST OIL FLOW (GPM)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	0-3				
TOTAL SEAL LEAKAGE (SCFM)	9.8	6.4	9.8	15.7	14.4	14.9	8.5	20.4				
TEST BEARING OUTER RING (°F)	600	600	615	610	600	605	620	650				
TEST BEARING INNER RING (°F)	615	615	620	610	610	615	625	650				
ROLLER BEARING OUTER RING (°F)	510	510	505	505	505	510	520	520				
OIL SEAL HOUSING (°F)	650	650	590	570	580	570	590	580				
AIR SEAL HOUSING (°F)	860	865	855	845	845	850	850	865				
TEST BEARING HOUSING (°F)	615	620	615	595	595	600	605	610				
ROLLER BEARING HOUSING (°F)	580	580	570	560	560	570	570	560				
AIR SEAL BELLOWS (°F)	—	—	—	—	—	—	—	—				
HOT AIR IN MANIFOLD (°F)	1055	1055	1070	1070	1070	1070	1070	1040				
OIL INLET (°F)	545	540	545	535	540	540	555	560				
OIL OUTLET (°F)	—	—	—	—	—	—	—	—				

TEST BEARING # 267111 [M-50 Steel Bearing, 4599816 (Series 1)]

OIL USED MOBIL XRM 111F

DATE 7/31 - 8/1/68

Running Time, Hours	0.2	1.7	2.0	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1
Speed, RPM	STOP: OIL SEAL HOUSING "O" RING LEAKING OIL	STOP: OIL BY PASS VALVE STUCK	STOP: RIG SEAL LEAKING BADLY	14	14	14	14	14	14	14	14	14
Air Manifold Press. (psi)				107	107	107	101	107	107	107	107	107
Bearing Cavity Press. (psi)				6-7	6-7	6-7	6	6-7	6-7	6-7	6-7	6-7
Seal Cavity Press. (psi)				111	111	109	113	110	110	110	110	110
Hot Air Flow (scfm)				50	50	35	44	40	40	40	40	40
Test Oil Flow (gpm)				1.5	1.0	1.0	1.5	—	—	—	—	—
Total Seal Leakage (scfm)				19.5	21.2	4.2	4.7	8.3	8.3	9.0	8.1	9.0
Test Bearing Outer Ring (°F)				645	670	645	640	650	650	650	640	640
Test Bearing Inner Ring (°F)				650	640	680	655	650	650	650	640	640
Roller Bearing Outer Ring (°F)				585	620	580	540	640	620	620	620	620
Oil Seal Housing (°F)				—	—	—	—	—	—	—	—	—
Air Seal Housing (°F)				960	985	960	975	940	1005	970	970	970
Test Bearing Housing (°F)				655	665	660	650	650	620	570	580	570
Roller Bearing Housing (°F)				560	570	560	550	570	570	570	550	550
Air Seal Bellows (°F)				—	—	—	—	—	—	—	—	—
Hot Air in Manifold (°F)				1190	1200	1190	1100	1100	1100	1100	1100	1100
Oil Inlet (°F)				490	490	490	490	500	510	520	520	520
Oil Outlet (°F)				568	580	565	550	580	585	570	570	570

← TEST CONDITIONS

The majority of the total seal leakage was across the oil seal.
The oxygen content in the test bearing chamber was 0.009-0.49%.

TEST BEARING # 267111 [M-50 Steel Bearing, 459981G (Series I)]

OIL USED MOBIL XRM 177F

DATE 8/1-13/68

Running Time, Hours	13.1	14.1	14.6	15.6	16.6	16.9	19.8	21.8	22.8	238	248	258
Speed, RPM	14	STOP. END OF TEST PERIOD	14	14	14	STOP. TEST CONDITIONS NEVER REACHED. OIL SEAL WAS REPLACED	AFTER RESTARTING AN OIL LINE BROKE	14	14	14	14	14
Air Manifold Press. (psi)	107		106	106	106			106	106	106	106	106
Bearing Cavity Press. (psi)	6-7		8	7-8	10			6	6-7	6-7	6-7	6-7
Seal Cavity Press. (psi)	110		111	111	111			111	111	111	111	111
Hot Air Flow (scfm)	40		48	42	42			40	39	40	39	45
Test Oil Flow (gpm)	1.5		1.25	1.25	1.25			1.0	1.0	1.0	2.0	2.0
Total Seal Leakage (scfm)	9.3		23.8	29.5	48.5			11.0	8.5	10.2	10.6	12.3
Test Bearing Outer Ring (°F)	640		600	620	600			640	650	650	650	660
Test Bearing Inner Ring (°F)	640		600	620	600			640	650	680	660	660
Roller Bearing Outer Ring (°F)	620		550	600	600			645	615	600	600	600
Oil Seal Housing (°F)	—		—	—	—			—	—	—	—	—
Air Seal Housing (°F)	975		885	860	850			990	950	980	1000	1000
Test Bearing Housing (°F)	570		460	590	560			740	750	720	740	770
Roller Bearing Housing (°F)	545		410	510	520			600	590	580	585	600
Air Seal Bellows (°F)	—		—	—	—			750	745	740	740	720
Hot Air in Manifold (°F)	1100		1180	1190	1190			1360	1230	1320	1360	1350
Oil Inlet (°F)	520		470	500	490			510	500	510	520	530
Oil Outlet (°F)	570		500	540	540			575	560	540	575	570

← TEST CONDITIONS (21.8)

← WRONG TYPE CARBON USED USG 2925 INSTEAD OF CDJ83 (16.9)

The majority of the total seal leakage from 14.6 to 16.9 hours was across the oil seal. The oxygen content during this time in the test bearing chamber was 0.009 to 0.6%.

TEST BEARING # 267111

OIL USED MOBIL XRM 177F

DATE 8/13-14/68

Running Time, Hours	26.8	27.8	28.8	29.8	30.6	31.6	32.6	33.6	34.6	35.6	36.6	37.6
Speed, RPM	14	14	14	14		14	14	14	14	14	14	14
Air Manifold Press. (psi)	106	106	106	106		106	106	106	106	106	106	106
Bearing Cavity Press. (psi)	6-7	6-7	6-7	6-7		6	6	6	6	6	6	6
Seal Cavity Press. (psi)	111	111	111	111	STOP: SHEAR PINS BROKE	111	111	111	111	111	111	111
Hot Air Flow (scfm)	45	44	42	48		46	46	46	46	46	47	47
Test Oil Flow (gpm)	2.0	2.0	1.75	1.75		2.0	2.0	2.0	2.0	2.0	2.0	2.0
Total Seal Leakage (scfm)	10.6	9.8	11.9	12.7		11.0	10.2	11.0	11.0	11.9	9.8	11.9
Test Bearing Outer Ring (°F)	640	640	640	660		640	645	650	650	650	650	645
Test Bearing Inner Ring (°F)	650	—	650	680		650	670	660	670	—	650	645
Roller Bearing Outer Ring (°F)	590	565	575	600		600	590	580	600	600	605	595
Oil Seal Housing (°F)	—	—	—	—		—	—	—	—	—	—	—
Air Seal Housing (°F)	1000	1000	970	980		960	1000	1030	1030	1040	1050	1050
Test Bearing Housing (°F)	680	580	575	580		490	530	525	525	550	565	540
Roller Bearing Housing (°F)	530	480	470	490		490	490	480	480	505	505	495
Air Seal Bellows (°F)	720	740	720	740		720	730	735	740	765	765	760
Hot Air in Manifold (°F)	1350	1350	1360	1350		1200	1200	1200	1200	1200	1200	1200
Oil Inlet (°F)	530	520	520	530		510	520	520	520	525	525	525
Oil Outlet (°F)	550	530	540	560		550	555	555	550	570	560	560

TEST CONDITIONS

TEST BEARING # 267111

OIL USED MOBIL XRM-177F

DATE 8/14/68

Running Time, Hours	38.6	39.6	40.6	41.6	43.3	44.3	45.3	46.3	47.3	48.3	49.3	50.3
Speed, RPM	14	14	14	14	14	14	14	14	14	14	14	14
Air Manifold Press. (psi)	106	106	106	106	106	106	106	106	106	106	106	106
Bearing Cavity Press. (psi)	6	6	6	6	6	6	7	7	7-8	7	7	7
Seal Cavity Press. (psi)	111	111	111	111	111	111	111	111	111	111	111	111
Hot Air Flow (scfm)	46	47	46	47	42	40	47	48	47	47	48	47
Test Oil Flow (gpm)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Total Seal Leakage (scfm)	10.2	9.8	11.5	11.5	4.2	4.2	3.8	4.1	4.2	4.2	4.3	4.3
Test Bearing Outer Ring (°F)	650	645	655	655	650	660	650	650	650	650	650	650
Test Bearing Inner Ring (°F)	650	645	655	655	650	660	650	650	650	650	650	650
Roller Bearing Outer Ring (°F)	610	595	605	610	550	580	555	555	550	540	565	565
Oil Seal Housing (°F)	—	—	—	—	—	—	—	—	—	—	—	—
Air Seal Housing (°F)	1050	1060	1040	1035	1050	1050	1055	1060	1060	1050	1060	1075
Test Bearing Housing (°F)	550	545	550	555	530	540	540	550	540	535	545	600
Roller Bearing Housing (°F)	505	500	505	510	530	500	480	475	470	470	475	480
Air Seal Bellows (°F)	770	760	770	770	880	890	875	880	880	875	880	880
Hot Air in Manifold (°F)	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Oil Inlet (°F)	530	530	530	530	525	520	490	495	490	490	500	500
Oil Outlet (°F)	570	560	570	570	570	590	560	565	570	565	590	580

TEST CONDITIONS (arrow to 43.3 column)

END OF TEST PERIOD (arrow to 41.6 column)

TEST BEARING # 267111

OIL USED MOBIL XRM 177F

DATE 8/14-16/68

Running Time, Hours	51.3	52.3	53.3	54.6	55.6	56.6	57.6	58.6	59.6	60.6	61.6	62.4
Speed, RPM	14	14	STOP: END OF TEST PERIOD	14	14	14	14	14	14	14	14	STOP: OIL SUMP HEATER FAILED!
Air Manifold Press. (psi)	106	106		106	106	106	106	106	106	106	106	
Bearing Cavity Press. (psi)	7	7		6	6	6	6	6	6	6	6	
Seal Cavity Press. (psi)	111	111		111	111	111	111	111	111	111	111	
Hot Air Flow (SCFM)	48	48		46	44	44	44	44	44	44	44	
Test Oil Flow (GPM)	2.0	2.0		2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	
Total Seal Leakage (SCFM)	4.3	4.2		6.1	3.6	3.8	3.8	3.6	4.3	3.6	4.3	
Test Bearing Outer Ring (°F)	655	655		660	660	660	660	655	655	660	670	
Test Bearing Inner Ring (°F)	655	655		650	650	660	660	655	655	660	670	
Roller Bearing Outer Ring (°F)	560	570		550	570	580	580	560	570	570	575	
Oil Seal Housing (°F)	—	—		—	—	—	—	—	—	—	—	
Air Seal Housing (°F)	1060	1060		1040	1050	1050	1050	1050	1050	1050	1050	
Test Bearing Housing (°F)	545	555		530	550	550	550	530	550	550	565	
Roller Bearing Housing (°F)	480	485		460	460	500	500	490	490	490	500	
Air Seal Bellows (°F)	880	880		870	890	890	890	880	880	880	885	
Hot Air in Manifold (°F)	1200	1200		1200	1200	1200	1200	1200	1200	1200	1200	
Oil Inlet (°F)	510	520		500	500	500	500	500	500	500	500	
Oil Outlet (°F)	580	590		560	580	590	590	580	580	580	590	

TEST CONDITIONS (arrow pointing to the 54.6 column)

TEST BEARING # 267111

OIL USED MOBIL XRM177F

DATE 8/22/68

RUNNING TIME, HOURS	63.4	63.6	64.6	65.6	66.4	67.4	68.4	69.4	70.4	71.5	72.5	73.4
SPEED, RPM		14	14	14	14	14	14	14	14	14	14	14
AIR MANIFOLD PRESS. (PSI)		106	106	106	106	106	106	106	106	106	106	106
BEARING CAVITY PRESS. (PSI)		6	6	6	6	6	6	6	6	6	6	6
SEAL CAVITY PRESS. (PSI)		111	111	111	111	111	111	111	111	111	111	111
HOT AIR FLOW (SCFM)		50	52	50	50	50	52	50	50	50	50	50
TEST OIL FLOW (GPM)		1.5	1.5	1.5	1.5	1.5	1.75	1.75	1.75	1.75	1.75	1.75
TOTAL SEAL LEAKAGE (SCFM)		4.1	4.8	4.4	3.1	4.2	3.1	3.5	3.5	3.5	3.5	4.0
TEST BEARING OUTER RING (°F)		660	660	650	650	650	655	655	655	650	650	650
TEST BEARING INNER RING (°F)	TEST CONDITIONS	665	680	675	680	680	670	675	675	675	675	675
ROLLER BEARING OUTER RING (°F)		565	570	555	560	560	560	560	550	550	560	560
OIL SEAL HOUSING (°F)		—	—	—	—	—	—	—	—	—	—	—
AIR SEAL HOUSING (°F)		1030	1035	1030	1040	1040	1035	1040	1050	1065	1065	1065
TEST BEARING HOUSING (°F)		670	700	690	700	695	700	695	670	670	670	640
ROLLER BEARING HOUSING (°F)		550	555	550	555	555	560	555	550	550	560	560
AIR SEAL BELLOWS (°F)		—	900	890	910	910	905	905	915	930	930	930
HOT AIR IN MANIFOLD (°F)		—	—	—	—	—	—	—	—	1200	1200	1200
OIL INLET (°F)		500	505	495	495	495	495	490	490	490	490	490
OIL OUTLET (°F)		575	585	570	575	575	575	570	570	570	570	570

STOP: END OF TEST PERIOD (arrow to 73.4 column)

TEST BEARING # 267111

OIL USED MOBIL XRM-177F

DATE 8/23-29/68

RUNNING TIME, HOURS	74.4	75.3	76.4	77.5	78.5	79.5	80.5	81.8	81.3	82.9	83.3	83.4
SPEED, RPM	14		14	14	14	14	14		14	14		14
AIR MANIFOLD PRESS. (PSI)	106	STOP: OIL RETURN LINE SPLIT	106	106	106	106	106	COMPRESSOR SHUTDOWN	106	106	COMPRESSOR SHUTDOWN	106
BEARING CAVITY PRESS. (PSI)	6		6	6	6	6	6		6	6		6
SEAL CAVITY PRESS. (PSI)	111		111	111	111	111	111		111	111		111
HOT AIR FLOW (SCFM)	50		46	46	43	54	46		48	48		44
TEST OIL FLOW (GPM)	1.75		1.25	1.25	1.25	1.25	1.25		1.25	1.25		1.25
TOTAL SEAL LEAKAGE (SCFM)	4.4		3.8	3.0	3.9	4.2	3.2		—	4.6		4.6
TEST BEARING OUTER RING (°F)	650		640	640	640	650	650		640	660		640
TEST BEARING INNER RING (°F)	670		640	660	670	670	675		640	670		640
ROLLER BEARING OUTER RING (°F)	560		555	555	560	560	565		560	580		580
OIL SEAL HOUSING (°F)	—		—	—	—	—	—		—	—		—
AIR SEAL HOUSING (°F)	1030		1035	1030	1045	975	1005		865	975		975
TEST BEARING HOUSING (°F)	670		700	700	705	695	695		700	690		690
ROLLER BEARING HOUSING (°F)	550		555	555	560	560	565		550	560		560
AIR SEAL BELLOWS (°F)	—		850	850	860	865	840		700	840		840
HOT AIR IN MANIFOLD (°F)	1200		1150	1130	1190	1000	1100		1100	1100		1100
OIL INLET (°F)	500		500	500	500	500	500		500	515		515
OIL OUTLET (°F)	570		565	565	570	570	575		560	680		580

TEST CONDITIONS

The majority of the total seal leakage was across the oil seal. The oxygen content in the test bearing chamber was 0.008-0.01%.

TEST BEARING # 267111

OIL USED MOBIL XRM 177F

DATE 8/29-9/5/68

RUNNING TIME, HOURS	84.4	84.7	85.1	86.4	87.2	87.8	88.8	89.8	90.8	91.8	92.8	93.8
SPEED, RPM	14	COMPRESSOR SHUTDOWN	14	14	STOP: END OF TEST PERIOD	14	14	14	14	14	14	14
AIR MANIFOLD PRESS. (PSI)	106		106	106		106	106	106	106	106	106	106
BEARING CAVITY PRESS. (PSI)	6		6	6		6-7	6-7	6-7	6-7	6-7	6-7	6-7
SEAL CAVITY PRESS. (PSI)	111		111	111		111	111	111	111	111	111	111
HOT AIR FLOW (SCFM)	46		46	46		48	49	49	49	49	48	47
TEST OIL FLOW (GPM)	1.25		1.25	1.25		1.5	1.5	1.5	1.5	1.5	1.5	1.5
TOTAL SEAL LEAKAGE (SCFM)	3.8		4.1	3.8		9.3	9.2	7.7	6.8	8.3	7.6	6.0
TEST BEARING OUTER RING (°F)	650		650	660		650	650	650	650	650	650	650
TEST BEARING INNER RING (°F)	670		670	670		670	670	670	670	670	660	660
ROLLER BEARING OUTER RING (°F)	580		580	590		580	575	580	580	570	570	565
OIL SEAL HOUSING (°F)	—		—	—		—	—	—	—	—	—	—
AIR SEAL HOUSING (°F)	960		960	930		970	975	1005	1010	1010	1015	1000
TEST BEARING HOUSING (°F)	700		700	700		700	700	710	710	690	710	700
ROLLER BEARING HOUSING (°F)	550		550	570		520	520	530	530	520	520	520
AIR SEAL BELLOWS (°F)	830		830	830		780	800	840	840	840	840	820
HOT AIR IN MANIFOLD (°F)	1100		1100	1100		1200	1200	1200	1200	1200	1250	1250
OIL INLET (°F)	515		515	515		520	520	520	510	570	510	510
OIL OUTLET (°F)	580		580	590		580	570	570	570	560	570	570

TEST CONDITIONS (85.1 and 87.8)

TEST BEARING # 267111

OIL USED MOBIL XRM 177F

DATE 9/5/68

RUNNING TIME, HOURS	94.8	95.8	96.8	97.8	97.8	98.4	99.4	100.4	101.4	102.4	103.4	104.4
SPEED, RPM	14	14	14	14	STOP. END OF TEST PERIOD	14	14	14	14	14	14	14
AIR MANIFOLD PRESS. (PSI)	106	106	106	106		106	106	106	106	106	106	106
BEARING CAVITY PRESS. (PSI)	6-7	6-7	6-7	6-7		6-7	6-7	6-7	6-7	6-7	6-7	6-7
SEAL CAVITY PRESS. (PSI)	111	111	111	111		111	111	111	111	111	111	111
HOT AIR FLOW (SCFM)	48	47	48	47		40	44	44	44	44	46	46
TEST OIL FLOW (GPM)	1.5	1.5	1.5	1.5		1.0	2.0	2.0	2.0	2.0	2.0	2.0
TOTAL SEAL LEAKAGE (SCFM)	7.4	6.5	7.5	6.9		5.2	5.3	4.9	6.6	6.8	5.5	5.5
TEST BEARING OUTER RING (°F)	655	660	660	650		640	650	650	640	650	650	650
TEST BEARING INNER RING (°F)	660	660	665	665		650	650	650	650	650	650	650
ROLLER BEARING OUTER RING (°F)	565	560	560	565		540	580	580	570	580	580	570
OIL SEAL HOUSING (°F)	—	—	—	—		—	—	—	—	—	—	—
AIR SEAL HOUSING (°F)	1005	1005	1005	1010		965	1035	1030	1030	1050	1050	1050
TEST BEARING HOUSING (°F)	705	695	695	695		670	710	710	705	710	715	700
ROLLER BEARING HOUSING (°F)	520	515	520	520		520	550	550	550	550	550	560
AIR SEAL BELLOWS (°F)	830	830	830	830		790	850	890	840	855	855	860
HOT AIR IN MANIFOLD (°F)	1250	1250	1250	1250		1040	1120	1120	1100	1130	1130	1130
OIL INLET (°F)	510	510	510	510		500	520	510	510	505	510	510
OIL OUTLET (°F)	570	565	565	575		540	575	570	567	575	570	570

TEST CONDITIONS (arrow to 98.4 column)

The majority of the total seal leakage was across the oil seal.
The oxygen content in the test bearing chamber was 0.009-0.01%.

TEST BEARING # 267111

OIL USED MOBIL XRM 177F

DATE 9/5-6/68

Running Time, Hours	105.4	106.4	107.4	108.4	108.4	109.2	110.2	111.2	112.2	113.2	114.2	115.2
Speed, RPM	14	14	14	14	STOP: END OF TEST PERIOD	14	14	14	14	14	14	14
Air Manifold Press. (psi)	106	106	106	106		106	106	106	106	106	106	106
Bearing Cavity Press. (psi)	6-7	6-7	6-7	6-7		6-7	6-7	6-7	6-7	6-7	6.5	6.5
Seal Cavity Press. (psi)	111	111	111	111		111	111	111	111	111	111	111
Hot Air Flow (SCFM)	46	46	46	46		46	48	47	47	47	48	48
Test Oil Flow (GPM)	2.0	2.0	2.0	2.0		1.5	2.0	2.0	2.0	2.0	2.0	2.0
Total Seal Leakage (SCFM)	5.0	4.8	6.3	5.3		12.3	10.9	12.3	10.6	10.9	12.0	12.0
Test Bearing Outer Ring (°F)	650	650	650	650		640	640	640	645	650	650	640
Test Bearing Inner Ring (°F)	650	650	650	650		630	640	640	645	650	650	640
Roller Bearing Outer Ring (°F)	570	570	570	600		590	600	605	600	600	605	590
Oil Seal Housing (°F)	—	—	—	—		—	—	—	—	—	—	—
Air Seal Housing (°F)	1050	1050	1055	1045		930	970	970	975	970	965	970
Test Bearing Housing (°F)	710	710	710	710		640	690	695	710	705	710	710
Roller Bearing Housing (°F)	560	560	540	560		515	550	550	560	560	560	555
Air Seal Bellows (°F)	860	860	860	850		695	725	730	730	725	730	725
Hot Air in Manifold (°F)	1130	1130	1130	1130		1140	1100	1080	1100	1100	1090	—
Oil Inlet (°F)	510	510	510	510		510	510	510	510	510	510	510
Oil Outlet (°F)	570	560	560	560		560	575	580	565	575	580	570

← TEST CONDITIONS

The majority of the total seal leakage was across the oil seal.
The oxygen content in the test bearing chamber was 0.009-0.01%.

TEST BEARING # 267111

OIL USED MOBIL XRM177F

DATE 9/6/68

Running Time, Hours	116.2	117.2	118.2	119.2	119.2	119.9	120.9	121.9	122.9	123.9	124.9	125.9
Speed, RPM	14	14	14	14	STOP: END OF TEST PERIOD	14	14	14	14	14	14	14
Air Manifold Press. (psi)	106	106	106	106		106	106	106	106	106	106	106
Bearing Cavity Press. (psi)	6-8	6-8	6-8	6-8		5-7	5-7	5-7	5-7	5-7	5-7	5-7
Seal Cavity Press. (psi)	111	111	111	111		111	111	111	111	111	111	111
Hot Air Flow (SCFM)	48	48	48	48		42	42	42	42	42	42	42
Test Oil Flow (GPM)	1.5	1.5	1.0	1.0		1.0	1.0	1.0	1.0	1.0	1.0	1.0
Total Seal Leakage (SCFM)	10.3	9.7	11.5	10.3		12.3	10.6	10.6	10.0	9.5	9.5	9.5
Test Bearing Outer Ring (°F)	645	650	650	650		650	660	655	650	650	650	650
Test Bearing Inner Ring (°F)	650	650	650	650		670	670	670	670	670	670	670
Roller Bearing Outer Ring (°F)	600	605	605	600		615	615	600	600	590	595	595
Oil Seal Housing (°F)	—	—	—	—		—	—	—	—	—	—	—
Air Seal Housing (°F)	1000	1000	995	1000		970	970	970	975	975	970	970
Test Bearing Housing (°F)	710	710	710	710		710	710	700	700	700	700	700
Roller Bearing Housing (°F)	560	560	560	560		615	615	600	600	590	595	595
Air Seal Bellows (°F)	750	750	745	745		730	730	730	730	730	730	730
Hot Air in Manifold (°F)	1150	—	—	—		1100	1100	1100	1100	1100	1100	1100
Oil Inlet (°F)	510	520	510	510		510	515	510	510	510	510	510
Oil Outlet (°F)	580	580	580	575		590	580	580	570	570	570	570

TEST CONDITIONS

The majority of the total seal leakage was across the oil seal..
The oxygen content in the test bearing chamber was 0.009-0.01%.

TEST BEARING # 267111

OIL USED MOBIL XRM 177F

DATE 9/6-9/68

Running Time, Hours	126.9	127.9	128.9	129.9	129.9	130.4	131.4	132.4	133.4	134.4	135.4	136.4
Speed, RPM	14	14	14	14	STOP: END OF TEST PERIOD	14	14	14	14	14	14	14
Air Manifold Press. (psi)	106	106	106	106		106	106	106	106	106	106	106
Bearing Cavity Press. (psi)	5-7	6-7	6-7	6-7		6-7	6-7	6-7	6-7	5-6	5-6	5-6
Seal Cavity Press. (psi)	111	111	111	111		111	111	111	111	111	111	111
Hot Air Flow (SCFM)	42	47	46	46		43	44	43	43	43	43	43
Test Oil Flow (GPM)	1.0	1.0	1.5	1.5		1-1.5	1-1.5	1-1.5	1-1.5	1-1.5	1-1.5	1-1.5
Total Seal Leakage (SCFM)	10.6	9.8	12.6	10.4		12.4	12.7	10.2	11.2	10.2	11.2	11.4
Test Bearing Outer Ring (°F)	650	650	645	645		640	640	650	650	650	645	645
Test Bearing Inner Ring (°F)	670	660	650	650		640	650	665	665	665	660	660
Roller Bearing Outer Ring (°F)	595	610	600	600		590	595	600	600	600	600	600
Oil Seal Housing (°F)	—	—	—	—		—	—	—	—	—	—	—
Air Seal Housing (°F)	970	970	990	980		960	995	995	1000	1000	1000	990
Test Bearing Housing (°F)	700	710	710	710		670	720	710	710	710	710	710
Roller Bearing Housing (°F)	550	560	555	560		510	555	550	550	560	560	560
Air Seal Bellows (°F)	730	730	740	735		700	745	760	755	755	750	750
Hot Air in Manifold (°F)	1100	1100	1100	1100		1100	1100	1100	1100	1100	1100	1100
Oil Inlet (°F)	510	510	510	510		500	510	510	510	510	510	510
Oil Outlet (°F)	570	580	580	575		555	570	580	580	580	580	575

← TEST CONDITIONS (arrow to the 130.4 column)

The majority of the total seal leakage was across the oil seal.

The oxygen content in the test bearing chamber was 0.009-0.01%.

TEST BEARING # 267111

OIL USED MOBIL XRM 177F

DATE 9/9-10/68

Running Time, Hours	137.4	138.5	139.5	140.4		140.8	141.8	142.8	143.8	144.8	145.8	146.8
Speed, RPM	14	14	14	14		14	14	14	14	14	14	14
Air Manifold Press. (psi)	106	106	106	106		106	106	106	106	106	106	106
Bearing Cavity Press. (psi)	5-6	5-6	5-6	5-6	STOP: END OF TEST PERIOD	6	6.5	6.5	6.5	6.5	6.5	6.5
Seal Cavity Press. (psi)	111	111	111	111		111	111	111	111	111	111	111
Hot Air Flow (SCFM)	43	43	43	42		47	47	47	48	47	46	47
Test Oil Flow (GPM)	1-1.5	1-1.5	1-1.5	1-1.5		1.5	1.5	1.5	1.5	1.5	1.5	1.5
Total Seal Leakage (SCFM)	12.0	12.0	12.3	10.0		12.0	14.7	13.1	12.4	14.4	12.7	12.7
Test Bearing Outer Ring (°F)	650	650	650	650		640	660	660	645	650	655	650
Test Bearing Inner Ring (°F)	665	665	665	660		640	665	670	665	660	665	660
Roller Bearing Outer Ring (°F)	600	600	610	605		585	610	610	600	605	610	605
Oil Seal Housing (°F)	—	—	—	—		—	—	—	—	—	—	—
Air Seal Housing (°F)	995	995	990	995		985	985	995	995	995	990	995
Test Bearing Housing (°F)	710	690	655	655		550	650	650	665	670	670	680
Roller Bearing Housing (°F)	560	570	545	545		450	550	550	540	550	550	550
Air Seal Bellows (°F)	750	740	740	735		700	725	730	725	725	730	725
Hot Air in Manifold (°F)	1100	1100	1100	1100		1100	1100	1100	1350	1350	1350	1110
Oil Inlet (°F)	510	510	510	510		510	510	510	510	510	510	510
Oil Outlet (°F)	580	580	580	585		530	580	585	575	580	580	575

TEST CONDITIONS (arrow pointing to the 140.8 column)

TEST BEARING # 267111

OIL USED MOBIL XRM 177F

DATE 9/10-11/68

RUNNING TIME, HOURS	147.8	148.8	149.9	150.9	150.9	151.8	152.6	153.3	154.3	155.3	156.3	157.3
SPEED, RPM	14	14	14	14	STOP: END OF TEST PERIOD	14	STOP: OIL FITTING BROKEN	14	14	14	14	14
AIR MANIFOLD PRESS. (PSI)	106	106	106	106		106		106	106	106	106	106
BEARING CAVITY PRESS. (PSI)	6	6	6	6		6		6-7	6-7	6-7	6-7	6-7
SEAL CAVITY PRESS. (PSI)	111	111	111	111		111		111	111	111	111	111
HOT AIR FLOW (SCFM)	47	47	47	47		48		46	46	46	47	47
TEST OIL FLOW (GPM)	1.5	1.5	1.5	1.5		1.5		2.0	2.0	2.0	2.0	2.0
TOTAL SEAL LEAKAGE (SCFM)	12.4	11.3	11.0	12.3		8.9		11.0	12.7	13.6	12.6	12.2
TEST BEARING OUTER RING (°F)	650	650	655	655		650		650	650	650	650	655
TEST BEARING INNER RING (°F)	660	660	660	660		650		630	670	660	655	660
ROLLER BEARING OUTER RING (°F)	600	600	605	605		600		580	625	620	615	615
OIL SEAL HOUSING (°F)	—	—	—	—		—		—	—	—	—	—
AIR SEAL HOUSING (°F)	1005	995	1000	995		995		900	930	925	940	945
TEST BEARING HOUSING (°F)	675	675	675	675		665		605	670	670	670	670
ROLLER BEARING HOUSING (°F)	560	560	555	560		555		560	620	610	600	640
AIR SEAL BELLOWS (°F)	730	740	740	740		740		685	720	735	700	705
HOT AIR IN MANIFOLD (°F)	1110	1120	1120	1120		1120		1040	1060	1080	1080	1080
OIL INLET (°F)	510	510	510	510		515		510	510	510	510	520
OIL OUTLET (°F)	575	575	575	575		575		550	590	590	580	585

TEST CONDITIONS (arrows to 151.8 and 153.3 columns)

TEST BEARING # 267111

OIL USED MOBIL XRM 177F

DATE 9/11-12/68

RUNNING TIME, HOURS	158.3	159.3	160.3	161.3	162.3	163.3	163.6	164.6	165.6	166.6	167.6	168.0
SPEED, RPM	14	14	14	14	14		14	14	14	14	14	
AIR MANIFOLD PRESS. (PSI)	106	106	106	106	106		106	106	106	106	106	
BEARING CAVITY PRESS. (PSI)	6-7	6-7	6-7	6	6		6	6	6	6	6	
SEAL CAVITY PRESS. (PSI)	111	111	111	111	111		111	111	111	111	111	
HOT AIR FLOW (SCFM)	47	45	46	47	47		45	48	47	48	48	
TEST OIL FLOW (GPM)	2.0	2.0	2.0	2.0	2.0		2.0	2.0	2.0	2.0	2.0	
TOTAL SEAL LEAKAGE (SCFM)	12.4	12.4	12.4	12.4	12.7		8.7	8.7	7.6	8.5	9.8	
TEST BEARING OUTER RING (°F)	645	655	650	650	650		640	650	655	655	660	
TEST BEARING INNER RING (°F)	650	650	655	660	660		640	660	670	660	675	
ROLLER BEARING OUTER RING (°F)	600	600	610	605	610		560	610	610	615	615	
OIL SEAL HOUSING (°F)	—	—	—	—	—		—	—	—	—	—	
AIR SEAL HOUSING (°F)	945	940	940	955	955	STOP: FIRE	960	985	1015	1005	1010	STOP: SHEAR PINS BROKEN
TEST BEARING HOUSING (°F)	680	665	670	675	665		—	505	520	590	605	
ROLLER BEARING HOUSING (°F)	560	560	555	555	560		—	480	495	520	520	
AIR SEAL BELLOWS (°F)	710	710	710	715	715		730	—	820	—	—	
HOT AIR IN MANIFOLD (°F)	1090	1095	1090	1090	1090		1090	1110	1120	1110	1140	
OIL INLET (°F)	510	510	510	500	500		490	510	510	510	505	
OIL OUTLET (°F)	570	570	580	570	575		500	560	570	575	575	

TEST CONDITIONS (arrow to 163.6 column)

TEST BEARING # 267111

OIL USED MOBIL XRM 177F

DATE 9/12-18/68

RUNNING TIME, HOURS	168.9	169.3	169.8	171.4	172.4	173.4	174.4	175.4	176.4	177.4	178.4	179.4
SPEED, RPM	14	STOP: (OIL INLET TEMPERATURE DROPPING) RESTART	STOP: ROLLER END HOUSING HEATERS REPLACED	14	14	14	14	14	14	14	14	14
AIR MANIFOLD PRESS. (PSI)	106			106	106	106	106	106	106	106	106	106
BEARING CAVITY PRESS. (PSI)	6			6	6	6	6	6	6	6	6	6
SEAL CAVITY PRESS. (PSI)	111			111	111	111	111	111	111	111	111	111
HOT AIR FLOW (SCFM)	48			52	48	47	50	47	46	47	48	48
TEST OIL FLOW (GPM)	2			1.5	1.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0
TOTAL SEAL LEAKAGE (SCFM)	8.5			4.2	4.0	4.8	4.8	4.4	5.1	4.6	5.9	5.0
TEST BEARING OUTER RING (°F)	640			640	640	655	650	640	660	655	655	650
TEST BEARING INNER RING (°F)	660			650	660	670	665	660	670	670	670	670
ROLLER BEARING OUTER RING (°F)	585			565	555	570	545	540	550	550	550	550
OIL SEAL HOUSING (°F)	—			—	—	—	—	—	—	—	—	—
AIR SEAL HOUSING (°F)	1025			970	1025	1030	1040	1035	1035	1035	1035	1035
TEST BEARING HOUSING (°F)	510			610	650	650	635	615	630	645	650	660
ROLLER BEARING HOUSING (°F)	460			560	560	550	525	515	530	540	540	540
AIR SEAL BELLOWS (°F)	—			—	—	—	—	—	—	—	—	—
HOT AIR IN MANIFOLD (°F)	1080			1060	1040	1150	1150	1150	1160	1160	1160	1160
OIL INLET (°F)	470			510	515	515	510	510	510	510	510	510
OIL OUTLET (°F)	540			510	560	580	550	550	555	555	555	560

← TEST CONDITIONS

TEST BEARING # 267111

OIL USED MOBIL XRM 177F

DATE 9/18-19/68

Running Time, Hours	180.4	181.4	181.4	181.9	182.9	183.9	184.9	185.9	186.9	187.9	188.9	189.9
Speed, RPM	14	14	STOP: END OF TEST PERIOD	14	14	14	14	14	14	14	14	14
Air Manifold Press. (PSI)	106	106		106	106	106	106	106	106	106	106	106
Bearing Cavity Press. (PSI)	6-7	6-7		6	6	6	6	6	6	6	6	6
Seal Cavity Press. (PSI)	111	111		111	111	111	111	111	111	111	111	111
Hot Air Flow (SCFM)	48	48		46	48	49	48	48	48	48	48	48
Test Oil Flow (GPM)	2.0	2.0		2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Total Seal Leakage (SCFM)	4.7	5.9		6.8	5.9	4.9	5.1	4.8	4.5	4.8	4.4	4.1
Test Bearing Outer Ring (°F)	650	660		640	655	655	660	660	660	650	650	650
Test Bearing Inner Ring (°F)	670	670		640	670	670	670	670	670	675	670	675
Roller Bearing Outer Ring (°F)	545	560		550	590	570	590	590	590	590	575	580
Oil Seal Housing (°F)	—	—		—	—	—	—	—	—	—	—	—
Air Seal Housing (°F)	1040	1040		940	1025	1015	1025	1035	1025	1030	1025	1035
Test Bearing Housing (°F)	650	655		580	680	700	680	685	690	685	680	680
Roller Bearing Housing (°F)	540	565		510	555	560	560	560	560	550	550	565
Air Seal Bellows (°F)	—	—		790	810	865	900	890	870	875	880	885
Hot Air in Manifold (°F)	116	1160		1130	1150	1155	1150	1160	1160	1155	1150	1150
Oil Inlet (°F)	510	520		510	510	510	510	510	510	510	505	505
Oil Outlet (°F)	555	565		540	575	550	540	560	580	565	580	570

TEST BEARING # 267111

OIL USED MOBIL XRM-177F

DATE 9/19-23/68

Running Time, Hours	190.4	191.1	191.6	192.0	192.6	193.0	193.4	193.5	194.5	195.5	196.5	197.5
Speed, RPM	STOP: SHEAR PINS	14	STOP: SHEAR PINS	14	STOP: SHEAR PINS	14	STOP: CHECK SHEAR PINS; OK	TEST CONDITIONS	14	14	14	14
Air Manifold Press. (psi)		106		106		106			106	106	106	106
Bearing Cavity Press. (psi)		6		6		6			6	6	6	6
Seal Cavity Press. (psi)		111		111		111			111	111	111	111
Hot Air Flow (SCFM)		46		46		46			46	46	46	46
Test Oil Flow (GPM)		1.5		2.0		2.0			2.0	2.0	2.0	2.0
Total Seal Leakage (SCFM)		5.1		5.8		5.3			5.3	4.8	4.8	5.3
Test Bearing Outer Ring (°F)		640		640		640			650	650	650	650
Test Bearing Inner Ring (°F)		660		—		—			—	—	—	—
Roller Bearing Outer Ring (°F)		570		550		550			565	565	570	570
Oil Seal Housing (°F)		—		—		—			—	—	—	—
Air Seal Housing (°F)		1000		990		990			1005	1005	1005	1000
Test Bearing Housing (°F)		650		640		640			655	660	655	645
Roller Bearing Housing (°F)		550		550		550			560	565	570	565
Air Seal Bellows (°F)		870		850		860			880	875	880	880
Hot Air in Manifold (°F)		1180		1130		1150			1150	1150	1150	1150
Oil Inlet (°F)		500		500		490			490	495	495	495
Oil Outlet (°F)		570		560		560			575	575	575	575

TEST BEARING # 267111

OIL USED MOBIL XRM 177F

DATE 9/23-24/68

RUNNING TIME, HOURS	198.5	199.5	200.5	201.5	202.5	203.5	203.5	204.5	205.5	206.5	207.5	208.5
SPEED, RPM	14	14	14	14	14	14	STOP: END OF TEST PERIOD	14	14	14	14	14
AIR MANIFOLD PRESS. (PSI)	106	106	106	106	106	106		106	106	106	106	106
BEARING CAVITY PRESS. (PSI)	6	6	6	6	6	6		6	6	6	6	6
SEAL CAVITY PRESS. (PSI)	111	111	111	111	111	111		111	111	111	111	111
HOT AIR FLOW (SCFM)	46	46	46	46	46	46		46	48	47	48	48
TEST OIL FLOW (GPM)	2.0	2.0	2.0	2.0	2.0	2.0		2.0	2.0	2.0	2.0	2.0
TOTAL SEAL LEAKAGE (SCFM)	4.2	4.8	4.1	4.8	4.8	4.3		9.3	7.3	6.7	8.2	6.1
TEST BEARING OUTER RING (°F)	650	650	650	650	650	650		640	650	650	650	650
TEST BEARING INNER RING (°F)	—	—	—	—	—	—		640	665	660	—	—
ROLLER BEARING OUTER RING (°F)	570	570	570	570	570	570		545	580	575	580	580
OIL SEAL HOUSING (°F)	—	—	—	—	—	—		—	—	—	—	—
AIR SEAL HOUSING (°F)	1005	1005	1000	1000	1000	1000		950	975	975	980	980
TEST BEARING HOUSING (°F)	655	650	650	650	650	650		590	635	640	640	640
ROLLER BEARING HOUSING (°F)	565	565	565	565	565	565		505	540	540	540	540
AIR SEAL BELLOWS (°F)	880	880	880	880	880	880		780	835	830	830	830
HOT AIR IN MANIFOLD (°F)	1130	1130	1130	1130	1130	1130		1120	1130	1120	1140	1140
OIL INLET (°F)	495	495	495	500	500	500		490	500	500	500	500
OIL OUTLET (°F)	575	575	575	575	575	575		530	570	565	570	565

TEST CONDITIONS

The majority of the total seal leakage was across the oil seal.
The oxygen content in the test bearing chamber was 0.008-0.01%.

TEST BEARING # 267111

OIL USED MOBIL XRM 177F

DATE 9/24 - 10/1 /68

Running Time, Hours	209.2	210.2	211.2	212.2	212.3	214.0	215.2	216.2	217.0	218.0	219.0	220.0
Speed, RPM	STOP: COLLAR HOLDING PULLEY CAME LOOSE	14	14	14	STOP: SHEAR PINS BROKE PILLOW BLOCK BEARING SPALLED	14	14	14	14	14	14	14
Air Manifold Press. (psi)		106	106	106		106	106	106	106	106	106	106
Bearing Cavity Press. (psi)		6	6	6		6	6	6	6	6	6	6
Seal Cavity Press. (psi)		111	111	111		111	111	111	111	111	111	111
Hot Air Flow (SCFM)		48	48	48		48	48	48	48	48	48	48
Test Oil Flow (GPM)		1.5	1.5	1.5		2.0	2.0	2.0	2.0	2.0	2.0	2.0
Total Seal Leakage (SCFM)		5.1	13.8	10.3		5.0	3.7	4.8	4.1	3.7	3.7	5.1
Test Bearing Outer Ring (°F)		640	660	660		640	640	645	650	650	650	650
Test Bearing Inner Ring (°F)		—	—	—		640	650	660	660	660	660	660
Roller Bearing Outer Ring (°F)		580	—	—		—	—	—	—	—	—	—
Oil Seal Housing (°F)		—	—	—		—	—	—	—	—	—	—
Air Seal Housing (°F)		940	970	970		1020	1040	1030	1030	1030	1030	1030
Test Bearing Housing (°F)		630	630	630		630	660	650	645	645	645	650
Roller Bearing Housing (°F)		510	575	575		525	550	550	550	550	550	550
Air Seal Bellows (°F)		730	750	750		860	875	875	880	875	875	840
Hot Air in Manifold (°F)		1130	1140	1140		1150	1160	1155	1150	1150	1150	1150
Oil Inlet (°F)		510	510	510		500	500	500	510	510	510	510
Oil Outlet (°F)		580	585	585		555	565	565	575	570	570	570

TEST CONDITIONS (arrows to columns 210.2 and 214.0)

TEST BEARING # 267111

OIL USED MOBIL XRM 177F

DATE 10/1-10/68

Running Time, Hours	221.0	222.0	223.0	223.1	228.6	229.6	230.6	231.6	232.6	233.6	234.6	235.6
Speed, RPM	14	14	14	STOP: LOOSE COUPLING	14	14	14	14	14	14	14	14
Air Manifold Press. (psi)	106	106	106		106	106	106	106	106	106	106	106
Bearing Cavity Press. (psi)	6	6	6		6	6	6	6	6	6	6	6
Seal Cavity Press. (psi)	111	111	111		111	111	111	111	111	111	111	111
Hot Air Flow (scfm)	48	48	48		50	44	45	43	45	46	46	44
Test Oil Flow (gpm)	2.0	2.0	2.0		2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Total Seal Leakage (scfm)	6.8	6.8	7.6		4.7	4.9	4.9	4.2	3.6	4.2	3.9	3.5
Test Bearing Outer Ring (°F)	650	650	650		650	640	650	650	650	650	650	650
Test Bearing Inner Ring (°F)	660	660	660		695	665	680	690	670	670	670	670
Roller Bearing Outer Ring (°F)	—	—	—		545	540	540	560	560	560	560	550
Oil Seal Housing (°F)	—	—	—		—	—	—	—	—	—	—	—
Air Seal Housing (°F)	1030	1030	1030		1015	975	1015	985	980	975	985	980
Test Bearing Housing (°F)	650	650	650		655	655	655	670	680	690	685	680
Roller Bearing Housing (°F)	550	550	550		545	540	545	550	555	550	550	540
Air Seal Bellows (°F)	830	830	830		840	800	845	830	805	805	815	815
Hot Air in Manifold (°F)	1150	1150	1150		1160	1150	1160	1120	1100	1100	1100	1100
Oil Inlet (°F)	510	510	510		500	500	500	510	510	510	510	510
Oil Outlet (°F)	580	580	580		580	560	560	565	565	565	565	555

↑ TEST CONDITIONS (228.6)

The majority of the total seal leakage was across the oil seal. The oxygen content in the test bearing chamber was 0.008-0.01%.

TEST BEARING # 267111

OIL USED MOBIL XRM 177F

DATE 10/10-11/69

Running Time, Hours	236.6	237.6	238.6	238.6	239.3	240.3	241.3	242.3	243.3	244.3	245.3	246.3
Speed, RPM	14	14	14		14	14	14	14	14	14	14	14
Air Manifold Press. (psi)	106	106	106	STOP: END OF TEST PERIOD	106	106	106	106	106	106	106	106
Bearing Cavity Press. (psi)	6	6	6		6	6	6	6	6	6	6	6
Seal Cavity Press. (psi)	111	111	111		111	111	111	111	111	111	111	111
Hot Air Flow (scfm)	44	45	45		46	46	46	47	46	46	46	46
Test Oil Flow (gpm)	2.0	2.0	2.0		2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Total Seal Leakage (scfm)	3.5	3.9	4.2		6.0	5.6	5.5	5.8	4.9	5.6	5.0	5.3
Test Bearing Outer Ring (°F)	645	640	650		640	650	650	645	650	650	650	665
Test Bearing Inner Ring (°F)	670	660	670		640	670	675	665	670	670	675	695
Roller Bearing Outer Ring (°F)	555	545	555		535	555	560	565	565	580	575	580
Oil Seal Housing (°F)	—	—	—		—	—	—	—	—	—	—	—
Air Seal Housing (°F)	985	980	985		945	940	975	940	980	990	950	955
Test Bearing Housing (°F)	680	675	675		630	585	690	685	690	695	700	695
Roller Bearing Housing (°F)	540	545	545		510	545	550	550	555	560	560	560
Air Seal Bellows (°F)	815	810	810		750	885	790	790	795	795	800	805
Hot Air in Manifold (°F)	1100	1100	1100		980	1090	1090	1090	1100	1100	1100	1100
Oil Inlet (°F)	510	515	515		500	510	520	520	520	520	520	510
Oil Outlet (°F)	555	550	560		530	560	560	565	575	570	585	580

TEST CONDITIONS

The majority of the total seal leakage was across the oil seal:
The oxygen content in the test bearing chamber was 0.008-0.01%.

TEST BEARING # 267111

OIL USED MOBIL XRM 177F

DATE 10/11-12/68

Running Time, Hours	247.3	248.3	249.3	249.3	249.7	250.7	251.7	252.7	253.7	254.7	255.7	256.7
Speed, RPM	14	14	14	STOP: END OF TEST PERIOD	14	14	14	14	14	14	14	14
Air Manifold Press. (psi)	106	106	106		106	106	106	106	106	106	106	106
Bearing Cavity Press. (psi)	6	6	6		6	6	6	6	6	6	6	6
Seal Cavity Press. (psi)	111	111	111		111	111	111	111	111	111	111	111
Hot Air Flow (scfm)	46	46	46		46	50	50	48	50	50	50	50
Test Oil Flow (gpm)	2.0	2.0	2.0		2.0	2.0	2.0	2.0	1.75	1.5	1.75	2.0
Total Seal Leakage (scfm)	5.5	4.8	5.3		12.3	13.3	13.3	14.8	15.3	15.3	14.9	14.9
Test Bearing Outer Ring (°F)	650	650	650		650	650	650	650	640	640	650	650
Test Bearing Inner Ring (°F)	675	675	675		680	670	680	680	670	690	670	675
Roller Bearing Outer Ring (°F)	560	555	560		590	575	575	575	570	625	620	610
Oil Seal Housing (°F)	—	—	—		—	—	—	—	—	—	—	—
Air Seal Housing (°F)	950	950	950		895	855	845	845	875	890	900	890
Test Bearing Housing (°F)	690	685	690		700	690	685	685	690	685	685	690
Roller Bearing Housing (°F)	555	558	555		570	565	565	570	560	555	565	570
Air Seal Bellows (°F)	800	800	800		700	680	670	670	670	680	690	690
Hot Air in Manifold (°F)	1100	1105	1105		1100	1100	1100	1100	1100	1100	1100	1120
Oil Inlet (°F)	510	510	510		500	510	510	510	510	510	570	510
Oil Outlet (°F)	560	560	560		570	565	565	575	555	570	575	575

← TEST CONDITIONS (arrow to the 249.7 column)

TEST BEARING # 267111

OIL USED MOBIL XRM 177F

DATE 10/12/68

RUNNING TIME, HOURS	257.7	258.7	259.7	259.7	260.3	261.3	262.3	263.3	264.3	265.3	266.3	266.8
SPEED, RPM	14	14	14	STOP: END OF TEST PERIOD	14	14	14	14	14	14	14	STOP: END OF TEST PERIOD
AIR MANIFOLD PRESS. (PSI)	106	106	106		106	106	106	106	106	106	106	
BEARING CAVITY PRESS. (PSI)	6	6	6		6	6	6	6	6	6	6	
SEAL CAVITY PRESS. (PSI)	111	111	111		111	111	111	111	111	111	111	
HOT AIR FLOW (SCFM)	50	50	50		48	48	48	46	46	45	44	
TEST OIL FLOW (GPM)	2.0	2.0	2.0		2.0	2.0	2.0	1.0	1.0	1.0	1.0	
TOTAL SEAL LEAKAGE (SCFM)	14.4	14.1	13.6		7.3	6.1	7.6	5.6	5.1	6.1	4.7	
TEST BEARING OUTER RING (°F)	650	645	645		645	655	655	650	650	650	650	
TEST BEARING INNER RING (°F)	680	675	680		680	685	685	680	680	680	680	
ROLLER BEARING OUTER RING (°F)	610	610	610		610	615	610	610	610	610	610	
OIL SEAL HOUSING (°F)	—	—	—		—	—	—	—	—	—	—	
AIR SEAL HOUSING (°F)	890	900	890		985	995	1000	1000	1000	995	1005	
TEST BEARING HOUSING (°F)	685	690	690		655	665	665	660	655	660	650	
ROLLER BEARING HOUSING (°F)	570	565	565		535	555	555	555	555	555	555	
AIR SEAL BELLOWS (°F)	690	695	705		780	800	800	800	800	820	825	
HOT AIR IN MANIFOLD (°F)	1120	1120	1130		1125	1110	1110	1120	1120	1120	1110	
OIL INLET (°F)	510	510	510		495	495	495	495	500	495	495	
OIL OUTLET (°F)	570	570	575		565	570	570	570	570	570	570	

← TEST CONDITIONS

TEST BEARING # 267111

OIL USED MOBIL XRM-177F

DATE 10/13/68

RUNNING TIME, HOURS	267.6	268.6	269.6	270.6	271.6	272.6	273.6	273.6				
SPEED, RPM	14	14	14	14	14	14	14					
AIR MANIFOLD PRESS. (PSI)	106	106	106	106	106	106	106					
BEARING CAVITY PRESS. (PSI)	6	6	6	6	6	6	6					
SEAL CAVITY PRESS. (PSI)	111	111	111	111	111	111	111					
HOT AIR FLOW (SCFM)	44	46	47	46	47	47	46					
TEST OIL FLOW (GPM)	2.0	2.0	2.0	2.0	2.0	2.0	2.0					
TOTAL SEAL LEAKAGE (SCFM)	9.8	10.6	7.5	8.3	6.9	8.2	8.9					
TEST BEARING OUTER RING (°F)	640	645	645	645	645	640	640					
TEST BEARING INNER RING (°F)	650	670	670	670	670	665	665	STOP: TIME UP				
ROLLER BEARING OUTER RING (°F)	580	610	610	600	600	600	590					
OIL SEAL HOUSING (°F)	—	—	—	—	—	—	—					
AIR SEAL HOUSING (°F)	880	930	950	960	960	970	970					
TEST BEARING HOUSING (°F)	610	560	535	530	530	525	510					
ROLLER BEARING HOUSING (°F)	510	510	510	500	500	500	490					
AIR SEAL BELLOWS (°F)	620	720	745	750	755	755	725					
HOT AIR IN MANIFOLD (°F)	1040	1070	1080	1080	1080	1080	1080					
OIL INLET (°F)	500	500	500	500	500	500	505					
OIL OUTLET (°F)	535	570	580	570	570	570	560					

↑ TEST CONDITIONS (267.6 column)

TEST BEARING # 267112 [M-50 Steel Bearing, 459981G (Series I)]

OIL USED MOBIL XRM-109F + 10% BY WGT. KENDALL HEAVY RESIN 0839 DATE 12/10/68

Running Time, Hours	0.9	0.9	1.9	2.9	3.9	5.0	5.9	7.2	8.2	9.2	10.2	10.9
Speed, RPM	TEST CONDITIONS	14	14	14	14	14	14	14	14	14	14	STOP: END OF TEST PERIOD
Air Manifold Press. (psi)		106	106	106	106	106	106	106	106	106	106	
Bearing Cavity Press. (psi)		6	6	6	6	6	6	6	6	6	6	
Seal Cavity Press. (psi)		111	111	111	111	111	111	111	111	111	111	
Hot Air Flow (SCFM)		42	41	45	45	45	44	46	48	48	49	
Test Oil Flow (GPM)		2	2	2	2	2	2	2	2	2	2	
Total Seal Leakage (SCFM)		6.5	5.5	7.9	5.9	5.3	4.7	5.3	5.9	4.6	5.1	
Test Bearing Outer Ring (°F)		655	640	650	650	660	660	660	660	660	660	
Test Bearing Inner Ring (°F)		665	660	685	675	680	685	685	680	680	680	
Roller Bearing Outer Ring (°F)		585	570	580	575	575	580	580	580	580	575	
Oil Seal Housing (°F)		—	—	—	—	—	—	—	—	—	—	
Air Seal Housing (°F)		900	890	905	902	905	910	905	920	925	930	
Test Bearing Housing (°F)		690	690	700	690	690	695	690	690	690	690	
Roller Bearing Housing (°F)		590	580	595	580	570	570	570	570	570	570	
Air Seal Bellows (°F)		820	800	800	802	812	818	825	830	835	840	
Hot Air in Manifold (°F)		1000	1000	1000	1005	1005	1008	1015	1050	1050	1050	
Oil Inlet (°F)		500	500	505	510	510	510	510	510	510	510	
Oil Outlet (°F)		640	590	605	600	602	605	605	610	605	605	

The majority of the total seal leakage was across the oil seal.
The oxygen content in the test bearing chamber was .008 - .011%.

TEST BEARING # 267112

OIL USED MOBIL XRM 109F + 10% BY WGT KENDALL HEAVY RESIN 0839 DATE 12/11/68

RUNNING TIME, HOURS	11.8	12.8	13.8	14.8	15.8	16.8	17.9	18.8	19.9	20.8	21.8	21.8
SPEED, RPM	TEST CONDITIONS:	14	14	14	14	14	14	14	14	14	14	STOP: END OF TEST PERIOD
AIR MANIFOLD PRESS. (PSI)		106	106	106	106	106	106	107	106	106	106	
BEARING CAVITY PRESS. (PSI)		6	6	6	6	6	6	6	6	6	6	
SEAL CAVITY PRESS. (PSI)		111	111	111	111	111	111	111	111	111	111	
HOT AIR FLOW (SCFM)		44	44	43	43	44	44	43	44	43	44	
TEST OIL FLOW (GPM)		2	2	2	2	2	2	2	2	2	2	
TOTAL SEAL LEAKAGE (SCFM)		4.9	5.3	6.6	6.4	5.1	6.4	5.5	5.9	6.4	5.4	
TEST BEARING OUTER RING (°F)		650	660	660	660	660	655	670	665	665	668	
TEST BEARING INNER RING (°F)		640	660	670	670	665	665	675	675	682	685	
ROLLER BEARING OUTER RING (°F)		570	570	580	580	575	565	590	585	592	595	
OIL SEAL HOUSING (°F)		—	—	—	—	—	—	—	—	—	—	
AIR SEAL HOUSING (°F)		885	830	825	910	930	910	910	910	—	—	
TEST BEARING HOUSING (°F)		675	670	665	675	650	670	670	670	672	668	
ROLLER BEARING HOUSING (°F)		550	555	560	560	540	545	560	560	565	561	
AIR SEAL BELLOWS (°F)		785	805	810	810	810	815	820	820	825	825	
HOT AIR IN MANIFOLD (°F)		1030	1040	1040	1040	1035	1035	1035	1040	1040	1040	
OIL INLET (°F)		510	510	510	510	510	510	510	510	500	500	
OIL OUTLET (°F)		600	600	610	610	605	598	618	610	618	615	

The majority of the total seal leakage was across the oil seal.
The oxygen content in the test bearing chamber was 0.37 - 0.45%.

TEST BEARING # 267112

OIL USED MOBIL XRM-109F+10% BY WGT. KENDALL HEAVY RESIN 0839 DATE 12/11-12/68

RUNNING TIME, HOURS	22.5	23.5	24.5	25.5	26.5	27.5	28.5	29.5	30.5	31.5	32.5	32.5
SPEED, RPM		14	14	14	14	14	14	14	14	14	14	
AIR MANIFOLD PRESS. (PSI)		106	106	106	106	106	106	106	106	106	106	
BEARING CAVITY PRESS. (PSI)		6	6	6	6	6	6	6	6	6	6	
SEAL CAVITY PRESS. (PSI)		111	111	111	111	111	111	111	111	111	111	
HOT AIR FLOW (SCFM)		56	54	55	56	56	42	44	43	44	44	
TEST OIL FLOW (GPM)		1	1	1	1	1	1	1	1	1	1	
TOTAL SEAL LEAKAGE (SCFM)		4.8	6.0	4.6	4.8	5.1	5.9	4.8	4.6	5.9	4.6	
TEST BEARING OUTER RING (°F)		640	640	645	645	645	640	640	640	640	640	
TEST BEARING INNER RING (°F)		655	655	665	675	670	650	655	650	650	650	
ROLLER BEARING OUTER RING (°F)	TEST CONDITIONS	570	560	580	580	575	570	580	570	580	580	STOP: END OF TEST PERIOD
OIL SEAL HOUSING (°F)		—	—	—	—	—	—	—	—	—	—	
AIR SEAL HOUSING (°F)		910	920	925	925	925	900	900	890	895	885	
TEST BEARING HOUSING (°F)		660	660	660	660	670	660	660	670	670	660	
ROLLER BEARING HOUSING (°F)		560	560	560	560	560	550	550	545	550	550	
AIR SEAL BELLOWS (°F)		830	840	845	845	845	820	820	820	820	820	
HOT AIR IN MANIFOLD (°F)		1050	1050	1060	1060	1060	1030	1040	1030	1035	1035	
OIL INLET (°F)		510	510	510	510	510	510	510	510	510	510	
OIL OUTLET (°F)		590	590	590	590	600	595	600	600	600	600	

TEST BEARING # 267112

OIL USED MOBIL-XRM 109F + 10% BY WGT. KENDALL HEAVY RESIN 0839 DATE 12/12-16/68

Running Time, Hours	33.9	34.9	35.0	35.6	36.6	37.6	38.6	39.6	40.6	41.6	42.6	43.6
Speed, RPM	TEST CONDITIONS	14	STOP: SLIP RINGS FAILED	TEST CONDITIONS	14	14	14	14	14	14	14	14
Air Manifold Press. (PSI)		106			106	106	106	106	106	106	106	106
Bearing Cavity Press. (PSI)		6			6	6	6	6	6	6	6	6
Seal Cavity Press. (PSI)		111			111	111	111	111	111	111	111	111
Hot Air Flow (SCFM)		44			40	41	41	41	41	47	48	48
Test Oil Flow (GPM)		2			1.5	1.5	1.5	1.5	1.5	1.75	1.75	1.75
Total Seal Leakage (SCFM)		5.1			6.1	5.3	4.6	5.3	4.8	5.1	5.5	5.6
Test Bearing Outer Ring (°F)		650			660	650	650	655	655	655	655	655
Test Bearing Inner Ring (°F)		610			630	630	625	630	630	630	630	630
Roller Bearing Outer Ring (°F)		595			575	580	565	570	565	590	590	590
Oil Seal Housing (°F)		—			—	—	—	—	—	—	—	—
Air Seal Housing (°F)		1020			1000	1000	1000	1000	1000	1010	1030	1030
Test Bearing Housing (°F)		650			640	645	650	640	640	645	640	635
Roller Bearing Housing (°F)		575			565	565	560	565	565	570	575	570
Air Seal Bellows (°F)		860			845	845	845	840	845	840	860	860
Hot Air in Manifold (°F)		1090			1065	1070	1075	1070	1070	1090	1110	1110
Oil Inlet (°F)		510			520	515	515	520	525	515	525	525
Oil Outlet (°F)		620			610	605	600	600	600	620	620	610

TEST BEARING # 267112

OIL USED MOBIL XRM-109F + 10 o/o BY WGT. KENDALL HEAVY RESIN 0839 DATE 12/16-18/68

Running Time, Hours	44.6	45.6	45.6	46.5	47.5	48.5	49.8	50.7	51.7	52.7	53.7	54.7
Speed, RPM	14	14	STOP: END OF TEST PERIOD	TEST CONDITIONS:	14	14	14	14	14	14	14	14
Air Manifold Press. (psi)	106	106			106	106	106	106	107	106	107	107
Bearing Cavity Press. (psi)	6	6			6	6	6	6	6	6	6	6
Seal Cavity Press. (psi)	111	111			111	111	111	111	111	111	111	111
Hot Air Flow (scfm)	48	49			50	50	48	50	50	50	50	50
Test Oil Flow (gpm)	1.75	1.75			1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Total Seal Leakage (scfm)	5.7	5.1			6.9	6.0	5.9	6.3	6.3	6.8	6.3	6.5
Test Bearing Outer Ring (°F)	660	660			655	650	660	660	660	660	660	660
Test Bearing Inner Ring (°F)	640	640			640	645	660	665	665	665	665	665
Roller Bearing Outer Ring (°F)	585	590			580	580	580	570	570	575	580	575
Oil Seal Housing (°F)	—	—			—	—	—	—	—	—	—	—
Air Seal Housing (°F)	1035	1040			1040	1050	1045	1040	1040	1040	1040	1040
Test Bearing Housing (°F)	640	640			650	650	650	635	650	650	650	650
Roller Bearing Housing (°F)	570	575			565	575	570	560	565	570	570	570
Air Seal Bellows (°F)	860	865			865	860	860	855	850	855	860	855
Hot Air in Manifold (°F)	1110	1115			1120	1120	1120	1120	1120	1120	1120	1120
Oil Inlet (°F)	520	520			520	520	520	520	510	500	500	510
Oil Outlet (°F)	620	620			615	612	612	610	610	610	612	612

TEST BEARING # 267112

OIL USED MOBIL XRM-109F + 10 o/o BY WGT KENDALL HEAVY RESIN 0839 DATE 12/18-19/68

Running Time, Hours	55.6	56.5	57.4	58.4	59.4	60.4	61.4	62.4	63.6	64.4	65.6	66.4
Speed, RPM	14	STOP: END OF TEST PERIOD	TEST CONDITIONS	14	14	14	14	14	14	14	14	14
Air Manifold Press. (psi)	106			106	106	106	106	106	106	106	106	106
Bearing Cavity Press. (psi)	6			6	6	6	6	6	6	6	6	6
Seal Cavity Press. (psi)	111			111	111	111	111	111	111	111	111	111
Hot Air Flow (SCFM)	49			45	44	45	46	45	50	50	50	50
Test Oil Flow (GPM)	1.5			1.75	1.75	1.75	1.75	1.75	1.5	1.5	1.5	1.5
Total Seal Leakage (SCFM)	5.3			7.8	7.8	7.1	7.9	8.1	7.2	7.6	8.1	8.5
Test Bearing Outer Ring (°F)	660			655	660	650	660	665	660	660	660	660
Test Bearing Inner Ring (°F)	655			640	645	640	645	645	650	660	660	660
Roller Bearing Outer Ring (°F)	575			585	590	600	590	595	582	582	578	578
Oil Seal Housing (°F)	—			—	—	—	—	—	—	—	—	—
Air Seal Housing (°F)	1040			1020	1010	1015	1015	1010	1030	1030	1030	1035
Test Bearing Housing (°F)	640			660	655	645	650	655	650	650	645	650
Roller Bearing Housing (°F)	570			580	580	580	580	585	570	570	565	565
Air Seal Bellows (°F)	855			815	820	820	820	825	830	830	830	835
Hot Air in Manifold (°F)	1120			1100	1100	1100	1105	1100	1120	1120	1120	1120
Oil Inlet (°F)	510			510	520	510	520	530	515	510	510	510
Oil Outlet (°F)	615			620	630	625	620	625	615	615	615	610

The total seal leakage was about evenly split between the oil seal and the air seal. The oxygen content in the test bearing cavity was 0.013%.

TEST BEARING # 267112

OIL USED MOBIL XRM-109F + 10 o/o BY WGT. KENDALL HEAVY RESIN 0839 DATE 12/19-20/68

Running Time, Hours	67.4	67.4	68.0	69.0	70.0	71.0	72.0	73.0	74.0	75.0	76.0	77.0
Speed, RPM	14			14	14	14	14	14	14	14	14	14
Air Manifold Press. (psi)	106			106	106	106	106	106	106	106	106	106
Bearing Cavity Press. (psi)	6			6	6	6	6	6	6	6	6	6
Seal Cavity Press. (psi)	111			111	111	111	111	111	111	111	111	111
Hot Air Flow (scfm)	50			56	57	56	56	46	47	45	45	45
Test Oil Flow (gpm)	1.5			1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Total Seal Leakage (scfm)	7.0			6.3	8.0	6.7	5.8	6.9	5.9	6.5	6.3	5.5
Test Bearing Outer Ring (°F)	660			660	658	670	670	680	640	650	650	650
Test Bearing Inner Ring (°F)	660			665	665	675	675	680	640	650	650	650
Roller Bearing Outer Ring (°F)	575	STOP: END OF TEST PERIOD	TEST CONDITIONS	570	570	565	560	590	590	600	590	595
Oil Seal Housing (°F)	—			—	—	—	—	—	—	—	—	—
Air Seal Housing (°F)	1035			1035	1040	1050	1040	1035	1030	1020	1025	1035
Test Bearing Housing (°F)	645			650	655	650	670	650	650	670	640	650
Roller Bearing Housing (°F)	565			560	560	560	560	560	570	570	570	575
Air Seal Bellows (°F)	840			855	865	855	860	855	850	850	850	850
Hot Air in Manifold (°F)	1120			1115	1120	1130	1130	1130	1120	1100	1110	1110
Oil Inlet (°F)	510			510	510	510	510	510	510	510	520	520
Oil Outlet (°F)	610			600	605	610	610	620	610	625	615	630

The majority of the total seal leakage was across the oil seal.
The oxygen content in the test bearing cavity was 0.012 - 0.016%.

TEST BEARING # 267112

OIL USED MOBIL XRM-109 F + 10 o/o BY WGT. KENDALL HEAVY RESIN 0839 DATE 12/20/68

Running Time, Hours	78.0	78.0	78.7	79.8	80.9	81.9	82.9	83.9	84.9	85.9	86.2
Speed, RPM	14	STOP: END OF TEST PERIOD	TEST CONDITIONS	14	14	14	14	14	14	14	STOP: OIL HEATER FUSE BLOWN
Air Manifold Press. (psi)	106			106	106	106	106	106	106	106	
Bearing Cavity Press. (psi)	6			6	6	6	6	6	6	6	
Seal Cavity Press. (psi)	111			111	111	111	111	111	111	111	
Hot Air Flow (scfm)	44			48	48	48	48	50	50	50	
Test Oil Flow (gpm)	1.5			1.5	1.5	1.5	1.5	1.5	1.5	1.5	
Total Seal Leakage (scfm)	7.0			5.6	7.5	7.0	5.9	6.8	7.0	7.5	
Test Bearing Outer Ring (°F)	650			650	660	660	660	660	660	660	
Test Bearing Inner Ring (°F)	650			655	662	660	660	660	660	660	
Roller Bearing Outer Ring (°F)	590			610	585	585	585	590	590	590	
Oil Seal Housing (°F)	—			—	—	—	—	—	—	—	
Air Seal Housing (°F)	1020			1040	1035	1040	1040	1040	1040	1040	
Test Bearing Housing (°F)	645			650	645	645	640	640	640	640	
Roller Bearing Housing (°F)	565			560	570	560	580	585	585	585	
Air Seal Bellows (°F)	845			850	850	860	860	860	860	860	
Hot Air in Manifold (°F)	1110			1130	1130	1130	1130	1140	1140	1140	
Oil Inlet (°F)	520			510	510	520	520	520	520	520	
Oil Outlet (°F)	620			610	615	620	620	620	625	625	

TEST BEARING # 267112

OIL USED MOBIL XRM 109F + 10o/o BY WGT. KENDALL HEAVY RESIN 0839 DATE 1/2-3/69

RUNNING TIME, HOURS	87.9	89.1	90.9	91.9	92.9	93.9	94.9	95.9	96.4	97.1	98.1	99.1
SPEED, RPM		14	14	14	14	14	14	14	STOP: INSTRUMENT MALFUCTION	TEST CONDITIONS	14	14
AIR MANIFOLD PRESS. (PSI)		106	106	106	106	106	106	106			106	106
BEARING CAVITY PRESS. (PSI)		6	6	6	6	6	6	6			6	6
SEAL CAVITY PRESS. (PSI)		111	111	111	111	111	111	111			111	111
HOT AIR FLOW (SCFM)		56	53	49	51	51	51	52			45	47
TEST OIL FLOW (GPM)		1.75	1.75	1.75	1.75	1.75	1.75	1.75			1.5	1.5
TOTAL SEAL LEAKAGE (SCFM)		12.7	9.0	10.6	11.3	10.6	10.6	11.3			10.7	11
TEST BEARING OUTER RING (°F)		650	670	675	660	660	660	660			640	650
TEST BEARING INNER RING (°F)		665	680	675	660	660	660	660			640	640
ROLLER BEARING OUTER RING (°F)		655	660	660	645	630	645	635			605	615
OIL SEAL HOUSING (°F)		—	—	—	—	—	—	—			—	—
AIR SEAL HOUSING (°F)		940	1020	1010	995	985	990	980			970	980
TEST BEARING HOUSING (°F)		695	695	695	635	625	625	630			590	600
ROLLER BEARING HOUSING (°F)		590	590	590	540	530	540	540			485	490
AIR SEAL BELLOWS (°F)		—	—	—	—	—	—	—			765	760
HOT AIR IN MANIFOLD (°F)		1050	1100	1100	1075	1075	1075	1075			1050	1050
OIL INLET (°F)		510	510	502	500	495	500	500			490	510
OIL OUTLET (°F)		610	620	625	610	600	600	620			550	550

The majority of the total seal leakage was across the oil seal for the first three hours and across the air seal for the remaining 6.5 hours.
The oxygen content in test bearing chamber was 0.012 - 0.016%.

TEST BEARING # 267112

OIL USED MOBIL XRM-109F + 10% BY WGT. KENDALL HEAVY RESIN 0839 DATE 1/3-9/69

Running Time, Hours	100.2	101.2	102.2	104.2	106.2	107.1	107.1	107.8	108.8	109.1	110.0	111.0
Speed, RPM	14	14	14	14	14	14	STOP: END OF TEST PERIOD	TEST CONDITIONS	14	STOP: AIR SEAL LEAKAGE HIGH	TEST CONDITIONS	14
Air Manifold Press. (PSI)	106	106	106	106	106	106			106			106
Bearing Cavity Press. (PSI)	6	6	6	6	6	6			6			6
Seal Cavity Press. (PSI)	111	111	111	111	111	111			111			111
Hot Air Flow (SCFM)	44	44	47	57	52	52			45			44
Test Oil Flow (GPM)	1.5	1.5	1.5	1.5	1.5	1.5			1.5			1.75
Total Seal Leakage (SCFM)	9.0	9.5	10.4	10.6	10.2	10.2			21.2			59
Test Bearing Outer Ring (°F)	665	650	660	670	660	660			650			655
Test Bearing Inner Ring (°F)	665	652	670	675	675	670			660			655
Roller Bearing Outer Ring (°F)	620	610	650	635	655	655			650			570
Oil Seal Housing (°F)	—	—	—	—	—	—			—			—
Air Seal Housing (°F)	990	1000	1000	950	990	990			880			980
Test Bearing Housing (°F)	610	555	680	670	690	680			685			675
Roller Bearing Housing (°F)	505	445	555	555	565	570			565			555
Air Seal Bellows (°F)	790	790	795	745	770	780			635			895
Hot Air in Manifold (°F)	1070	1090	1090	1050	1050	1050			1020			1100
Oil Inlet (°F)	470	500	510	510	500	500			500			520
Oil Outlet (°F)	570	565	595	595	600	608			585			600

The majority of the total seal leakage was across the oil seal.
The oxygen content in the test bearing chamber was 0.012 - 0.015%.

TEST BEARING # 267112

OIL USED MOBIL XRM-109F + 10 o/o BY WGT. KENDALL HEAVY RESIN 0839 DATE 1/9-10/69

Running Time, Hours	112.1	114.6	116.0	117.0	118.0	119.0	120.0	120.8	121.8	122.8	123.8	124.8
Speed, RPM	14	14	14	14	14	14	STOP: END OF TEST PERIOD	TEST CONDITIONS	14	14	14	14
Air Manifold Press. (psi)	106	106	106	106	106	106			106	106	106	106
Bearing Cavity Press. (psi)	6	6	6	6	6	6			6	6	6	6
Seal Cavity Press. (psi)	111	111	111	111	111	111			111	111	111	111
Hot Air Flow (scfm)	56	56	56	56	56	56			45	46	47	47
Test Oil Flow (gpm)	1.75	1.75	1.75	1.75	1.75	1.75			2	2	2	1.75
Total Seal Leakage (scfm)	5.7	5.5	5.7	6.3	6.1	5.9			6.4	6.1	5.3	12.7
Test Bearing Outer Ring (°F)	660	665	655	655	660	660			645	640	650	650
Test Bearing Inner Ring (°F)	660	665	655	655	660	660			660	650	660	670
Roller Bearing Outer Ring (°F)	565	590	560	580	565	570			560	550	555	555
Oil Seal Housing (°F)	—	—	—	—	—	—			—	—	—	—
Air Seal Housing (°F)	1010	960	920	900	990	970			895	900	910	775
Test Bearing Housing (°F)	670	685	655	660	660	670			650	625	635	650
Roller Bearing Housing (°F)	555	560	550	540	530	520			640	645	655	650
Air Seal Bellows (°F)	880	890	870	890	890	910			890	890	910	750
Hot Air in Manifold (°F)	1080	1090	1130	1130	1130	1130			1030	1030	1035	1100
Oil Inlet (°F)	510	515	505	505	505	505			510	510	510	510
Oil Outlet (°F)	600	610	590	610	610	590			585	590	580	585

TEST BEARING # 267112

OIL USED MOBIL XRM-109F + 10 o/o BY WGT. KENDALL HEAVY RESIN 0839 DATE 1/10-16/69

RUNNING TIME, HOURS	125.1	126.4	127.3	127.4	127.9	128.9	130.4	133.4	134.9	135.9	136.9	137.9
SPEED, RPM	STOP: EXCESSIVE RIG SEAL LEAKAGE ROLLER BEARING REPLACED	TEST CONDITIONS	14	STOP: OIL LEAK	TEST CONDITIONS	14	14	14	14	14	14	STOP: END OF TEST PERIOD
AIR MANIFOLD PRESS. (PSI)			106			106	106	106	106	106	106	
BEARING CAVITY PRESS. (PSI)			6			6	6	6	6	6	6	
SEAL CAVITY PRESS. (PSI)			111			111	111	111	111	111	111	
HOT AIR FLOW (SCFM)			43			54	56	56	56	56	56	
TEST OIL FLOW (GPM)			1.5			1.75	1.75	1.75	1.75	1.75	1.75	
TOTAL SEAL LEAKAGE (SCFM)			8.5			7.2	6.8	7.2	6.1	5.8	7.2	
TEST BEARING OUTER RING (°F)			640			650	650	650	650	650	650	
TEST BEARING INNER RING (°F)			655			662	660	660	655	655	655	
ROLLER BEARING OUTER RING (°F)			660			650	655	620	655	650	645	
OIL SEAL HOUSING (°F)			—			—	—	—	—	—	—	
AIR SEAL HOUSING (°F)			980			1000	—	—	1015	1000	1000	
TEST BEARING HOUSING (°F)			670			670	670	675	675	680	675	
ROLLER BEARING HOUSING (°F)			560			575	570	570	570	570	570	
AIR SEAL BELLOWS (°F)			830			900	870	890	895	895	885	
HOT AIR IN MANIFOLD (°F)			1120			1125	1125	1130	1130	1130	1130	
OIL INLET (°F)			520			505	520	510	515	510	515	
OIL OUTLET (°F)			600			608	615	610	610	610	600	

The majority of the total seal leakage was across the oil seal.
The oxygen content in the test bearing chamber was 0.012 - 0.015%.

TEST BEARING # 267112

OIL USED MOBIL XRM-109F + 10% BY WGT. KENDALL HEAVY RESIN 0839 DATE 1/16-17/69

RUNNING TIME, HOURS	138.2	139.2	140.2	141.2	142.2	143.2	144.2	145.2	146.2	147.2	148.2	148.2
SPEED, RPM	TEST CONDITIONS	14	14	14	14	14	14	14	14	14	14	STOP: END OF TEST PERIOD
AIR MANIFOLD PRESS. (PSI)		106	106	106	106	106	106	106	106	106	106	
BEARING CAVITY PRESS. (PSI)		6	6	6	6	6	6	6	6	6	6	
SEAL CAVITY PRESS. (PSI)		111	111	111	111	111	111	111	111	111	111	
HOT AIR FLOW (SCFM)		44	45	46	46	45	46	46	45	58	53	
TEST OIL FLOW (GPM)		1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	
TOTAL SEAL LEAKAGE (SCFM)		8.9	8.1	8.5	9.6	7.6	7.5	8.3	10.0	10.2	8.7	
TEST BEARING OUTER RING (°F)		650	650	650	645	650	650	650	650	650	650	
TEST BEARING INNER RING (°F)		650	655	650	650	660	660	660	660	—	—	
ROLLER BEARING OUTER RING (°F)		660	655	650	650	655	655	655	650	660	655	
OIL SEAL HOUSING (°F)		—	—	—	—	—	—	—	—	—	—	
AIR SEAL HOUSING (°F)		960	955	950	950	950	960	950	940	—	—	
TEST BEARING HOUSING (°F)		670	660	670	665	680	670	660	670	670	670	
ROLLER BEARING HOUSING (°F)		585	580	590	585	580	580	580	575	570	580	
AIR SEAL BELLOWS (°F)		855	850	850	845	845	850	850	840	855	820	
HOT AIR IN MANIFOLD (°F)		1050	1050	1045	1045	1045	1045	1045	1040	1070	1100	
OIL INLET (°F)		510	510	510	510	510	510	510	510	515	515	
OIL OUTLET (°F)		615	610	610	610	610	610	610	610	610	605	

The majority of the total seal leakage was across the oil seal.
The oxygen content in the test bearing chamber was 0.012 - 0.021%.

TEST BEARING # 267112

OIL USED MOBIL XRM-109F + 10% BY WGT KENDALL HEAVY RESIN 0839 DATE 1/17/69

Running Time, Hours	148.7	149.9	150.9	151.9	152.9	153.7	154.7	155.7	156.7	157.7	158.7
Speed, RPM	TEST CONDITIONS	14	14	14	14	14	14	14	14	14	STOP: END OF TEST PERIOD
Air Manifold Press. (psi)		106	106	106	106	106	106	106	106	106	
Bearing Cavity Press. (psi)		6	6	6	6	6	6	6	6	6	
Seal Cavity Press. (psi)		111	111	111	111	111	111	111	111	111	
Hot Air Flow (scfm)		54	54	54	54	54	54	54	54	54	
Test Oil Flow (gpm)		1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	
Total Seal Leakage (scfm)		7.0	8.5	8.5	8.0	8.0	7.6	7.0	6.3	6.1	
Test Bearing Outer Ring (°F)		655	655	655	655	655	655	660	660	660	
Test Bearing Inner Ring (°F)		660	660	660	660	660	660	665	665	665	
Roller Bearing Outer Ring (°F)		665	580	650	650	645	650	650	650	650	
Oil Seal Housing (°F)		—	—	—	—	—	—	—	—	—	
Air Seal Housing (°F)		960	800	960	965	960	960	960	960	965	
Test Bearing Housing (°F)		715	650	660	660	660	670	660	660	665	
Roller Bearing Housing (°F)		590	560	550	550	540	580	550	550	550	
Air Seal Bellows (°F)		870	800	870	870	870	870	870	870	875	
Hot Air in Manifold (°F)		1120	1120	1120	1120	1125	1125	1125	1125	1125	
Oil Inlet (°F)		500	500	500	500	500	500	500	500	500	
Oil Outlet (°F)		575	580	580	580	600	590	590	590	610	

TEST BEARING # 267112

OIL USED MOBIL XRM-109F + 10 % BY WGT. KENDALL HEAVY RESIN 0839 DATE 1/20/69

RUNNING TIME, HOURS	159.8	160.8	162.4	162.9	163.8	165.8	167.8	168.8	169.8	170.2	171.2	172.2
SPEED, RPM	TEST CONDITIONS:	14	14	14	14	14	14	14	STOP. END OF TEST PERIOD	TEST CONDITIONS	14	14
AIR MANIFOLD PRESS. (PSI)		106	106	106	106	106	106	106			106	106
BEARING CAVITY PRESS. (PSI)		6	6	6	6	6	6	6			6	6
SEAL CAVITY PRESS. (PSI)		111	111	111	111	111	111	111			111	111
HOT AIR FLOW (SCFM)		55	51	52	52	52	52	52			52	52
TEST OIL FLOW (GPM)		1.75	1.75	1.75	1.75	1.75	1.75	1.75			2	2
TOTAL SEAL LEAKAGE (SCFM)		7.5	7.7	7.1	7.1	6.8	7.7	7.5			6.9	6.4
TEST BEARING OUTER RING (°F)		650	650	655	650	650	650	650			650	650
TEST BEARING INNER RING (°F)		660	660	660	660	650	650	650			670	655
ROLLER BEARING OUTER RING (°F)		670	665	665	665	665	670	670			650	650
OIL SEAL HOUSING (°F)		—	—	—	—	—	—	—			—	—
AIR SEAL HOUSING (°F)		995	935	925	930	950	980	980			955	960
TEST BEARING HOUSING (°F)		680	680	680	680	680	690	690			620	620
ROLLER BEARING HOUSING (°F)		575	570	570	570	570	570	580			585	590
AIR SEAL BELLOWS (°F)		885	880	880	885	885	880	890			—	—
HOT AIR IN MANIFOLD (°F)		1125	1120	1120	1120	1120	1120	1120			1060	1065
OIL INLET (°F)		510	510	510	510	510	510	510			510	510
OIL OUTLET (°F)		630	610	612	610	615	615	620			630	630

The majority of the total seal leakage was across the oil seal.
The oxygen content in the test bearing chamber was 0.012% and for approximately one hour went to 0.55%.

TEST BEARING # 267112

OIL USED MOBIL XRM-109F + 10 % BY WGT KENDALL HEAVY RESIN 0839 DATE 1/21/69

Running Time, Hours	173.2	174.2	175.2	176.4	177.2	178.4	179.2	180.2	180.2	180.6	181.6	182.6
Speed, RPM	14	14	14	14	14	14	14	14	STOP: END OF TEST PERIOD	TEST CONDITIONS	14	14
Air Manifold Press. (psi)	106	106	106	106	106	106	106	106			106	106
Bearing Cavity Press. (psi)	6	6	6	6	6	6	6	6			6	6
Seal Cavity Press. (psi)	111	111	111	111	111	111	111	111			111	111
Hot Air Flow (SCFM)	53	53	53	53	55	55	55	54			52	50
Test Oil Flow (GPM)	2	2	2	2	2	2	2	2			1.75	1.75
Total Seal Leakage (SCFM)	7.1	7.1	7.3	6.2	7.6	6.2	7.3	6.8			7.1	7.7
Test Bearing Outer Ring (°F)	650	650	660	660	655	655	660	655			650	650
Test Bearing Inner Ring (°F)	665	665	675	675	665	670	675	670			655	655
Roller Bearing Outer Ring (°F)	650	650	660	655	645	650	650	650			615	635
Oil Seal Housing (°F)	—	—	—	—	—	—	—	—			—	—
Air Seal Housing (°F)	960	890	900	965	975	980	980	980			900	975
Test Bearing Housing (°F)	620	620	670	670	665	670	665	665			690	690
Roller Bearing Housing (°F)	580	580	580	570	575	575	575	575			595	595
Air Seal Bellows (°F)	—	—	870	870	890	900	890	890			870	870
Hot Air in Manifold (°F)	1065	1065	1065	1080	1095	1110	1110	1110			1115	1100
Oil Inlet (°F)	510	510	520	505	502	515	515	510			500	500
Oil Outlet (°F)	625	630	630	625	615	625	625	615			605	615

The majority of the total seal leakage was across the oil seal.
The oxygen content in the test bearing chamber was 0.013-0.014%.

TEST BEARING # 267112

OIL USED MOBIL XRM 109F + 10% BY WGT KENDALL HEAVY RESIN 0839 DATE 1/21-22/69

RUNNING TIME, HOURS	183.6	184.9	185.9	186.9	187.9	188.9	189.9	190.6	193.0	194.0	194.1	
SPEED, RPM $\times 10^3$	14	14	14	14	14	14	14	STOP: END OF TEST PERIOD	TEST CONDITIONS	14	STOP: OIL LEAKS	
AIR MANIFOLD PRESS. (PSI)	106	106	106	106	106	106	106			106		
BEARING CAVITY PRESS. (PSI)	6	6	6	6	6	6	6			6		
SEAL CAVITY PRESS. (PSI)	111	111	111	111	111	111	111			111		
HOT AIR FLOW (SCFM)	49	49	51	50	49	50	50			42		
TEST OIL FLOW (GPM)	1.7	1.7	1.7	1.7	1.7	2.0	2.0			1.5		
TOTAL SEAL LEAKAGE (SCFM)	6.8	7.0	7.3	7.1	7.2	7.6	8.0			6.8		
TEST BEARING OUTER RING (°F)	650	655	655	655	660	650	650			650		
TEST BEARING INNER RING (°F)	655	665	670	665	670	665	665			650		
ROLLER BEARING OUTER RING (°F)	625	630	630	630	670	635	620			625		
OIL SEAL HOUSING (°F)	—	—	—	—	—	—	—			—		
AIR SEAL HOUSING (°F)	880	870	890	885	850	960	920			970		
TEST BEARING HOUSING (°F)	680	685	670	670	680	675	680			680		
ROLLER BEARING HOUSING (°F)	590	600	600	600	605	610	605			590		
AIR SEAL BELLOWS (°F)	870	870	870	870	880	865	890			940		
HOT AIR IN MANIFOLD (°F)	1100	1100	1070	1070	1070	1070	1070			1070		
OIL INLET (°F)	500	500	500	500	500	500	500			520		
OIL OUTLET (°F)	610	620	620	620	630	625	630			640		

TEST BEARING # 267112

OIL USED MOBIL XRM109F + 10% BY WGT. KENDALL HEAVY RESIN 0839 DATE 1/22-23/69

Running Time, Hours	195.1	196.1	197.1	198.1	199.1	200.3	202.3	203.2	204.4	205.1	205.7	206.7
Speed, RPM X 10^3	1	14	14	14	14	14	14	14	14	STOP: END OF TEST PERIOD	TEST CONDITIONS	14
Air Manifold Press. (PSI)	TEST CONDITIONS:	106	106	106	106	106	106	106	106			106
Bearing Cavity Press. (PSI)		6	6	6	6	6	6	6	6			6
Seal Cavity Press. (PSI)		111	111	111	111	111	111	111	111			111
Hot Air Flow (SCFM)		44	48	51	53	54	54	54	53			52
Test Oil Flow (GPM)		1.5	1.5	1.5	1.5	1.5	1.5	1.5	2.0			1.8
Total Seal Leakage (SCFM)		7.1	7.3	7.9	7.4	6.8	6.8	7.6	7.5			7.6
Test Bearing Outer Ring (°F)		650	650	650	650	650	660	650	655			650
Test Bearing Inner Ring (°F)		660	660	660	660	660	670	665	665			655
Roller Bearing Outer Ring (°F)		605	650	650	645	645	650	640	640			650
Oil Seal Housing (°F)		—	—	—	—	—	—	—	—			—
Air Seal Housing (°F)		950	990	965	960	980	975	970	975			960
Test Bearing Housing (°F)		610	680	680	680	680	675	675	675			675
Roller Bearing Housing (°F)		510	580	590	570	580	565	580	585			590
Air Seal Bellows (°F)		810	850	860	860	880	880	875	875			870
Hot Air in Manifold (°F)		1120	1120	1120	1125	1125	1125	1125	1125			1100
Oil Inlet (°F)		500	500	500	500	500	495	500	505			500
Oil Outlet (°F)		590	610	610	605	610	605	610	610			610

The majority of the total seal leakage was across the oil seal.
The oxygen content in the bearing chamber was 0.013 - 0.015%.

TEST BEARING # 267112

OIL USED MOBIL XRM109F+10% BY WGT KENDALL HEAVY RESIN 0839 DATE 1/23-27/69

RUNNING TIME, HOURS	207.7	208.7	209.7	210.7	212.1	212.7	213.7	214.8	215.7	216.6	217.6	218.6
SPEED, RPM X 10^3	14	14	14	14	14	14	14	14	STOP: END OF TEST PERIOD	TEST CONDITIONS	14	14
AIR MANIFOLD PRESS. (PSI)	106	106	106	106	106	106	106	106			106	106
BEARING CAVITY PRESS. (PSI)	6	6	6	6	6	6	6	6			6	6
SEAL CAVITY PRESS. (PSI)	111	111	111	111	111	111	111	111			111	111
HOT AIR FLOW (SCFM)	52	50	50	50	51	53	50	52			56	56
TEST OIL FLOW (GPM)	1.8	1.5	1.5	1.5	1.5	1.5	1.5	1.5			1.75	1.75
TOTAL SEAL LEAKAGE (SCFM)	6.2	8.3	8.0	7.0	7.6	8.3	7.0	5.8			5.1	5.0
TEST BEARING OUTER RING (°F)	650	655	650	655	650	650	655	650			650	650
TEST BEARING INNER RING (°F)	655	665	665	670	665	665	665	660			660	660
ROLLER BEARING OUTER RING (°F)	650	650	650	645	650	585	600	630			640	640
OIL SEAL HOUSING (°F)	—	—	—	—	—	—	—	—			—	—
AIR SEAL HOUSING (°F)	965	970	950	955	915	900	940	950			970	970
TEST BEARING HOUSING (°F)	680	680	670	670	640	660	660	660			670	675
ROLLER BEARING HOUSING (°F)	580	580	585	590	560	570	565	570			680	—
AIR SEAL BELLOWS (°F)	870	875	850	840	820	850	850	840			890	910
HOT AIR IN MANIFOLD (°F)	1100	1100	1070	1060	1060	1060	1055	1055			1100	1100
OIL INLET (°F)	500	500	500	500	500	500	500	500			515	515
OIL OUTLET (°F)	610	610	610	610	545	505	580	595			610	610

TEST BEARING # 267112

OIL USED MOBIL XRM 109F +10% BY WGT. KENDALL HEAVY RESIN 0839 DATE 1/27-28/69

RUNNING TIME, HOURS	219.6	220.6	221.6	222.6	223.6	224.6	225.6	226.6	227.2	228.2	229.2	230.2
SPEED, RPM X 10^3	14	14	14	14	14	14	14	STOP: END OF TEST PERIOD	TEST CONDITIONS	14	14	14
AIR MANIFOLD PRESS. (PSI)	106	106	106	106	106	106	106			106	106	106
BEARING CAVITY PRESS. (PSI)	6	6	6	6	6	6	6			6	6	6
SEAL CAVITY PRESS. (PSI)	111	111	111	111	111	111	111			111	111	111
HOT AIR FLOW (SCFM)	54	53	52	52	52	52	51			50	50	51
TEST OIL FLOW (GPM)	1.75	1.75	1.75	1.75	1.75	1.75	1.75			1.75	1.75	1.75
TOTAL SEAL LEAKAGE (SCFM)	4.6	4.4	4.2	4.4	4.6	4.6	8.6			5.8	5.4	4.4
TEST BEARING OUTER RING (°F)	650	650	650	650	650	650	645			655	650	650
TEST BEARING INNER RING (°F)	660	660	660	660	660	660	655			660	660	660
ROLLER BEARING OUTER RING (°F)	630	630	635	640	640	640	640			640	640	645
OIL SEAL HOUSING (°F)	—	—	—	—	—	—	—			—	—	—
AIR SEAL HOUSING (°F)	970	980	980	970	980	980	945			1015	1015	1015
TEST BEARING HOUSING (°F)	670	670	670	670	670	670	680			680	680	680
ROLLER BEARING HOUSING (°F)	—	—	—	—	—	—	—			580	560	560
AIR SEAL BELLOWS (°F)	910	900	900	890	890	890	850			940	940	940
HOT AIR IN MANIFOLD (°F)	1100	1100	1100	1100	1100	1100	1100			1090	1095	1095
OIL INLET (°F)	505	505	505	505	505	505	505			510	510	510
OIL OUTLET (°F)	600	605	600	600	600	600	595			620	620	640

The majority of the total seal leakage was across the oil seal.
The oxygen content in the test bearing chamber was 0.016 - 0.022%.

TEST BEARING # 267112

OIL USED MOBIL XRM 109F + 10% BY WGT KENDALL HEAVY RESIN 0839 DATE 1/28/69

Running Time, Hours	231.2	232.5	233.7	234.2	235.2	236.2	237.2	237.6	238.6	239.6	240.5	
Speed, RPM	14	14	14	14	14	14	STOP: END OF TEST PERIOD	TEST CONDITIONS	14	14	STOP: GEAR COUPLING BETWEEN MOTOR AND CLUTCH FAILED	
Air Manifold Press. (psi)	106	106	106	106	106	106			106	106		
Bearing Cavity Press. (psi)	6	6	6	6	6	6			6	6		
Seal Cavity Press. (psi)	111	111	111	111	111	111			111	111		
Hot Air Flow (scfm)	51	51	51	51	51	51			46	46		
Test Oil Flow (gpm)	1.75	1.75	1.75	1.75	1.75	1.75			1.8	1.8		
Total Seal Leakage (scfm)	5.1	5.1	5.7	5.5	4.4	5.3			4.4	5.1		
Test Bearing Outer Ring (°F)	650	650	650	650	650	650			650	650		
Test Bearing Inner Ring (°F)	660	660	—	—	—	—			660	660		
Roller Bearing Outer Ring (°F)	640	640	635	640	630	630			640	630		
Oil Seal Housing (°F)	—	—	—	—	—	—			—	—		
Air Seal Housing (°F)	1010	1010	1015	1020	1020	1010			1025	1030		
Test Bearing Housing (°F)	675	670	680	680	680	680			680	680		
Roller Bearing Housing (°F)	545	560	560	565	565	500			560	560		
Air Seal Bellows (°F)	935	930	940	945	940	935			930	935		
Hot Air in Manifold (°F)	1095	1095	1130	1130	1130	1130			1130	1130		
Oil Inlet (°F)	515	525	510	510	515	510			505	500		
Oil Outlet (°F)	590	620	612	615	610	605			610	605		

TEST BEARING # 267112

OIL USED MOBIL XRM 109F + 10 % BY WGT. KENDALL HEAVY RESIN 0839 DATE 1/30 - 31/69

RUNNING TIME, HOURS	241.2	242.2	243.2	244.2	245.2	246.2	247.2	248.2	249.2	250.2	251.2	
SPEED, RPM	TEST CONDITIONS	14	14	14	14	14	14	14	14	14	STOP: END OF TEST PERIOD	
AIR MANIFOLD PRESS. (PSI)		106	106	106	106	106	106	106	106	106		
BEARING CAVITY PRESS. (PSI)		6	6	6	6	6	6	6	6	6		
SEAL CAVITY PRESS. (PSI)		111	111	111	111	111	111	111	111	111		
HOT AIR FLOW (SCFM)		46	46	46	46	48	48	48	48	48		
TEST OIL FLOW (GPM)		1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9		
TOTAL SEAL LEAKAGE (SCFM)		4.2	5.1	4.2	4.8	4.8	4.9	4.9	4.4	4.6		
TEST BEARING OUTER RING (°F)		660	660	660	660	660	660	655	650	650		
TEST BEARING INNER RING (°F)		665	665	665	665	665	665	660	655	655		
ROLLER BEARING OUTER RING (°F)		650	650	650	650	650	650	640	645	650		
OIL SEAL HOUSING (°F)		—	—	—	—	—	—	—	—	—		
AIR SEAL HOUSING (°F)		1010	1010	1010	1010	1010	1010	1005	1010	1010		
TEST BEARING HOUSING (°F)		670	680	680	680	675	660	645	650	650		
ROLLER BEARING HOUSING (°F)		575	570	570	570	560	550	540	545	540		
AIR SEAL BELLOWS (°F)		940	935	940	940	935	940	930	935	930		
HOT AIR IN MANIFOLD (°F)		1120	1120	1120	1120	1120	1120	1115	1120	1120		
OIL INLET (°F)		500	500	500	500	500	500	500	500	500		
OIL OUTLET (°F)		630	630	630	630	630	630	630	620	620		

TEST BEARING # 267112

OIL USED MOBIL XRM 109F +10% BY WGT KENDALL HEAVY RESIN 0839 DATE 2/3/69

RUNNING TIME, HOURS	251.9	252.9	254.1	256.1	256.9	257.9	258.9	259.9	260.9	261.9		
SPEED, RPM	TEST CONDITIONS	14	14	14	14	14	14	14	14	STOP: END OF TEST PERIOD		
AIR MANIFOLD PRESS. (PSI)		106	106	106	106	106	106	106	106			
BEARING CAVITY PRESS. (PSI)		6	6	6	6	6	6	6	6			
SEAL CAVITY PRESS. (PSI)		111	111	111	111	111	111	111	111			
HOT AIR FLOW (SCFM)		50	50	50	52	53	54	54	54			
TEST OIL FLOW (GPM)		2.0	2.0	2.0	20	2.0	1.8	1.8	1.8			
TOTAL SEAL LEAKAGE (SCFM)		4.6	4.2	5.1	5.8	5.4	5.4	5.2	5.9			
TEST BEARING OUTER RING (°F)		660	660	655	660	660	660	660	660			
TEST BEARING INNER RING (°F)		670	670	665	670	670	670	670	670			
ROLLER BEARING OUTER RING (°F)		645	650	650	645	645	640	650	650			
OIL SEAL HOUSING (°F)		—	—	—	—	—	—	—	—			
AIR SEAL HOUSING (°F)		1020	1030	1025	1020	1035	1025	1020	1020			
TEST BEARING HOUSING (°F)		670	680	670	680	680	675	650	675			
ROLLER BEARING HOUSING (°F)		555	560	565	560	560	560	560	565			
AIR SEAL BELLOWS (°F)		930	930	935	930	925	930	930	925			
HOT AIR IN MANIFOLD (°F)		1120	1120	1120	1120	1120	1120	1120	1120			
OIL INLET (°F)		500	500	495	500	500	500	500	500			
OIL OUTLET (°F)		620	620	625	625	625	620	625	625			

TEST BEARING # 267112

OIL USED MOBIL XRM 109F + 10 o/o BY WGT. KENDALL HEAVY RESIN 0839 DATE 2/4/69

RUNNING TIME, HOURS	262.6	263.6	264.6	265.6	266.6	267.6	268.6	269.9	270.8	271.6	272.6
SPEED, RPM	TEST CONDITIONS	14	14	14	14	14	14	14	14	14	STOP: END OF TEST PERIOD
AIR MANIFOLD PRESS. (PSI)		106	106	106	106	106	106	106	106	106	
BEARING CAVITY PRESS. (PSI)		6	6	6	6	6	6	6	6	6	
SEAL CAVITY PRESS. (PSI)		111	111	111	111	111	111	111	111	111	
HOT AIR FLOW (SCFM)		48	50	50	50	51	50	50	50	50	
TEST OIL FLOW (GPM)		1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	
TOTAL SEAL LEAKAGE (SCFM)		4.9	4.9	4.7	4.9	5.1	5.3	6.5	6.5	5.6	
TEST BEARING OUTER RING (°F)		660	655	655	650	650	655	655	655	655	
TEST BEARING INNER RING (°F)		665	660	660	655	655	660	660	665	665	
ROLLER BEARING OUTER RING (°F)		650	650	650	645	620	645	645	655	650	
OIL SEAL HOUSING (°F)		—	—	—	—	—	—	—	—	—	
AIR SEAL HOUSING (°F)		990	995	995	990	980	990	985	980	970	
TEST BEARING HOUSING (°F)		680	675	670	675	670	675	665	670	665	
ROLLER BEARING HOUSING (°F)		565	575	590	590	590	590	580	590	580	
AIR SEAL BELLOWS (°F)		910	910	915	915	910	905	900	890	880	
HOT AIR IN MANIFOLD (°F)		1105	1110	1110	1115	1115	1115	1115	1115	1115	
OIL INLET (°F)		505	510	510	510	500	510	515	510	510	
OIL OUTLET (°F)		625	620	625	620	600	620	620	620	610	

TEST BEARING # 267112

OIL USED MOBIL XRM 109 F + 10 % BY WGT KENDALL HEAVY RESIN 0839 DATE 2/5-6/69

Running Time, Hours	273.4	274.4	275.4	276.4	277.4	278.4	279.4	280.2				
Speed, RPM	TEST CONDITIONS	14	14	14	14	14	14	STOP: TIME - UP				
Air Manifold Press. (psi)		106	106	106	106	106	106					
Bearing Cavity Press. (psi)		6	6	6	6	6	6					
Seal Cavity Press. (psi)		111	111	111	111	111	111					
Hot Air Flow (SCFM)		47	48	50	50	50	50					
Test Oil Flow (GPM)		1.8	1.6	1.6	1.6	1.6	1.6					
Total Seal Leakage (SCFM)		4.7	5.4	4.8	4.4	4.9	5.8					
Test Bearing Outer Ring (°F)		650	650	650	650	640	640					
Test Bearing Inner Ring (°F)		670	670	675	665	670	668					
Roller Bearing Outer Ring (°F)		610	650	630	630	625	630					
Oil Seal Housing (°F)		—	—	—	—	—	—					
Air Seal Housing (°F)		930	1005	990	980	970	960					
Test Bearing Housing (°F)		660	700	730	650	660	595					
Roller Bearing Housing (°F)		540	560	580	555	510	520					
Air Seal Bellows (°F)		880	900	935	915	885	935					
Hot Air in Manifold (°F)		1110	1070	1090	1090	1090	1090					
Oil Inlet (°F)		510	510	520	515	510	510					
Oil Outlet (°F)		580	625	625	600	595	590					

The majority of the total seal leakage was across the oil seal.
The oxygen content in the test bearing chamber was 0.015 - 0.018%.

TEST BEARING # 267113 [M-50 Steel Bearing, 459981G (Series I)]

OIL USED MOBIL JET II (OPEN ATMOSPHERE) DATE 10/13-28/69

RUNNING TIME, HOURS	0.0	0.7	1.1	1.8	2.4	2.9	2.9	3.5	3.5	3.9	3.9	5.3
SPEED, RPM	START	14	14	14	14	STOP: EXCESSIVE BRG. CAVITY PRES.	RESTART	STOP: EXCESSIVE TOTAL SEAL LEAKAGE	RESTART	STOP: REPLACE O_2 INLET LINE	RESTART	14
AIR MANIFOLD PRESS. (PSI)		106	106	106	106							106
BEARING CAVITY PRESS. (PSI)		6	6	6	6							6
SEAL CAVITY PRESS. (PSI)		111	111	111	111							111
HOT AIR FLOW (SCFM)		42	42	42	46							42
TEST OIL FLOW (GPM)		2	2	1.5	1.0							2.0
TOTAL SEAL LEAKAGE (SCFM)		14.4	12.7	15.3	15.3							13.2
TEST BEARING OUTER RING (°F)		490	500	510	545							470
TEST BEARING INNER RING (°F)		508	515	530	560							490
ROLLER BEARING OUTER RING (°F)		475	480	470	480							460
OIL SEAL HOUSING (°F)		—	—	—	—							—
AIR SEAL HOUSING (°F)		910	910	890	885							860
TEST BEARING HOUSING (°F)		480	490	485	480							470
ROLLER BEARING HOUSING (°F)		420	420	420	400							370
AIR SEAL BELLOWS (°F)		715	715	700	695							680
HOT AIR IN MANIFOLD (°F)		1015	1020	990	990							945
OIL INLET (°F)		395	410	390	380							
OIL OUTLET (°F)		445	450	450	450							430

TEST BEARING # 267113

OIL USED MOBIL JET II (OPEN ATMOSPHERE)

DATE 10/28-11/4/69

Running Time, Hours	5.35	5.6	5.8	6.7	7.25	8.0	10.5	10.5	11.3	11.45	13.45	14.0
Speed, RPM		16		16	16	16	17.5		18			18
Air Manifold Press. (psi)	STOP: RESTART SHEAR PINS	106	STOP: RESTART CHECK SHEAR PINS	106	106	106	STOP: BELT SLIPPED OFF PULLEY	RESTART: BELT ADJUSTMENTS	106	STOP: BELT CAME APART	BELT ADJUSTMENTS RESTART	106
Bearing Cavity Press. (psi)		6		6	6	6			6			6
Seal Cavity Press. (psi)		111		111	111	111			111			111
Hot Air Flow (scfm)		48		44	44	44			39			—
Test Oil Flow (gpm)		2.0		2.0	1.5	1.0			2.0			2.0
Total Seal Leakage (scfm)		13.2		—	7.2	6.8			8.9			—
Test Bearing Outer Ring (°F)		490		560	555	560			570			550
Test Bearing Inner Ring (°F)		495		570	570	580			570			545
Roller Bearing Outer Ring (°F)		470		540	540	520			475			515
Oil Seal Housing (°F)		—		—	—	—			—			—
Air Seal Housing (°F)		870		880	890	895			820			870
Test Bearing Housing (°F)		470		495	490	475			405			480
Roller Bearing Housing (°F)		380		450	450	410			350			400
Air Seal Bellows (°F)		680		745	760	775			690			750
Hot Air in Manifold (°F)		945		955	970	980			920			930
Oil Inlet (°F)		390		—	450	430			430			—
Oil Outlet (°F)		430		520	525	500			455			500

TEST BEARING # 267113

OIL USED MOBIL JET II (OPEN ATMOSPHERE)

DATE 11/4-5/69

Running Time, Hours	14.05	14.45	14.75	15.75	15.95	16.35	16.65	17.05	18.25	18.75	18.85	19.35
Speed, RPM	SHEAR PINS STOP: RESTART	STOP: RESTART	SHEAR PINS STOP: RESTART	STOP: RIG SEAL LIFT OFF: RESTART	18	STOP: RIG SEAL LIFT OFF: RESTART	18	18	18	18	18	18
Air Manifold Press. (psi)					106		106	106	106	106	106	106
Bearing Cavity Press. (psi)					6		6	6	6	6	6	6
Seal Cavity Press. (psi)					111		111	111	111	111	111	111
Hot Air Flow (SCFM)					46		40	40	42	44	44	38
Test Oil Flow (GPM)					2.0		1.5	1.5	1.0	1.0	0.75	0.75
Total Seal Leakage (SCFM)					7.6		7.2	6.8	6.8	5.9	—	6.8
Test Bearing Outer Ring (°F)					560		575	640	650	620	610	620
Test Bearing Inner Ring (°F)					560		575	645	680	635	630	640
Roller Bearing Outer Ring (°F)					505		510	570	560	540	540	525
Oil Seal Housing (°F)					—		—	—	—	—	—	—
Air Seal Housing (°F)					915		905	945	960	910	930	895
Test Bearing Housing (°F)					430		465	525	535	520	495	475
Roller Bearing Housing (°F)					380		455	435	445	410	415	370
Air Seal Bellows (°F)					775		775	840	840	807	810	780
Hot Air in Manifold (°F)					975		980	1005	1005	965	955	960
Oil Inlet (°F)					450		430	—	430	400	—	355
Oil Outlet (°F)					490		490	580	570	520	545	475

TEST BEARING # 267113

OIL USED MOBIL JET II (OPEN ATMOSPHERE) DATE 11/24/69

Running Time, Hours	19.35	20.05	20.25	20.45	20.75	20.75						
Speed, RPM	RESTART	20	RIG SEAL LIFT-OFF	20	20	STOP: SPEED CHANGE; FIRE						
Air Manifold Press. (psi)												
Bearing Cavity Press. (psi)												
Seal Cavity Press. (psi)												
Hot Air Flow (SCFM)												
Test Oil Flow (GPM)		1.5		1.0	1.0							
Total Seal Leakage (SCFM)												
Test Bearing Outer Ring (°F)		610		660	650							
Test Bearing Inner Ring (°F)		620		675	670							
Roller Bearing Outer Ring (°F)		560		605	600							
Oil Seal Housing (°F)		—		—	—							
Air Seal Housing (°F)		880		900	880							
Test Bearing Housing (°F)		505		540	560							
Roller Bearing Housing (°F)		430		475	450							
Air Seal Bellows (°F)		730		770	775							
Hot Air in Manifold (°F)		930		950	950							
Oil Inlet (°F)		—		—	—							
Oil Outlet (°F)		550		590	565							

TEST BEARING # 267114 M-50 Steel Bearing, 459981G (Series I)

OIL USED MOBIL JET II (OPEN ATMOSPHERE) DATE 8/3/70

RUNNING TIME, HOURS	0.0	1.5	1.7	1.9	2.1	OFF — LOST WATER PRESSURE TO MOTOR CLUTCH	2.6	3.0	3.6	4.6	5.7	STOP: BEARING SEIZURE
SPEED, RPM	START	15	16	18	20		20	20	20	20	20.8	
AIR MANIFOLD PRESS. (PSI)		106	106	106	106		106	106	106	106	106	
BEARING CAVITY PRESS. (PSI)		6	6	6	6		6	6	6	6	6	
SEAL CAVITY PRESS. (PSI)		111	111	111	111		111	111	111	111	111	
HOT AIR FLOW (SCFM)		35	35	45	42		42	32	42	42	42	
TEST OIL FLOW (GPM)		1.25	1.0	0.75	0.75		0.75	1.0	1.0	1.0	1.0	
TOTAL SEAL LEAKAGE (SCFM)		12.3	11.5	10.2	9.8		7.6	8.1	7.6	8.5	6.4	
TEST BEARING OUTER RING (°F)		390	410	440	400		510	510	560	570	575	
TEST BEARING INNER RING (°F)		420	440	460	520		535	600	600	610	620	
ROLLER BEARING OUTER RING (°F)		405	440	460	500		510	515	520	520	510	
OIL SEAL HOUSING (°F)		—	—	—	—		—	—	—	—	—	
AIR SEAL HOUSING (°F)		705	710	745	780		795	805	820	820	825	
TEST BEARING HOUSING (°F)		450	450	455	460		455	455	460	455	460	
ROLLER BEARING HOUSING (°F)		375	370	375	380		323	375	385	385	380	
AIR SEAL BELLOWS (°F)		590	585	610	635		650	670	685	690	690	
HOT AIR IN MANIFOLD (°F)		940	945	965	985		995	985	1005	1005	1005	
OIL INLET (°F)		190	190	205	210		175	210	210	210	210	
OIL OUTLET (°F)		390	345	370	400		405	435	430	430	440	

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