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FINAL REPORT

SMALL HIGH-SPEED SELF-ACTING SHAFT SEALS FOR LIQUID ROCKET ENGINES

by

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Rockwell International
Rocketdyne Division

prepared for

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16. Abstract

Design analysis, fabrication, and experimental evaluation was performed on three self-acting face-type LOX seal designs and one circumferential-type helium seal design. The LOX seals featured Rayleigh step lift pad and spiral groove geometry for lift augmentation. Machined metal bellows and piston ring secondary seal designs were tested. The helium purge seal featured floating rings with Rayleigh step lift pads.

The Rayleigh step pad piston ring and the spiral groove LOX seals were successfully tested for approximately 10 hours in liquid oxygen at 2,757,903 N/m^2a (400 psia) and 8062 rad/s (77,000 rpm). The helium seal was successfully tested for 24 hours at 206,843 N/m^2g (30 psig). The machined metal bellows LOX seal will require further development.

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FOREWORD

This program was funded by the National Aeronautics and Space Administration, Lewis Research Center, Chemical Rockets Section, under Contract NAS3-17769. The period of performance was July 1973 to December 1976.

The NASA Project Manager was Mr. C. J. Morgan. The Contracting Officer was Mr. Edward J. Kolman. Design support and technical consultation was provided by Mr. L. P. Ludwig, Mr. W. F. Hady, and Dr. John Zuk of the NASA Fluid Systems Components Division.

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SUMMARY

This report covers the design, analysis, fabrication, testing, and evaluation of three self-acting lift pad liquid oxygen face seals and one helium purge floating ring seal with self-acting lift pads on the floating ring ID. The objective of this program was to develop the technology for reliable, 10-hour life, multiple-start seals for use in small, high-speed liquid oxygen turbopumps. The seals were designed to operate at 9425 rad/s (90,000 rpm) on a 20-mm OD shaft with 3,102,640 N/m^2a (450 psia) LOX sealed pressure, 344,737 N/m^2a (50 psia) helium purge pressure, and 137,895 N/m^2a (20 psia) maximum drain cavity pressures for 300 starts.

The four seals evaluated were:

1. Shrouded Rayleigh step hydrodynamic lift pad LOX face seal with a machined metal bellows secondary seal
2. Shrouded Rayleigh step hydrodynamic lift pad LOX face seal with a piston ring secondary seal
3. Spiral groove hydrostatic/hydrodynamic LOX face seal with a piston ring secondary.
4. Helium purge intermediate floating ring seal with Rayleigh step lift pads on the ring ID

Experimental evaluation of the seals in a turbine driven seal tester is summarized below:

1. The Rayleigh step LOX face seal primary element was tested for 11 hours, 40 minutes, including 376 starts, with an average oxygen leakage of 0.762 m^3/minute (26.9 scfm) at 8063 rad/s (77,000 rpm) and 2,413,165 to 2,771,692 N/m^2g (350 to 402 psig) sealed pressure. The Rayleigh step concept appears quite feasible for small, high-speed, LOX turbopumps.
2. The piston ring secondary LOX seal was tested for 11 hours, 27 minutes, including 365 starts, and is feasible for small, high-speed liquid oxygen turbopumps.
3. The machined metal bellows secondary LOX seal was not feasible due to carbon wear and difficulty of fabrication.
4. The spiral groove LOX seal was tested for 11 hours, 43 minutes, including 339 starts with an average leakage of 0.657 m^3/minute (23.2 scfm) at 8063 rad/s (77,000 rpm) and 2,413,165 to 3,757,903 N/m^2g (350 to 400 psig) sealed pressure. The spiral groove concept also appears feasible for small, high-speed, oxygen turbopumps.
5. Five assemblies of the helium purge intermediate floating ring seal experienced satisfactory performance for 749 tests, totalling 24 hours of operation, demonstrating feasibility of this concept.
6. The reverse pumping upstream of the seal was not a reliable method of reducing the pressure at the seal. The pressure drop appeared to be a function of seal cavity through flow.

INTRODUCTION

Recent system studies of future DoD and NASA reusable vehicles for space maneuvering missions have shown that high-pressure, staged combustion cycle engines offer significant benefit in terms of higher vehicle payload capability. These engines which are in the 44,480 to 111,200 N (10,000 to 25,000 pounds) thrust class, require relatively low flow, high-head turbopumps which are physically smaller and fall outside the design state of the art of rocket turbomachinery. The preliminary designs which have evolved in the studies to date are based on current technology, presupposing a valid extrapolation of this technology to the smaller size. Additionally, and in contrast to past design requirements, reuse encompassing 300 starts and 10 hours time-between-overhauls is envisioned. Thus, designers are confronted with both size and life requirement uncertainties.

Preliminary designs of the oxygen turbopump indicate that shaft speeds up to 9425 rad/s (90,000 rpm) are desirable to achieve low weight and reasonable pump and turbine efficiencies. The shaft used to transmit torque from the turbine to the pump is of such size as to require seals with approximately 20-mm bore diameter. This translates into seal face equivalent rubbing velocities of over 182.88 m/sec (600 ft/sec) and exceeds the state of the art for the conventional rubbing contact seals. Although cryogenic testing has been limited, hydrostatic or hydrodynamic fluid film type seals appear to offer the means to achieve the required multiple starts and extended life capability since the fluid film concept essentially eliminates rubbing contact while maintaining an acceptable leakage rate.

This report documents the work accomplished under NASA Contract NAS3-17769 to develop the technology for reliable, 10-hour life, multiple-start seals for use in small, high-speed liquid oxygen turbopumps. The scope of the program consisted of a review and analysis of primary and intermediate seal designs furnished by NASA. Design and analysis of two alternate primary seal configurations, the spiral groove seal and the Rayleigh step piston ring seal; modification of an existing tester; and experimental evaluation of the NASA seals and the NASA/Rocketdyne selected alternate primary seal using both gaseous nitrogen and liquid oxygen were carried out. Hydrodynamic analysis of the NASA seal designs were provided by NASA-Lewis. Mechanical design, structural, thermal analysis, and dynamic analysis were performed by Rocketdyne. The spiral groove seal was designed and fabricated by Crane Packing Co. to Rocketdyne's specification. The seal tester, designed by Rocketdyne, made maximum use of hardware from an existing tester that was modified for this program. Thermal, stress, including finite element models of seal components, and dynamic analyses of the testor were made and the test program was accomplished at Wyle Laboratories.

SEAL DESIGN

A design analysis and detail design were performed on three different self-acting lift pad liquid oxygen face seal designs and one self-acting floating ring helium seal design. Preliminary design layouts were provided by NASA for the Rayleigh step self-acting lift pad bellows LOX seal, piston ring LOX seal, and helium seal. The Rayleigh step lift pad analysis was provided by NASA. The seal detail design was provided by Rocketdyne and the seal suppliers. The spiral groove LOX seal analysis and detail design were provided by Crane Packing Co. in accordance with Rocketdyne specifications.

The LOX seal designs are all interchangeable with each other. The Rayleigh step bellows seal and piston ring seal use the same carbon seal ring and rotating mating ring. The same Rayleigh step lift pad analysis and carbon seal ring deflection analysis were applied to both designs. The same mating ring stress and deflection analysis was applied to all three designs. The spiral groove seal mating ring is the same, except for the spiral grooves. All three designs utilize the same reverse pumping feature to reduce the sealed pressure. The materials are similar on all three seals.

The LOX seals were designed to the following specifications:

Fluid:

Liquid and/or gaseous oxygen

Gaseous nitrogen

Temperature:

105 to 145.2 K (-270 to -198 F) oxygen

294 K (70 F) nitrogen

Pressure:

137,895 to 3,102,641 N/m^2 (20 to 450 psia)

Speed:

2617 to 9425 rad/s (25,000 to 90,000 rpm)

Acceleration Rate:

4188 rad/s/s (40,000 rpm/sec)

Number of Starts:

300

Operating Life:

10 hours

Shaft Size:

20 mm (0.787 in.)

Operating Length:

0.0254 ±0.0005 m (1.000 ±0.020 in.)

The helium seal was designed for 344,738 N/m^2a (50 psia) gaseous helium purge at 294.3 K (70 F). The other requirements are the same as for the LOX seal.

RAYLEIGH PAD AND DAM

The Rayleigh step lift pads provide hydrodynamic lift for noncontact operation. A fluid film is developed at the seal face to support the seal ring without rubbing contact. The fluid film thickness or sealing gap is controlled by the hydrodynamic lifting force at the seal face. The lift force decreases for larger gaps and increases for smaller gaps to maintain the desired fluid film thickness. The film thickness is established by balancing the closing forces on the seal ring against the opening forces on the face. The seal ring seeks an equilibrium position where the opening force is equal to the closing force. The operating gap can be adjusted by changing the closing force.

The Rayleigh pad analysis was performed by NASA using a computer program titled NASA Revised Self-Acting Lift Pad Design Program for Gas Film Seals (Ref. 1). A summary of the final lift pad geometry is given in Table 1. The final Rayleigh pad carbon seal ring design is shown in Fig. 1.

The lift pad geometry was optimized for gaseous oxygen at 145.2 K (-198 F) to provide margin against rubbing contact due to decreased lift force if the liquid oxygen vaporized in the lift pad area. The lift force at 9425 rad/s (90,000 rpm) and 0.0000025 m (0.0001 in.) film thickness decreases from 146.8 N (33 pounds) for liquid oxygen to 93.4 N (21 pounds) for gaseous oxygen. If a design based on liquid conditions is run with gas, the decreased lift force may result in rubbing contact and seal damage. A gas design seal running in liquid or liquid and gas mixture will operate with a larger film thickness and increased leakage. The increased leakage is more acceptable than rubbing contact.

The relationship of generated lift force and operating film thickness for liquid oxygen, gaseous oxygen, and gaseous nitrogen is shown in Fig. 2 through 4 . The design condition that results in the minimum lift force determines the maximum seal spring load and pressure closing force. The minimum lift force for a desired operating film thickness of 0.0000025 m (0.0001 in.) is 22.24 N (5 pounds) with gaseous oxygen at the minimum design speed of 2618 rad/s (25,000 rpm). The operating film thickness at the maximum design speed of 9425 rad/s (90,000 rpm) would be approximately 0.0000063 m (0.00025 in.) with gaseous oxygen and 0.000013 m (0.0005 in.) with liquid oxygen using the 22.24 N (5-pound) closing force.

The sealing dam pressure opening force and the closing force due to the pressure acting on the bellows mean effective diameter or the secondary seal diameter were balanced as close as possible for the assumed conditions. The leakage across the sealing dam was assumed to be compressible fluid between parallel sealing surfaces with isentropic entrance conditions and choking (sonic flow) at the exit.

The NASA computer program titled Quasi-One-Dimensional Compressible Flow Across Face Seals and Narrow Slots (Ref. 2) was used to analyze the sealing dam opening force and leakage. The predicted average opening pressure at the

TABLE 1. SUMMARY OF RAYLEIGH PAD LOX SEAL GEOMETRY

Outer Diameter, m (in.)	0.04470 to 0.04415 (1.760 to 1.762)
Inner Diameter, m (in.)	0.03454 to 0.03459 (1.360 to 1.362)
Inside Shoulder, m (in.)	0.00051 to 0.00064 (0.020 to 0.025)
Outside Shoulder, m (in.)	0.00051 to 0.00064 (0.020 to 0.025)
Pad Width (nominal)	0.00406 (0.160)
Total Pad Length (including feed grooves), radians (degrees)	0.628 (36)
Number of Pads	10
Feed Groove, radians (degrees)	0.3840 (22)
Land Length (not including shroud), radians (degrees)	0.1920 (11)
Pad Depth, m (in.)	0.00001 to 0.000015 (0.0004 to 0.0006)
Feed Groove Depth, m (in.)	0.00076 to 0.0089 (0.030 to 0.035)
Feed Groove Radius, m (in.)	0.00038 to 0.00051 (0.015 to 0.020)
Ratio Pad/Land Lengths	2:1
Seal Ring Material	Carbon
Seal Ring Thickness, m (in.)	0.00635 to 0.00648 (0.250 to 0.255)

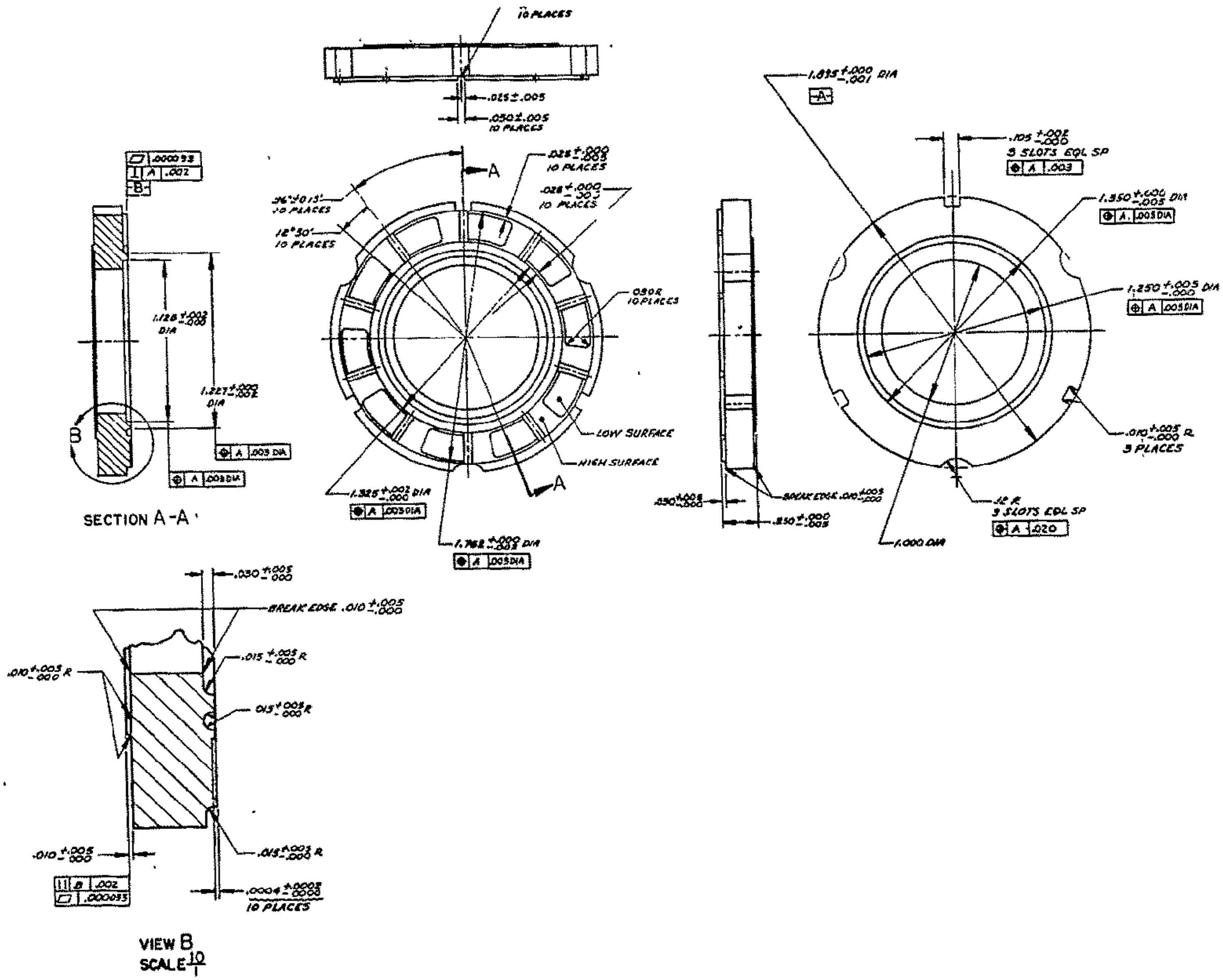


Figure 1. Final Rayleigh Pad LOX Seal Carbon Ring Design

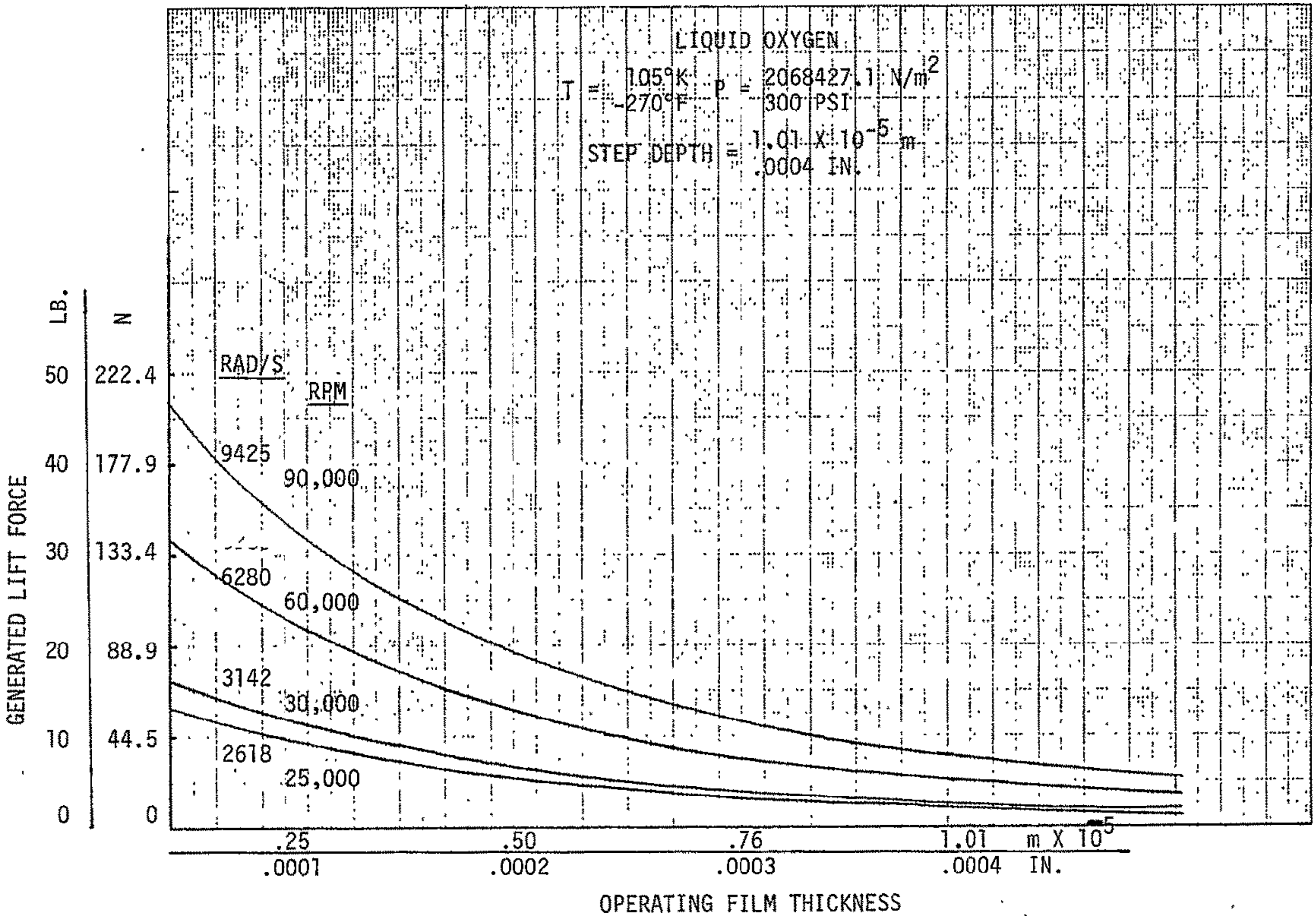


Figure 2. Rayleigh Pad LOX Seal Force vs Film Thickness for Liquid Oxygen

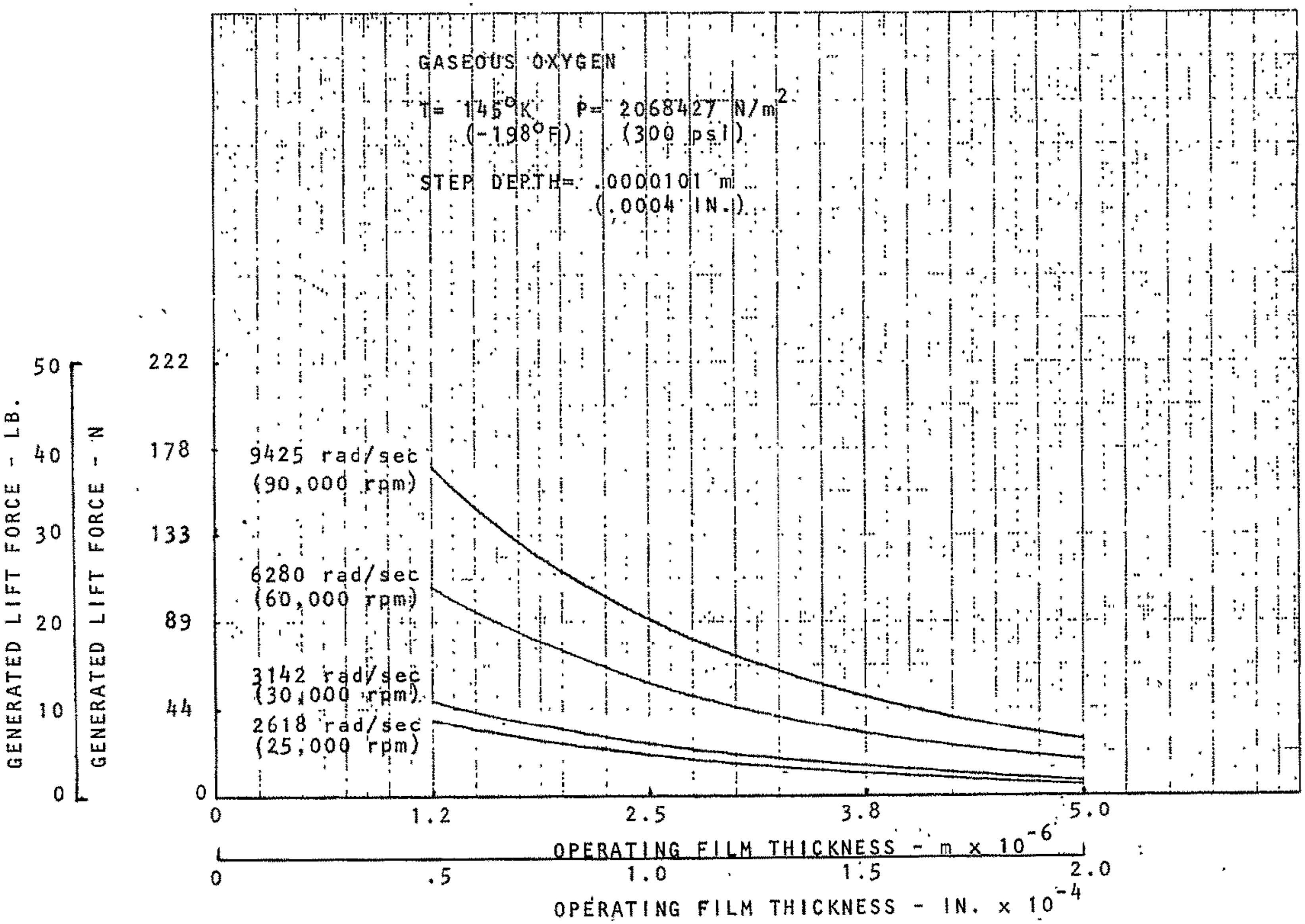


Figure 3. Rayleigh Pad LOX Seal Life Force vs Film Thickness for Gaseous Oxygen

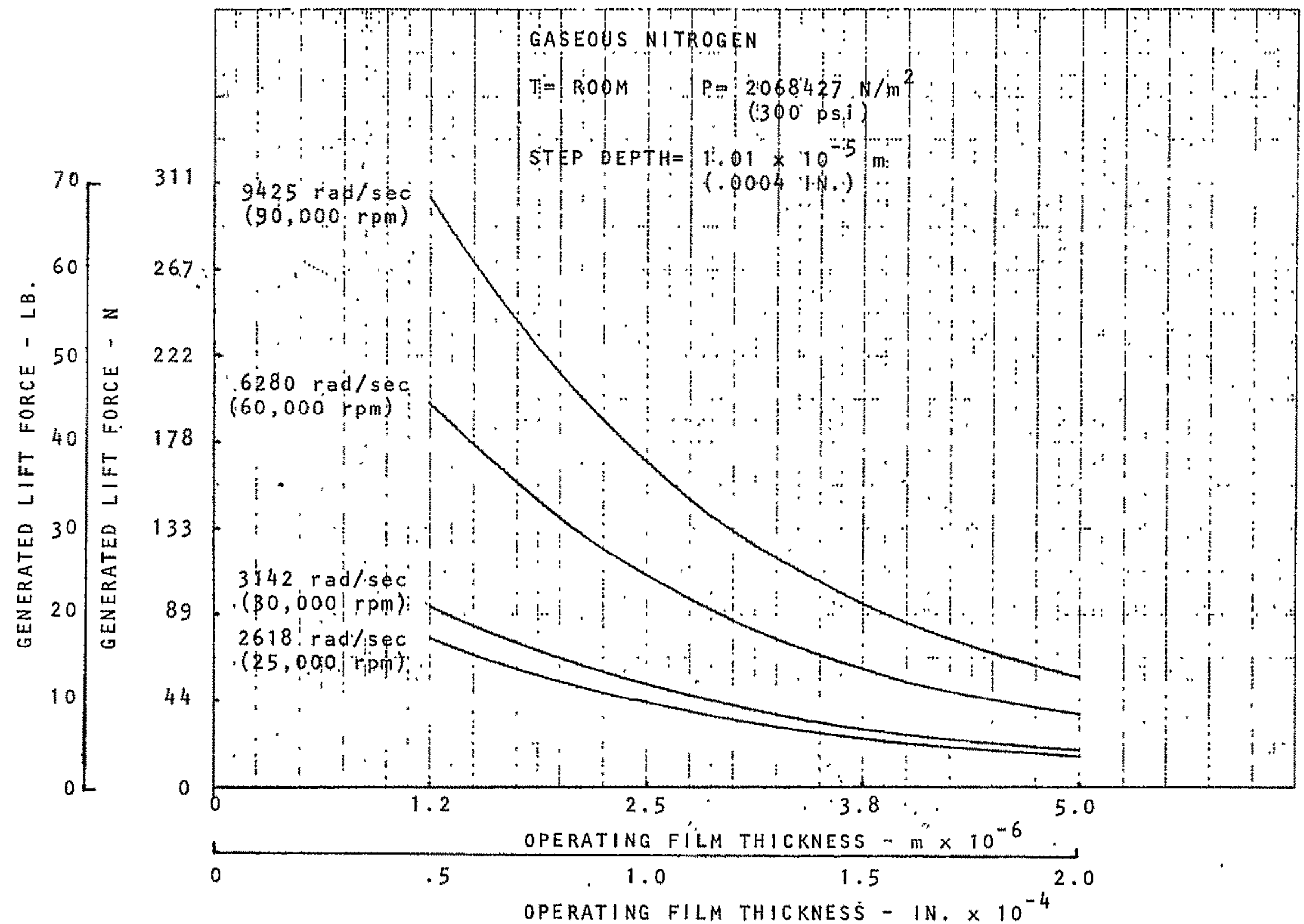


Figure 4. Rayleigh Pad LOX Seal Lift Force vs Film Thickness for Gaseous Nitrogen

sealing dam is 0.655 to 0.691 (pressure profile factor or force bar) of the pressure differential at the nominal pressure ratio of 20 (assumes 2,757,903 N/m^2a (400 psia) upstream and 137,895 N/m^2a (20 psia) downstream for the film thickness of 0.0000025 to 0.00001 m (0.0001 to 0.0004 in.). The variation within the expected pressure ratio range of 15 to 30 is 0.647 to 0.696. The relationship of force bar and pressure ratio is shown in Fig. 5.

The sealing dam dimensions were selected to provide a 0.7 balance ratio (closing area/dam area). The seal is pressure balanced when the balance ratio is equal to the sealing dam pressure profile factor. The design provides a slightly positive pressure closing force to allow for variations in fluid condition and sealing surface geometry.

The predicted sealing dam leakage rate as a function of operating film thickness and speed at pressures of 2,068,427 N/m^2a (300 psia) and 3,102,641 N/m^2a (450 psia) for gaseous oxygen and liquid oxygen is shown in Fig. 5 through 8. The liquid leakage tends to decrease at higher speed due to outward viscous pumping which opposes the inward leakage. The gas leakage is not a function of speed. The static leakage at the lapped joint dam between the seal ring and bellows end plate is not included in the sealing dam leakage. The lapped joint leakage is expected to be negligible. The bellows provides a leak-free secondary sealing element.

The heat loss in the lift pad area due to viscous shear of the sealed fluid is shown in Fig. 9 for liquid oxygen and Fig. 10 for gaseous oxygen. The heat loss at the sealing dam is shown in Fig. 11 and 12. It is expected that the heat loss to the sealed fluid will vaporize most of the liquid oxygen in the lift pad area.

REVERSE PUMPING

The effects of dynamic pumping on the tester rotating mating ring were investigated as a method of reducing the sealed pressure requirement. Dynamic pumping on the rotor faces affects the radial face pressure distribution, shaft axial thrust, and heat added to the fluid. The analysis indicates the possibility of reducing the pressure at the LOX seal to 2,068,427 N/m^2a (300 psia) for a cavity pressure of 3,102,641 N/m^2a (450 psia) at 9425 rad/s (90,000 rpm) using reverse pumping over the rotating mating ring face.

Reverse pumping results from pumping in the gap between the rotating mating ring and the stationary housing as shown in Fig. 13. The lower pressure at the seal reduces the structural requirements of the seal components and the seal leakage. The use of reverse pumping makes the machined metal bellows design feasible by allowing thinner bellows plates and lower spring rate bellows designs.

Analysis was performed on the reverse pumping concept to determine the mating ring geometry and the seal cavity coolant flowrate to achieve the desired radial pressure gradient. The analysis considered the friction heat addition, fluid temperature increase, head drop, density change, and pressure change versus geometry and coolant flowrate. The friction heat addition for the other

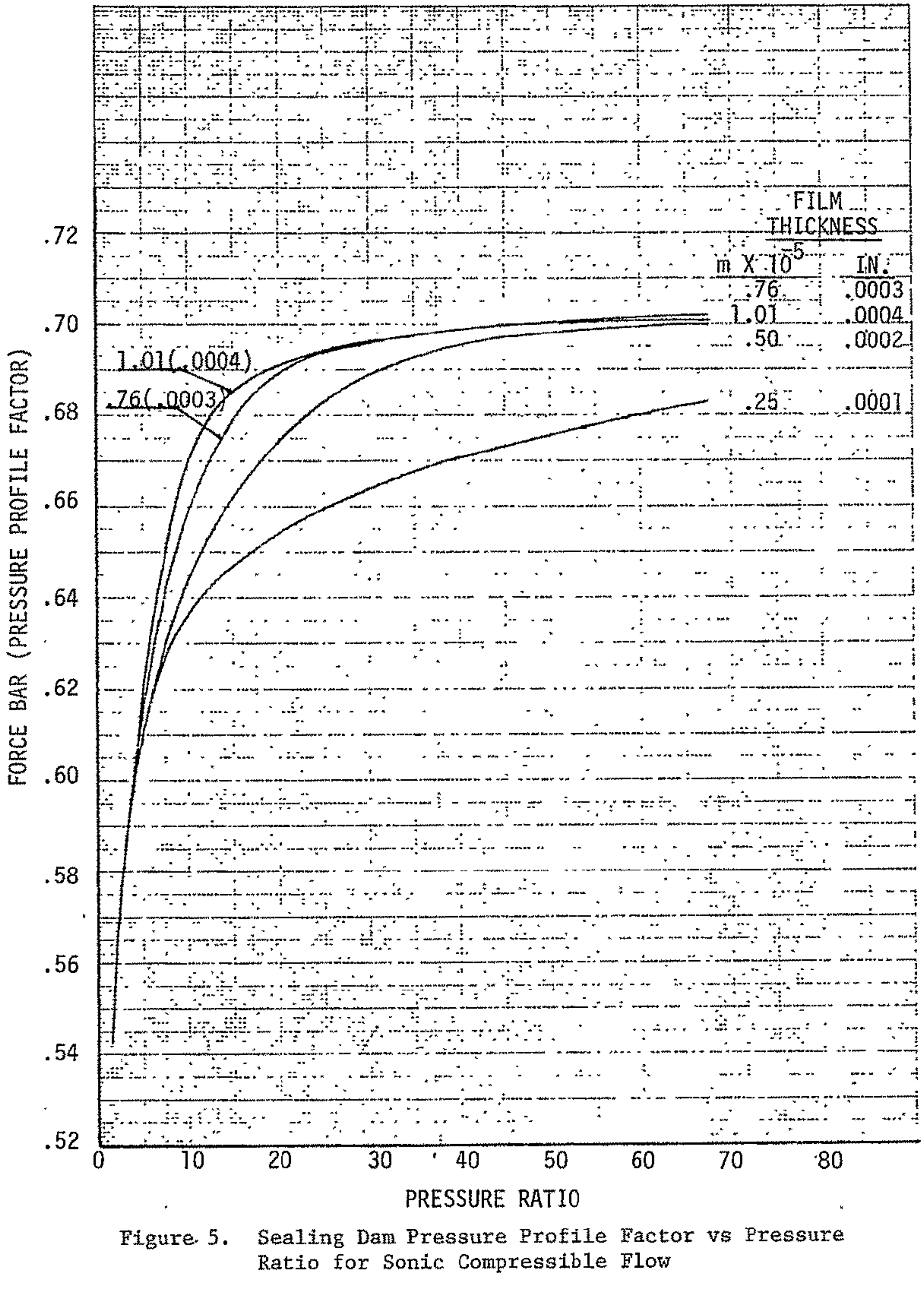


Figure 5. Sealing Dam Pressure Profile Factor vs Pressure Ratio for Sonic Compressible Flow

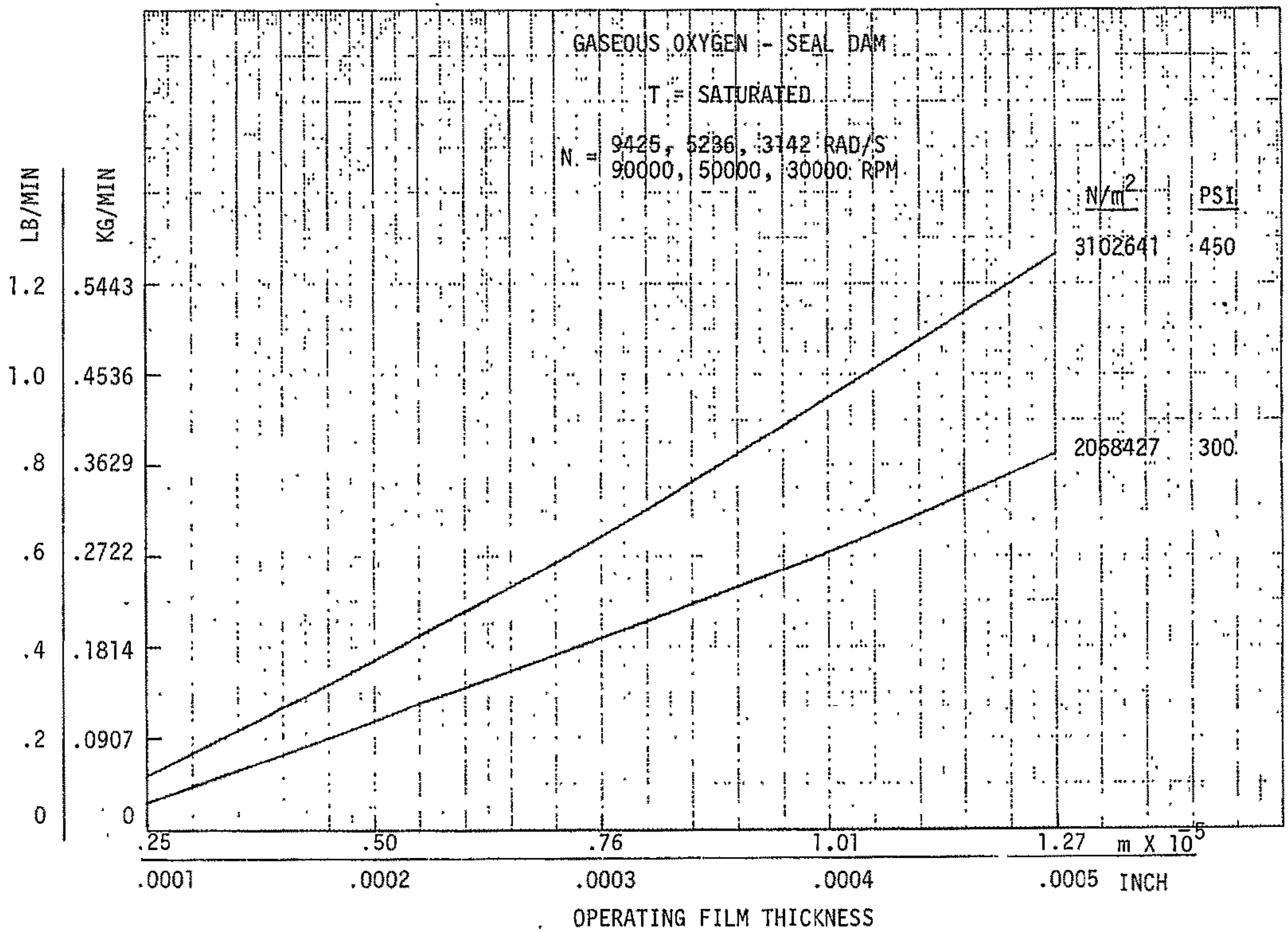


Figure 6. Rayleigh Pad LOX Seal Gaseous Oxygen Sealing Dam Leakage at 300 psia and 450 psia

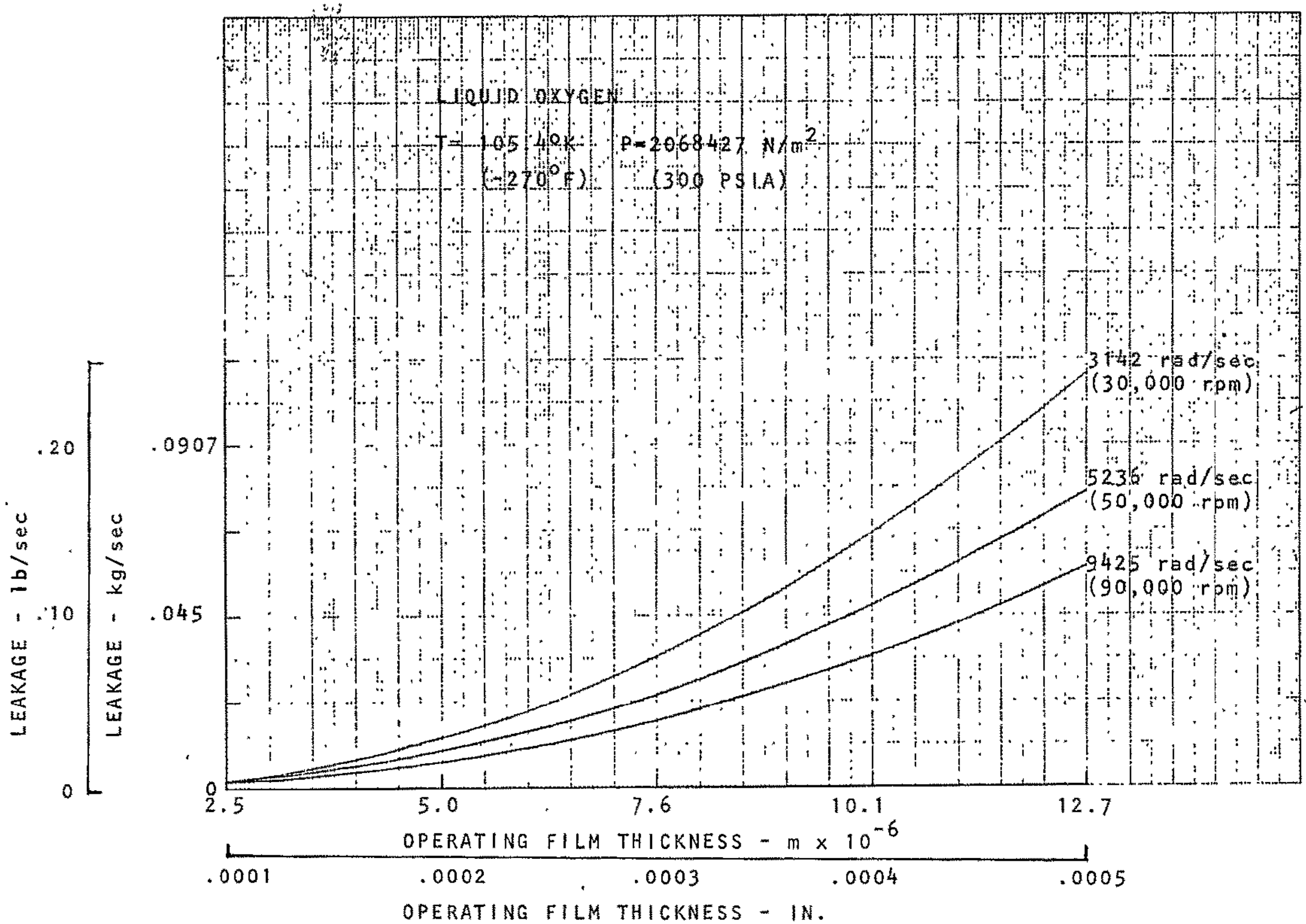


Figure 7. Rayleigh Pad LOX Seal Liquid Oxygen Sealing Dam Leakage at 300 psia

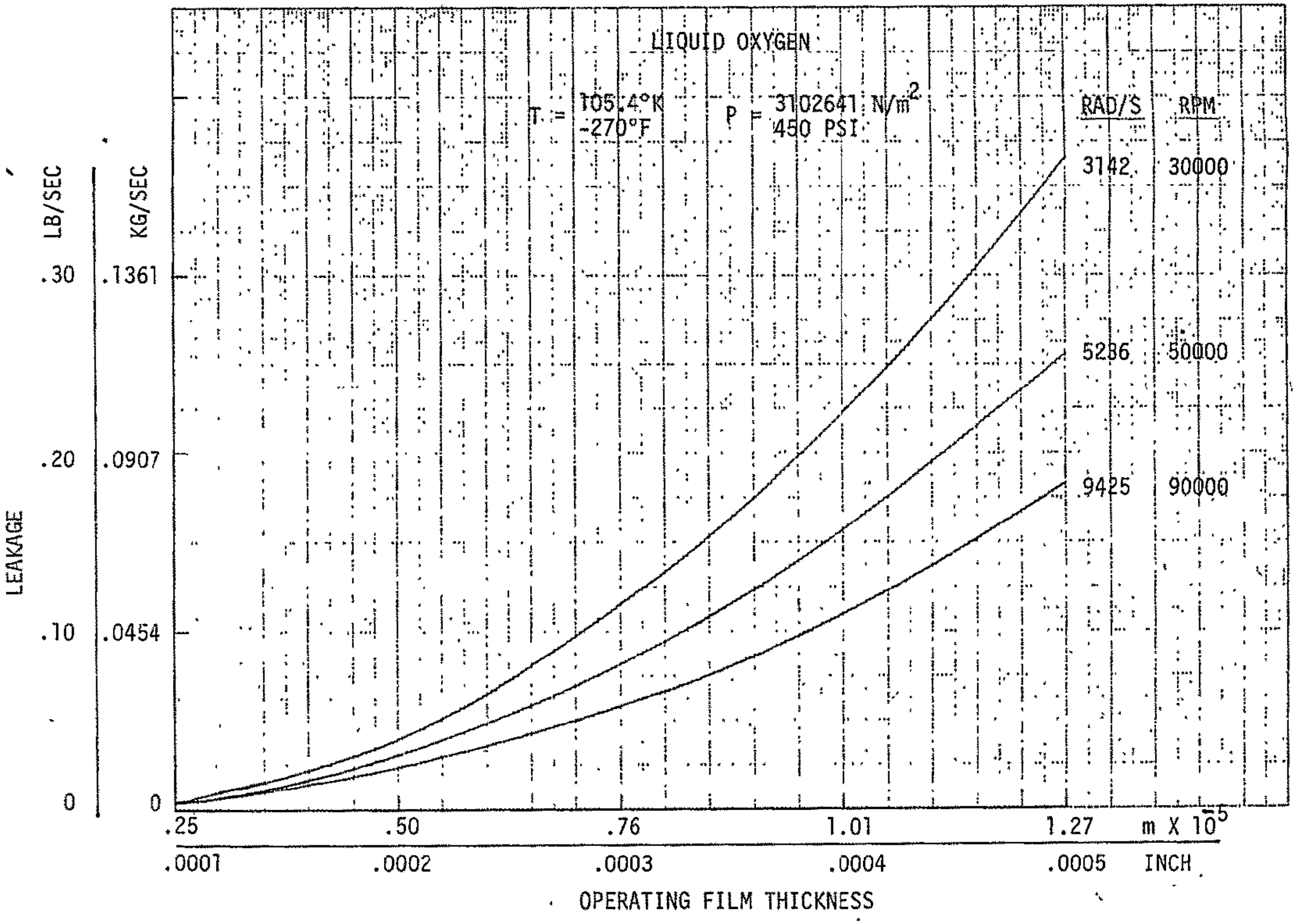


Figure 8. Rayleigh Pad LOX Seal Liquid Oxygen Sealing Dam Leakage at 3,102,641 N/m^2 (450 psia)

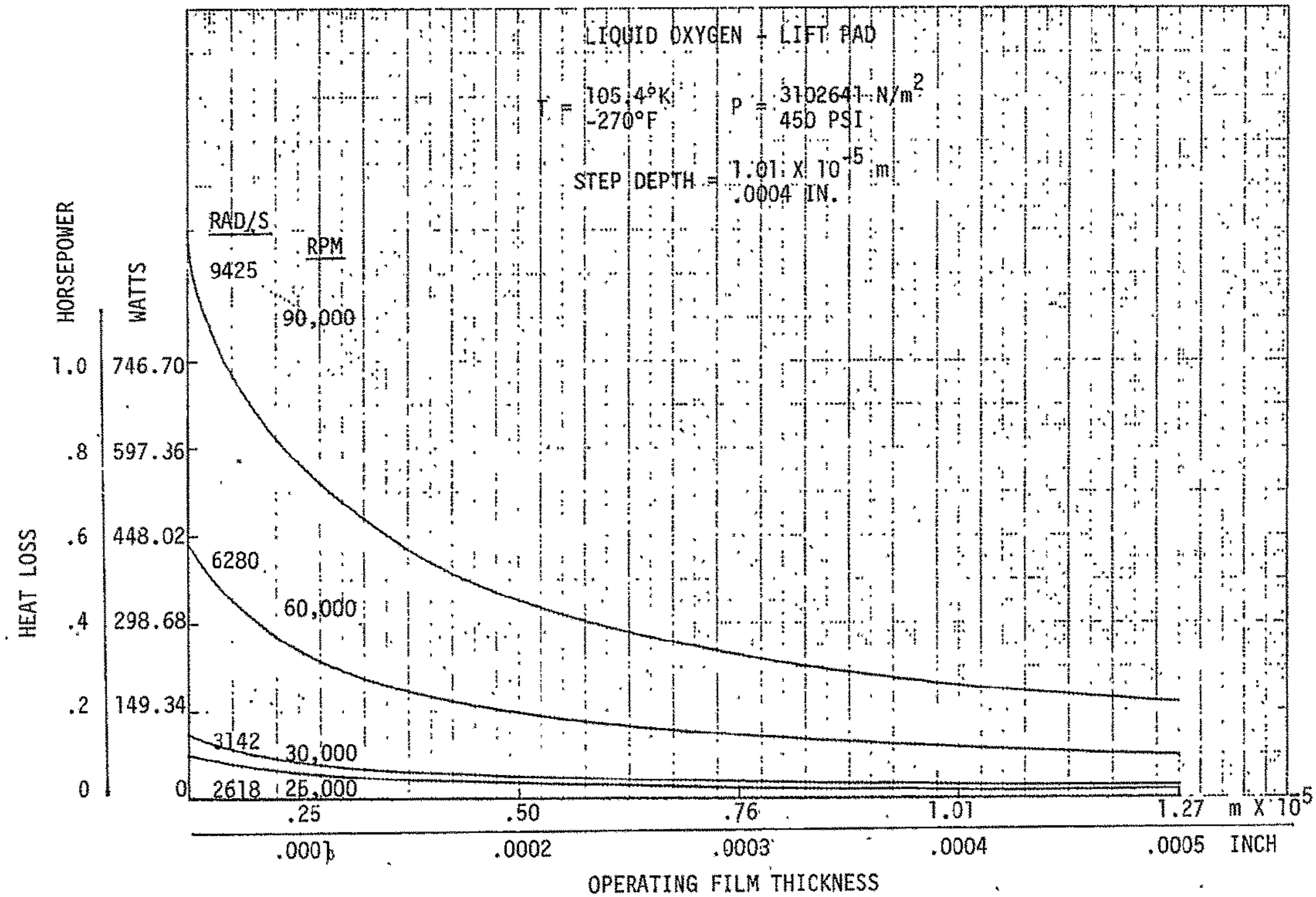


Figure 9. Rayleigh Pad LOX Seal Lift Pad Heat Loss for Liquid Oxygen

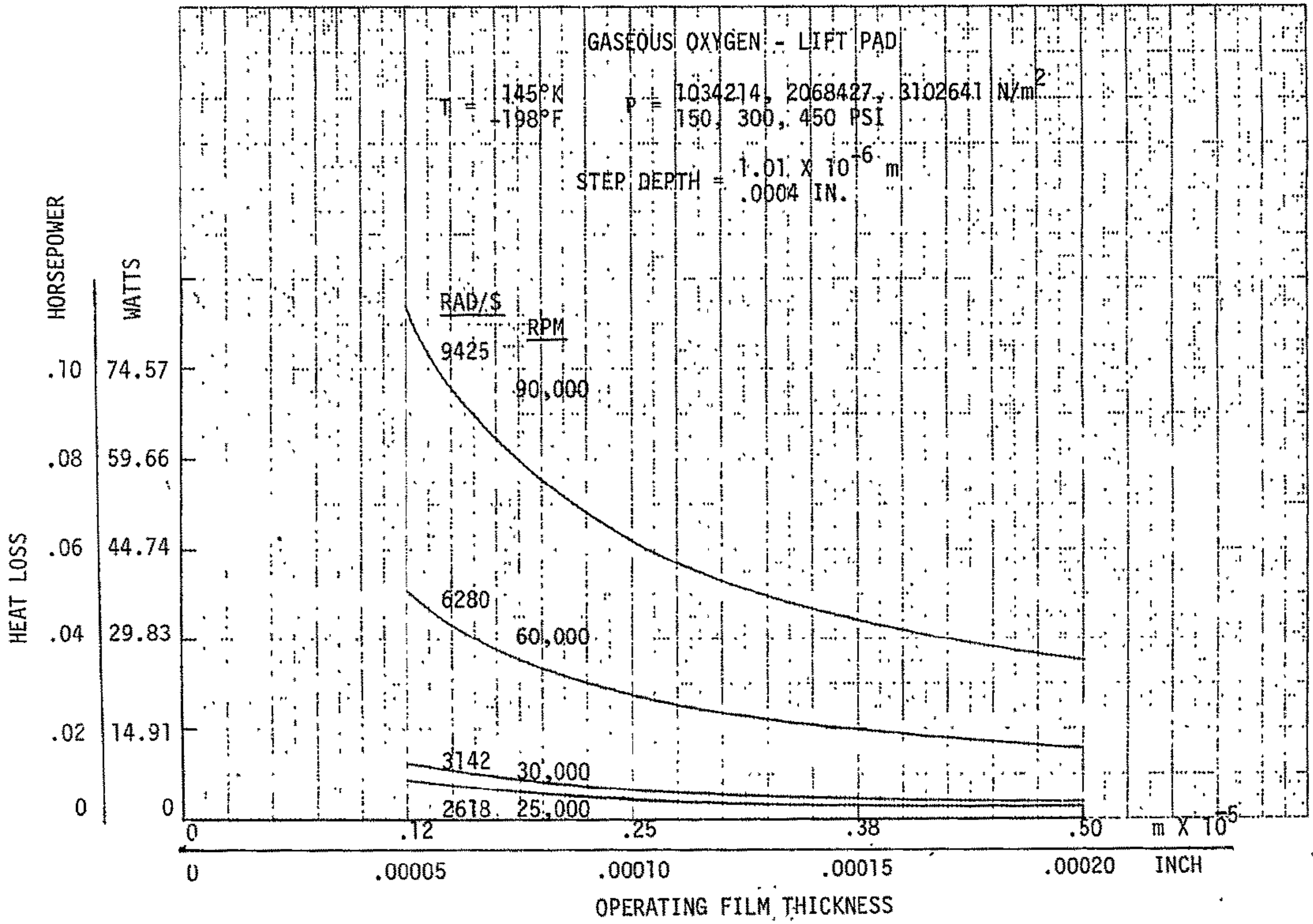


Figure 10. Rayleigh Pad LOX Seal Lift Pad Heat Loss for Gaseous Oxygen

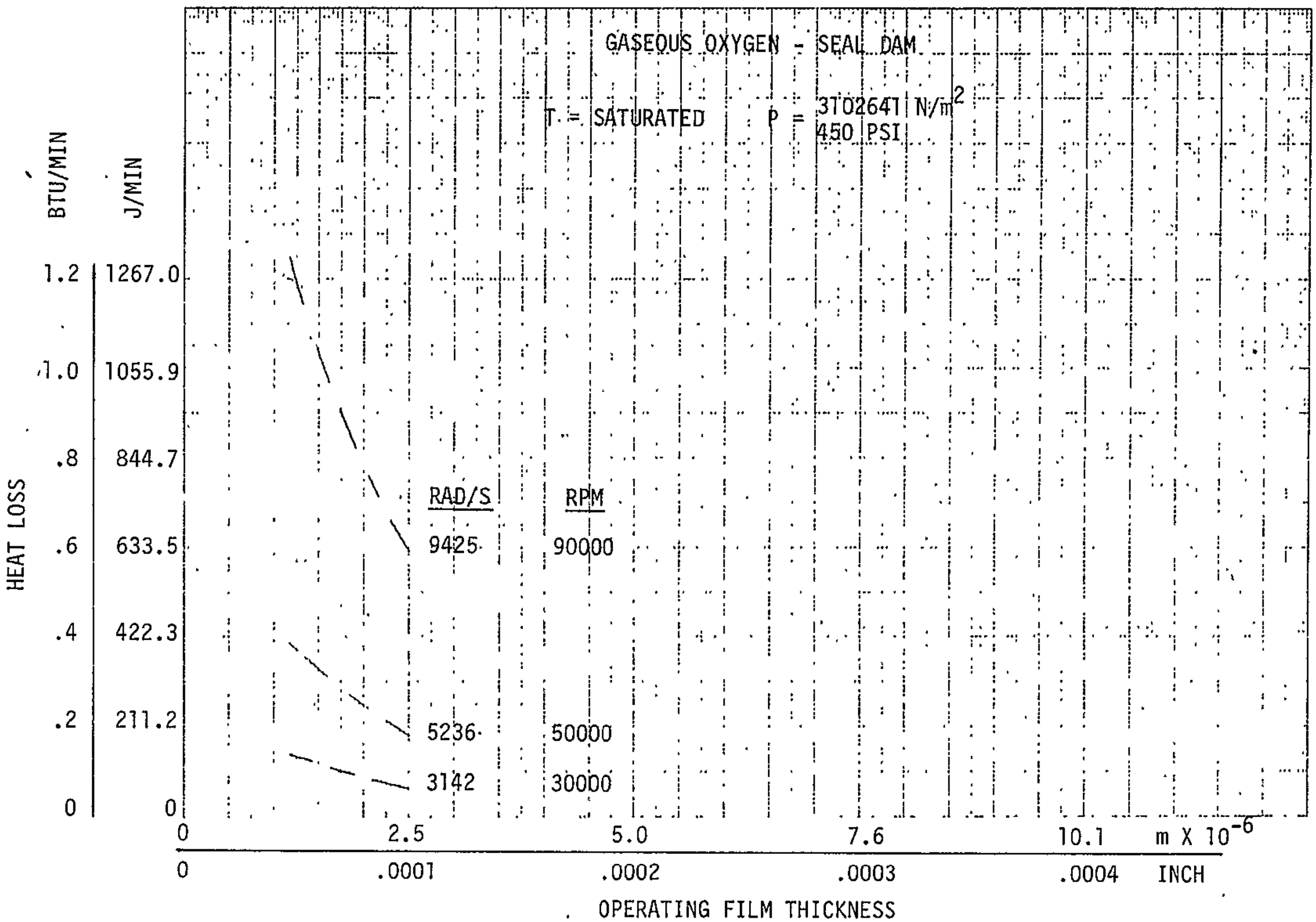


Figure 11. Rayleigh Pad LOX Seal Sealing Dam Heat Loss for Gaseous Oxygen

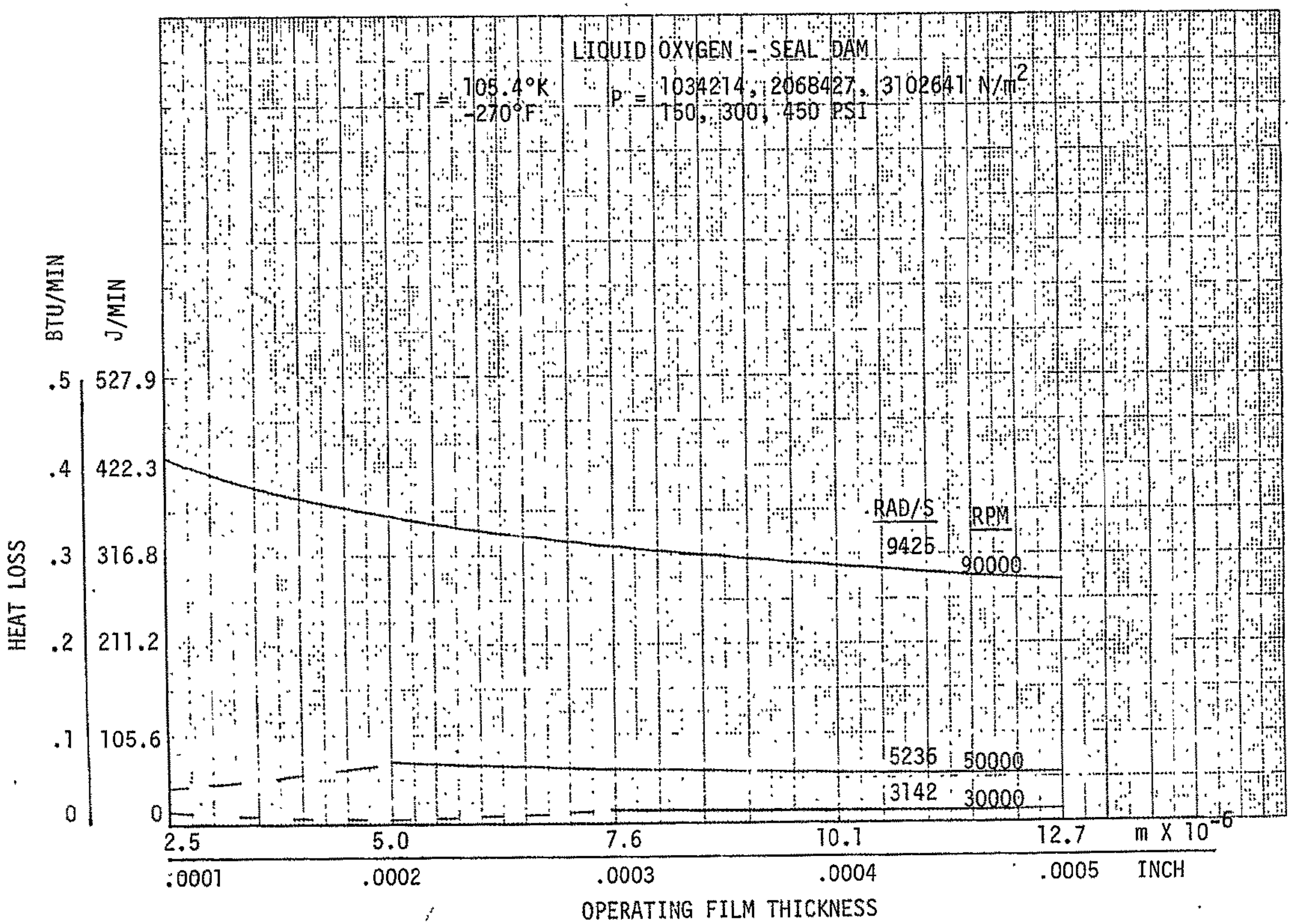


Figure 12. Rayleigh Pad LOX Seal Sealing Dam Heat Loss for Liquid Oxygen

CONCEPT: USE REVERSE PUMPING TO REDUCE SEALED PRESSURE TO VAPOR PRESSURE

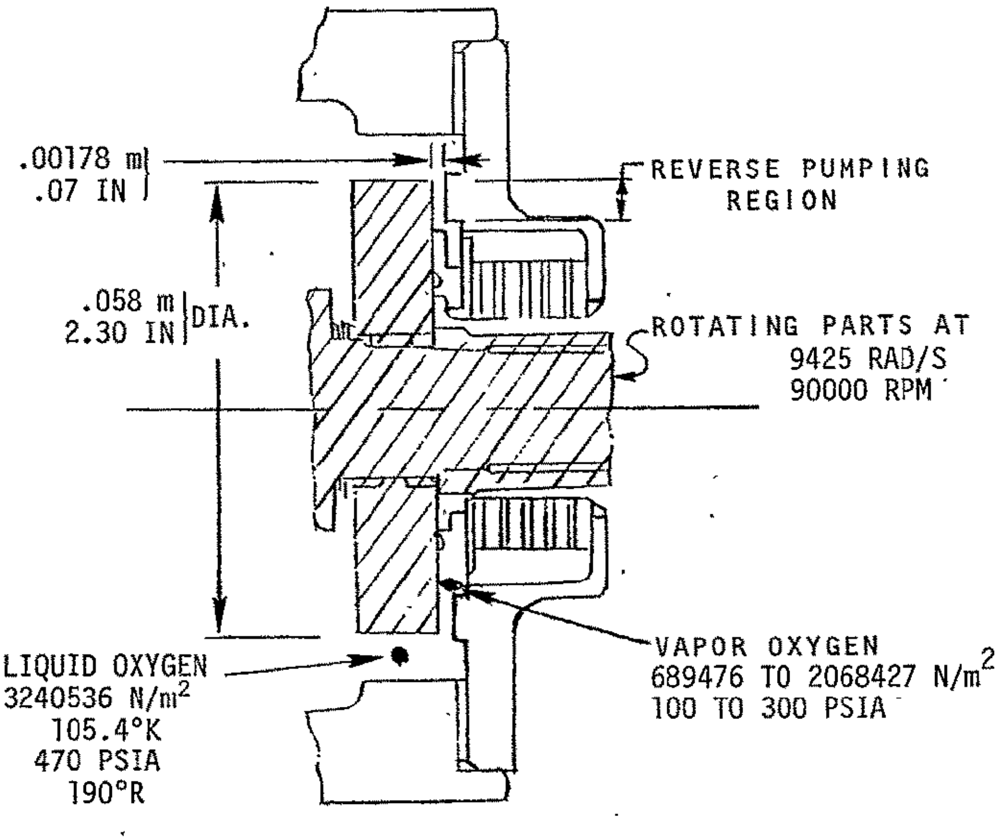


Figure 13. Reverse Pumping Configuration

rotating surfaces in the sealed fluid cavity was calculated to determine the total coolant flowrate. The computer program for the analysis was written for the GE 440 Timeshare computer using an NBS oxygen fluid property subroutine. The reverse pumping mating ring is essentially the same for both the Rayleigh step LOX seal and the spiral groove LOX seal design.

The pressure drop across the reverse pumping element was estimated for liquid oxygen as a function of speed. The upstream cavity pressure was used as the sealed presssure for gaseous nitrogen testing since no significant reverse pumping occurs with the low density gas. A pressure port was added in the oxygen seal housing to measure the actual pressure at the seal.

Analysis indicated that, at 9425 rad/s (90,000 rpm), increasing the face seal rotating mating ring diameter to 0.058 m (2.3 in.), and with an axial gap of 0.00178 m (0.07 in.), would result in reverse pumping of the fluid from the 2,102,641 N/m^2a (450 psia) cavity pressure to the vapor pressure of 689,476 N/m^2a (100 psia). The 0.058 m (2.3 in.) diameter mating ring at 9425 rad/s (90,000 rpm) with 0.1814 kg/s (0.4 lb/sec) coolant flow results in 96,266 N/m^2a (140 psia) oxygen vapor at the LOX seal carbon ring for 3,240,536 N/m^2a (470 psia) LOX sealed pressure. The design pressure range for seal components is 689,476 N/m^2a (100 psia) operational minimum and 2,068,427 N/m^2a (300 psia) structural maximum at maximum operating conditions.

CARBON SEAL RING

Preliminary force and moment balances indicated the oxygen face seal carbon ring thickness should be increased to reduce ring deflection. The ring thickness was increased from 0.0038 m (0.150 in.) to 0.00635 m (0.250 in.) which increased section stiffness by a factor of 6.6.

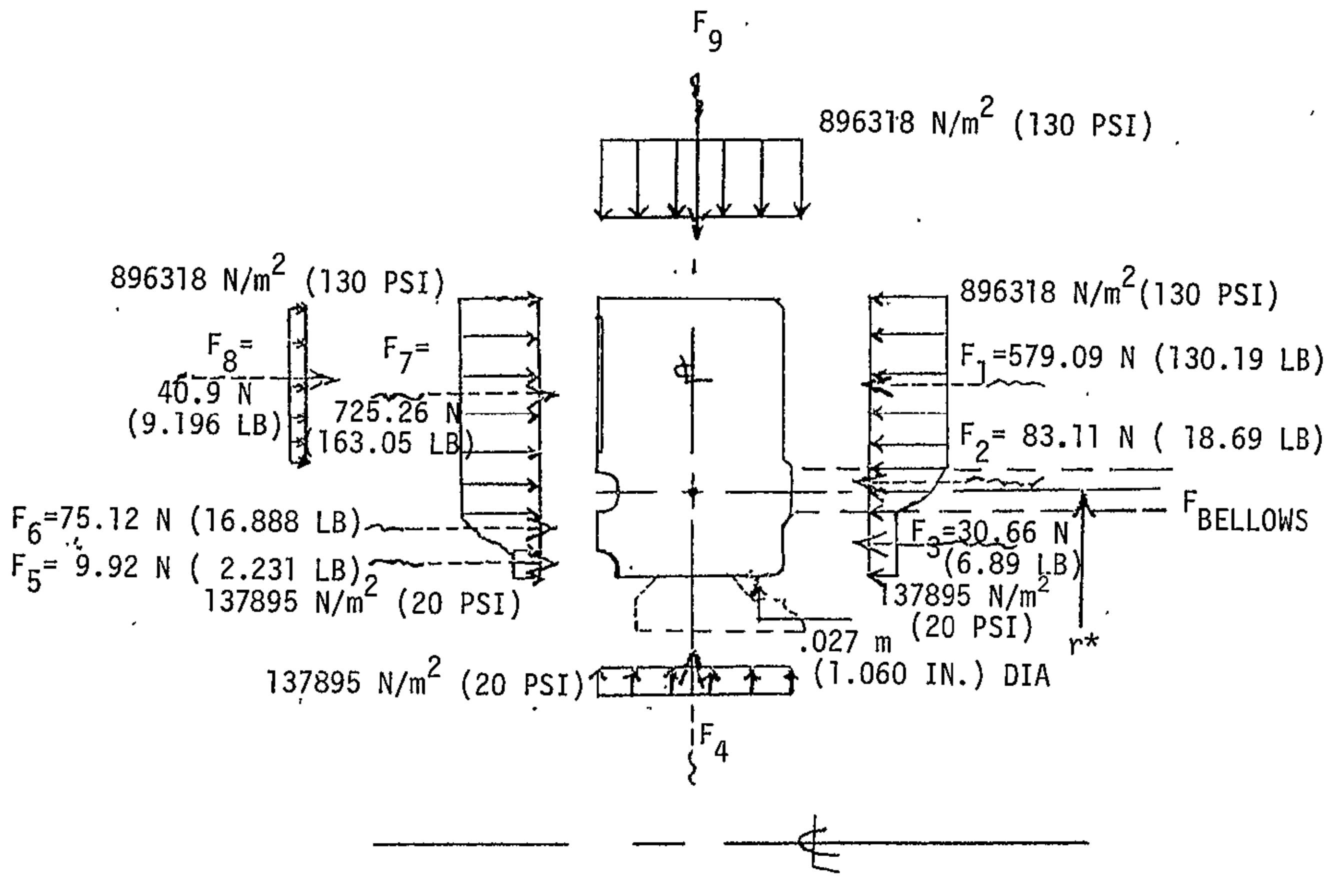
The pressure distribution and axial forces on the carbon ring with reverse pumping is shown in Fig. 14. A seal face pressure of 896,318 N/m^2 (130 psi) was used for structural analysis. The lapped joint diameter was computed to balance the bending moments on the carbon seal ring.

MATING RING

The LOX seal mating ring (Fig. 15) was designed to maintain flatness at operating conditions by isolating the ring from the shaft clamping forces and by balancing the bending moments as nearly as possible. The ring mounting configuration is shown in Fig. 16. The static seal provides a 1334 N (300 pound) clamping force that is not a function of the shaft axial stackup load.

Seal face flatness was achieved by finite element analysis using the force and pressure distribution shown in Fig. 17.

Results indicated a 0.785 rad (45 degree) chamfer 0.0023 m (0.090 in.) wide on the non-seal side outer corner would maintain seal face flatness at 9425 rad/s (90,000 rpm) considering pressure-induced forces and Poisson's effect for rotation (Fig. 18).



$F_{BELLOWS} = F_{SPRING} + \sum_{AXIAL}$ PRESSURE FORCES ON THE BELLOWS.

r* IS THE SEALING RADIUS TO BE DETERMINED SO THAT THE MATING RING IS IN ROTATIONAL EQUILIBRIUM. (I.E. $\sum M$ ABOUT THE CENTER OF TWIST = 0.)

Figure 14. LOX Seal Carbon Seal Ring Pressure Distribution and Axial Forces

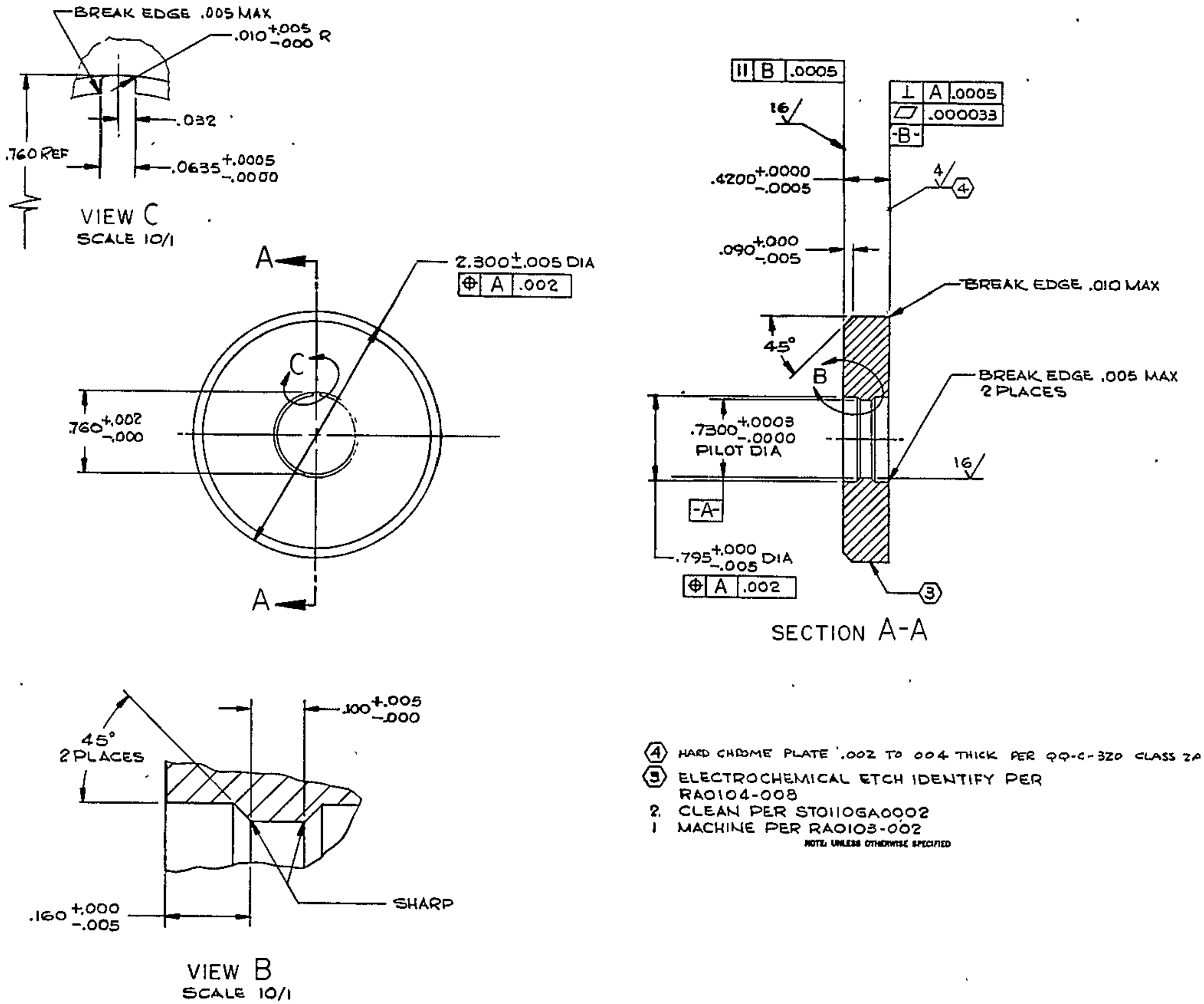


Figure 15. Ring, Mating, LOX Seal

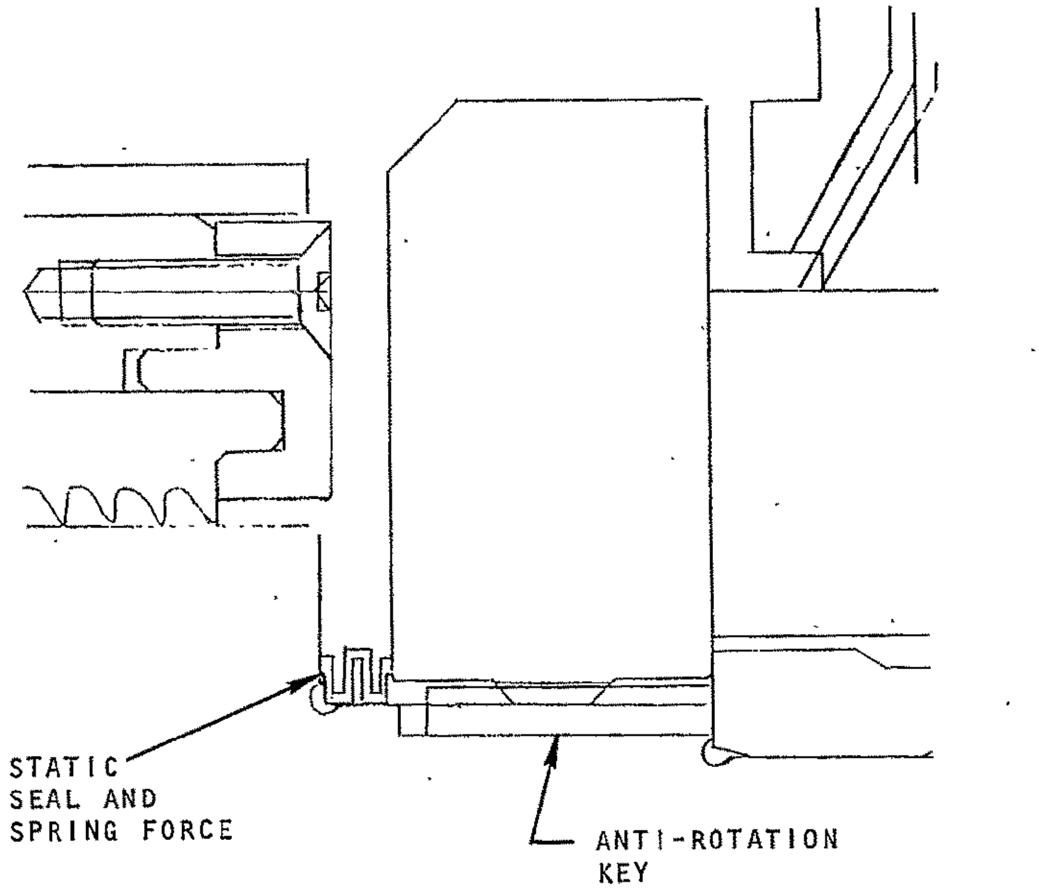


Figure 16. LOX Seal Mating Ring Mounting Configuration

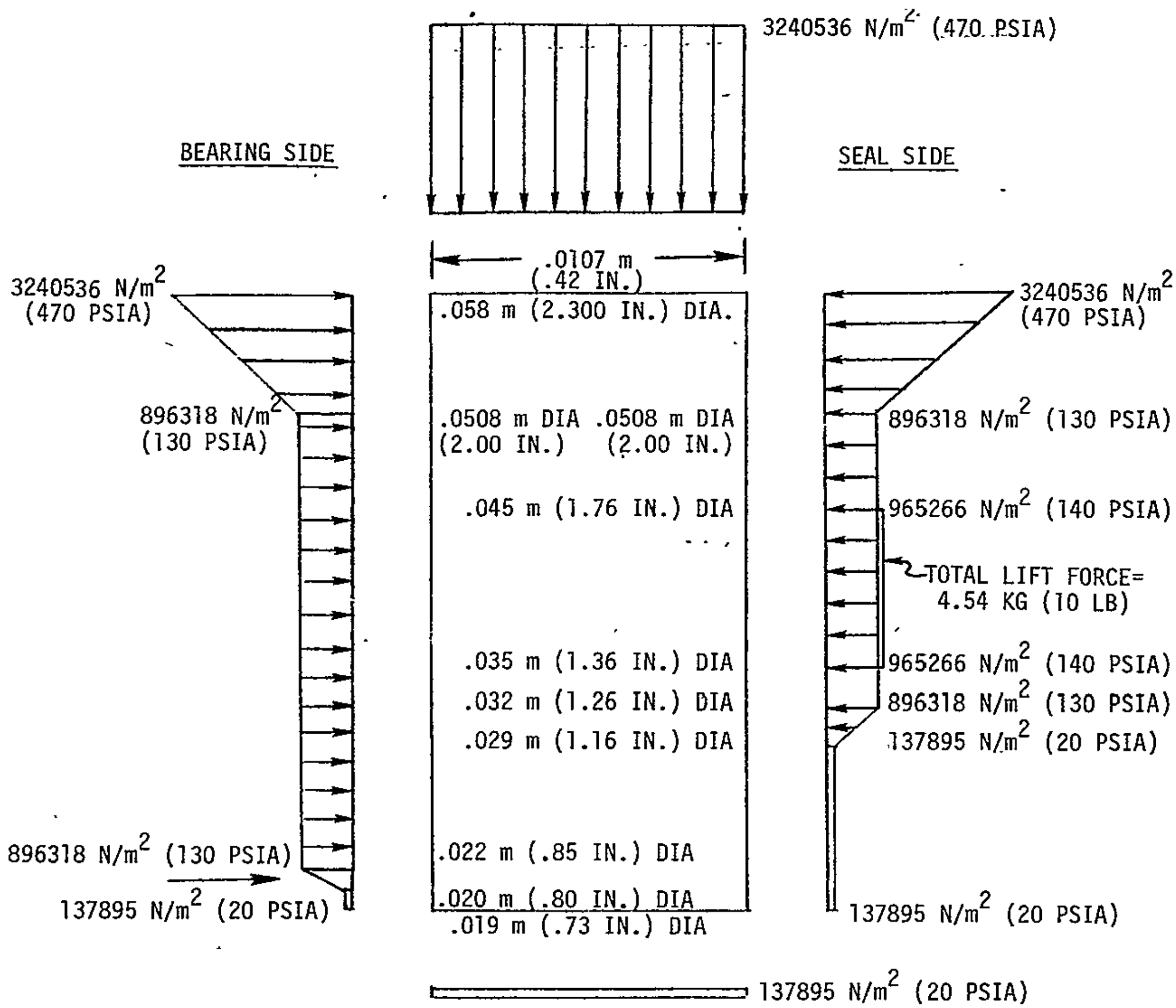


Figure 17. LOX Seal Mating Ring Force and Pressure Distribution

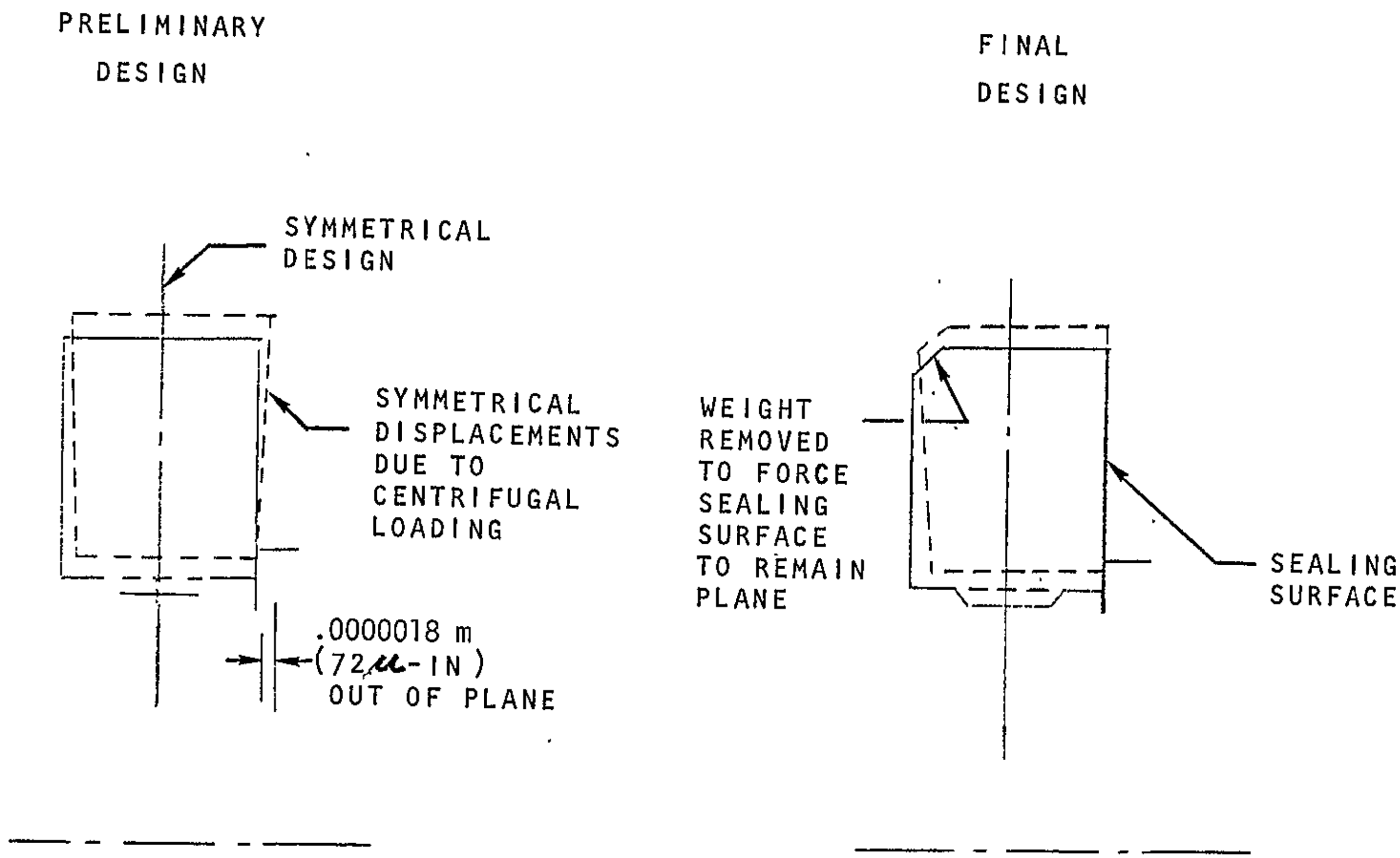


Figure 18. LOX Seal Mating Ring Modification to Maintain Flatness

The mating ring OD was increased from 0.0045 m (1.76 in.) to 0.058 m (2.30 in.) diameter to provide a reverse pumping region upstream of the seal.

A narrow pilot was used at the base of the mating ring to center the ring on the shaft and to isolate the ring from any distortions in the shaft.

The mating ring material is K-monel for strength and oxidation resistance. Hard chrome plate was applied over the sealing face for wear resistance.

RAYLEIGH PAD BELLOWS LOX SEAL

The Rayleigh pad bellows LOX seal (Fig. 19) consists of a face-type carbon seal ring with shrouded recess step hydrodynamic lift pads and a machined metal bellows secondary element. The machined metal bellows provides both the spring force required to seat the seal ring and a positive secondary sealing element between the seal ring and the housing. The bellows loads the carbon seal ring through a lapped joint to provide a static seal. The total closing force consists of the spring load in the bellows and the pressure load acting on the bellows mean effective diameter. The machined bellows provides a nearly constant effective diameter for varying pressure differential to maintain a consistent pressure closing force.

The carbon seal ring is free floating with a radial pilot and three antirotation lugs at the outside diameter. The floating seal ring provides for thermal contraction differentials to minimize distortion. The seal face has 10 recess pads to provide hydrodynamic lift and a continuous dam for sealing. The back side of the seal ring has a lapped joint dam to provide a static seal at the bellows end plate. The friction at the housing pilot and antirotation lugs provides vibration damping for the seal ring to prevent bellows vibration.

The NASA-provided bellows design (Fig. 20) was modified as follows:

1. Housing changed from press fit capsule to bolted flange for improved installation and static sealing.
2. Seal ring pilot moved to outside diameter to eliminate excessive clearance increase at cryogenic (90.38 K; -297 F) temperature due to thermal contraction differentials.
3. Seal ring pilot and antirotation lugs moved from the bellows end plate to the housing for vibration damping.
4. The carbon seal ring width was increased for additional stiffness to minimize distortion.
5. The bellows length was increased to lower the spring rate.
6. The mating ring mounting was changed from a clamped sleeve to a spring-loaded floating ring to minimize distortion.
7. The mating ring was modified to provide reverse pumping for reduced sealing pressure.
8. The seal ring material was changed from carbon P03N to carbon P692 for improved wear resistance in LOX and to minimize edge chipping.

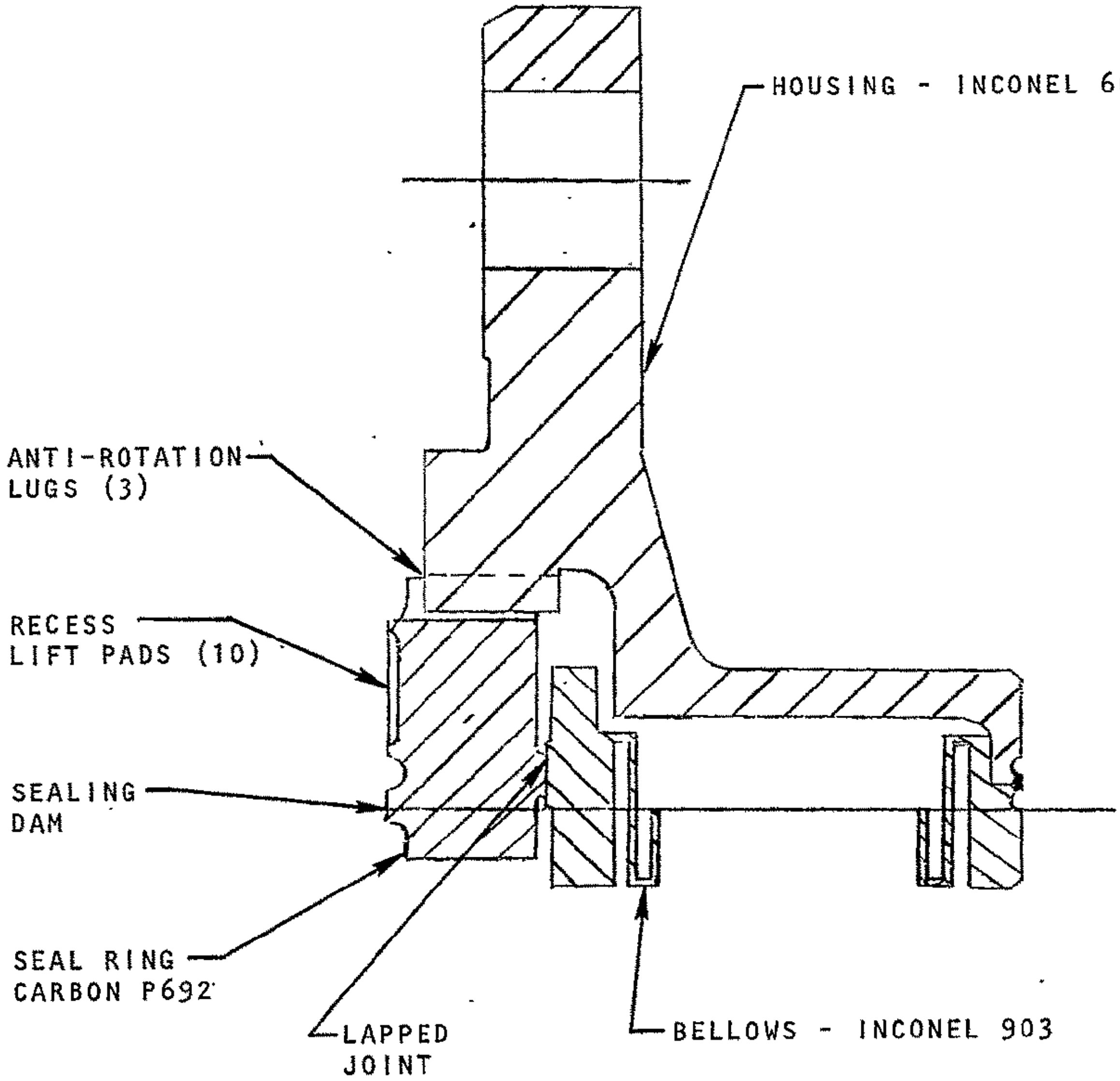


Figure 19. Rayleigh Pad Machined Metal Bellows LOX Seal Final Design Layout

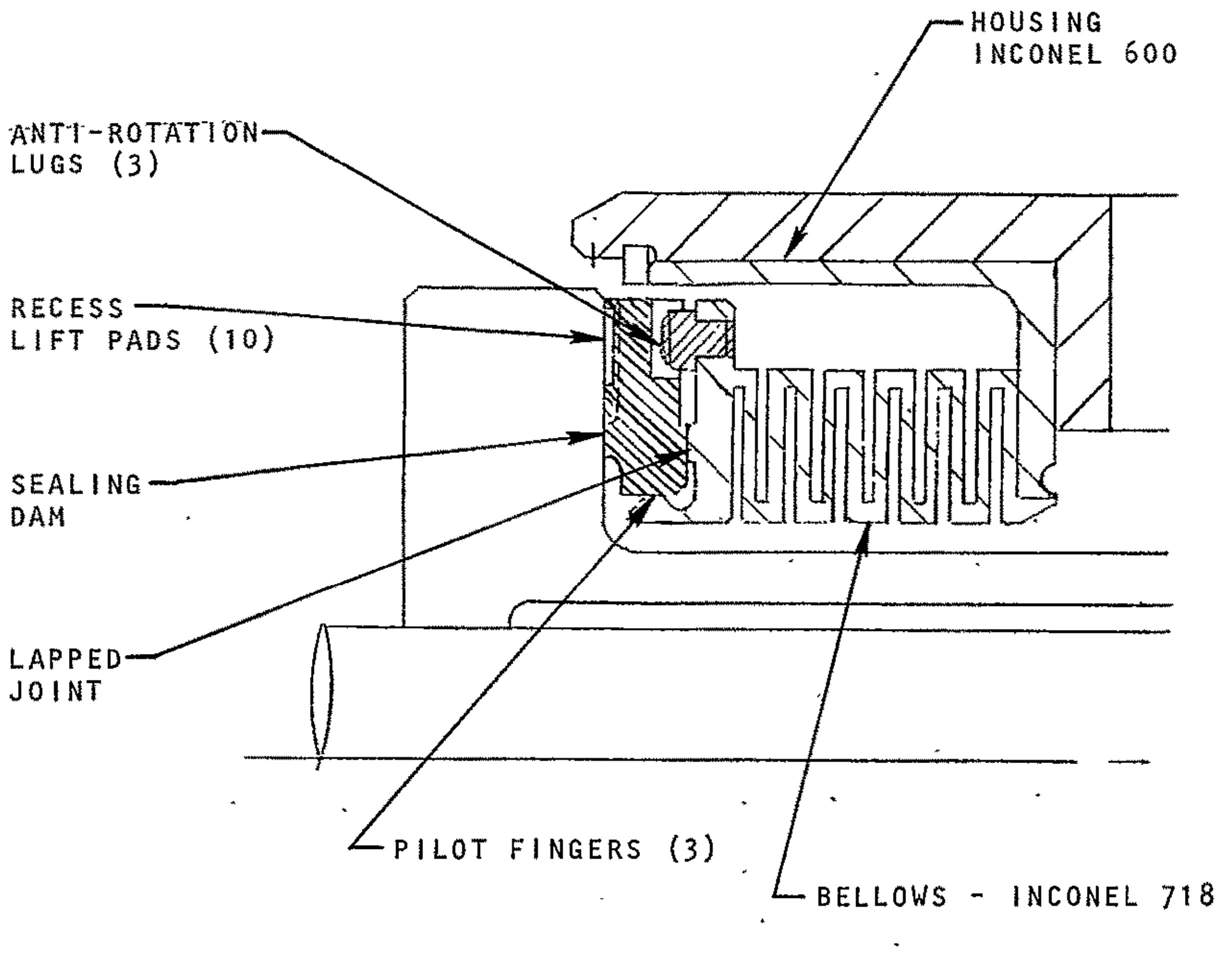


Figure 20. NASA-Provided Bellows LOX Seal Design Layout

9. The bellows material was changed from Inconel 718 to Inconel 903 for improved machining.

The bellows span, plate thickness and number of convolutions were analyzed to satisfy the stress and spring rate requirements. The pressure stress is proportional to the ratio of the span over the plate thickness $(s/t)^2$. The spring rate per convolution is proportional to the inverse of the same ratio $(t/s)^3$. Therefore, increasing the plate thickness decreases the pressure stress and increases the spring rate per convolution. The total spring rate is reduced by increasing the number of convolutions. The number of convolutions is limited by the available space.

The desired bellows spring rate was established at 17,512 N/m (100 lb/in.) by the design spring force of 22.2 N (5 pounds) and bellows compression of 0.0013 m (0.050 in.); however, analysis by the bellows manufacturer indicated that the minimum spring rate for the 3,102,641 N/m^2a (450 psia) pressure requirement was 48,157 N/m (275 lb/in.) using Inconel 718 material. The other higher strength maraging steel allows (Vascomax 300) were not satisfactory due to low temperature brittleness, notch sensitivity and corrosion.

A review of alternate designs indicated that a significant spring rate increase would result if the design was changed to allow the use of Inconel 718. A comparison of different designs is given below:

Design	Plate Thickness, m (in.)	Span, m (in.)	Stress, N/cm^2 (psi)	Spring Rate, N/m (lb/in.)
Present	0.000165 (0.0065)	0.00495 (0.195)	99974 (145,000)	20489 (117)
Alternate No. 1	0.000203 (0.008)	0.00495 (0.195)	74119 (107,500)	38189 (218
Alternate No. 2	0.000229 (0.009)	0.00495 (0.195)	63432 (920,000)	49016 (280)
Alternate No. 3	0.000254 (0.010)	0.00495 (0.195)	61639 (864,00)	74409 (425)
Alternate No. 4	0.000172 (0.0068)	0.00401 (0.158)	74808 (108,500)	43780 (250)

The bellows manufacturer indicated that it would be necessary either to increase the plate thickness or decrease the span to provide sufficient convolution rigidity for grinding of the Inconel 718 material, due to the large span-to-plate thickness ratio and the difficulty of grinding. The 0.000165 m (0.0065 in.) thick plates do not provide sufficient support for the 0.00406 m (0.016 in.) width grinding disks which are used to machine the convolution grooves.

Analysis indicated that the spring rate could be decreased if the test pressure requirements could be changed from 3,102,641 N/m^2a (450 psia) to 2,068,427 N/m^2a (300 psia.) Analysis of the turbopump requirements indicated 3,102641

N/m^2a (450 psia) was required in the seal cavity. Incorporating the reverse pumping element upstream of the seal reduced the pressure at the seal to 2,068,427 N/m^2a (300 psia) at operating speed, making the machined metal bellows feasible

Provisions were made in the housing design for a 0.00178 m (0.070 in.) axial gap between the mating ring face and the housing face for the reverse pumping element. Provisions were also made for a pressure measurement at the seal components downstream of the reverse pumping element.

A review of alternate materials indicated that Inconel 903 would satisfy the new design requirements and was potentially more machinable than Inconel 718. One satisfactory Inconel 903 machined bellows was completed by Hydrodyne. The following design changes were made to allow machining the bellows:

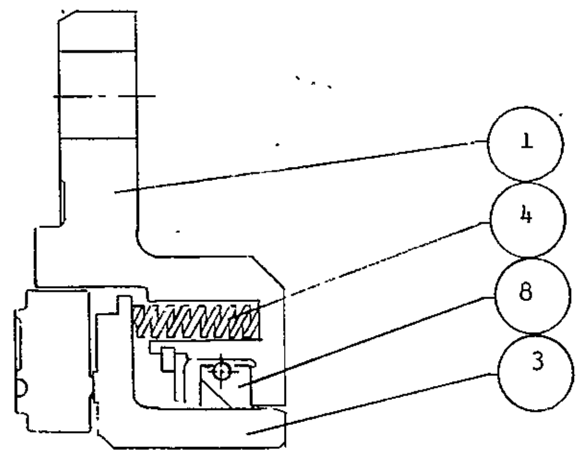
1. Plate thickness changed from 0.000165 m (0.0065 in.) to 0.000203 m (0.008 in.)
2. Bellows inside diameter changed from 0.0231 m (0.910 in.) to 0.0245 m (0.963 in.)
3. Bellows outside diameter changed from 0.0356 m (1.400 in.) to 0.0342 m (1.347 in.)
4. Bellows span changed from 0.00622 m (0.245 in.) to 0.00488 m (0.192 in.)
5. Bellows mean effective diameter (MED) remains the same at 0.02934 m (1.155 in.)
6. Spring rate changed from 20,489 N/m (117 lb/in.) to 35,039 ±10% N/m (200 ±10% lb/in.) (First part measured 31,171 N/m (178 lb/in.) at Hydrodyne.)

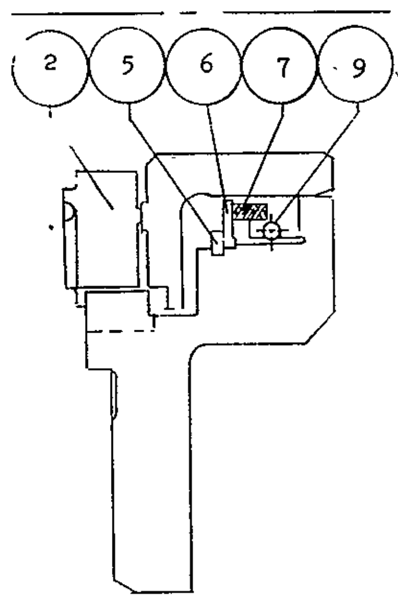
The second bellows seal was delayed due to machining difficulties at Hydrodyne. It was agreed to cancel requirements for the second bellows LOX seal due to machining difficulties. It was concluded that the design is not feasible for consistent manufacture even with the changes made to allow machining the first bellows, and requirements were cancelled. A total of 12 bellows was scrapped in an attempt to make the second bellows seal.

RAYLEIGH PAD PISTON RING LOX SEAL

The final design (Stein Seal Company) Rayleigh pad piston ring LOX seal (Fig. 21) consists of a face-type carbon seal ring with shrouded recess step hydrodynamic lift pads (same carbon ring as bellows seal) and a pressure-balanced segmented carbon piston ring secondary element. The seal ring is loaded through a pilot ring with compression coil springs.

The carbon seal ring is free floating with a radial pilot and three antirotation lugs at the outside diameter. The back side of the seal ring has a lapped joint dam to provide a static seal to the pilot ring.





ITEM	REQD	PART NO.	DESCRIPTION	MATL.	MATL. SPEC.
9	1	SSCY 5097-9	SPRING, EXTENSION	INCL X-750	AMS 5698 OR AMS 5699
8	1	SSCY 5097-8	RING, SEAL	CARBON-GRAPHITE	PURE CARBON P5 NR2
7	4	SSCY 5097-7	SPRING, COMPRESSION	INCL X-750	AMS 5698 OR AMS 5699
6	1	SSCY 5097-6	PLATE, BACK	SST	TYPE 302
5	1	SSCY 5097-5	RING, RETAINING	SST	TYPE 302
4	12	SSCY 5097-4	SPRING, COMPRESSION	SST	TYPE 302
3	1	SSCY 5097-3	RING, PILOT	INCL 718	AMS 5664
2	1	SSCY 5097-2	WAFER	CARBON-GRAPHITE	PURE CARBON GR P692
1	1	SSCY 5097-1	FLANGE	INCL 718	AMS 5664

Figure 21. Rayleigh Pad Piston Ring LOX Seal Final Design (Stein Seal Company)

The NASA-provided composite piston ring LOX seal design is shown in Fig. 22. The design was modified to use the same carbon seal ring as the bellows LOX seal. The composite piston ring was changed to a Stein Seal Company-designed segmented-carbon ring for more effective sealing.

The seal spring load was adjusted by changing the number of springs. The piston ring diameter was established to maintain a 0.7 pressure balance ratio (closing area/dam area) using the same carbon as the bellows LOX seal.

SPIRAL GROOVE PISTON RING LOX SEAL

The spiral groove piston ring LOX seal was designed by Crane Packing Company in accordance with Rocketdyne specifications (Fig. 23). The seal assembly is shown in Fig. 24. The seal consists of a solid carbon seal ring with a plain flat face running against spiral grooves in the hard chrome-plated surface of the rotating mating ring. A pressure-balanced split piston ring is used for the secondary seal.

The spiral grooves develop both hydrostatic and hydrodynamic lift to maintain face separation to eliminate rubbing contact. The hydrostatic lift is developed across the seal face when a pressure differential is applied under static conditions. The hydrodynamic lift adds to the hydrostatic lift as rotation starts. The lift force is proportional to the face clearance gap, decreasing as the gap increases. Therefore, the gap is self-adjusting to equalize the lift force and closing force. The theoretical gaps are as follows:

Condition	Gap
Static	0.000206 cm (0.000081 in.)
2618 rad/s (25,000 spm)	0.000348 cm (0.000137 in.)
9425 rad/s (90,000 rpm)	0.000508 cm (0.000200 in.)

The theoretical leakage across the seal face is given below:

Speed	Leakage
Static	0.0243 m^3/minute (0.859 scfm)
2618 (rad/s (25,000 rpm)	0.1124 m^3/minute (3.97 scfm)
9425 rad/s (90,000 rpm)	0.3310 m^3/minute (11.69 scfm)

The computer printouts for static, 2618 rad/s (25,000 rpm), and 9425 (rad/s (90,000 rpm) are shown in Fig. 25 through 27.

The piston ring was modified to add a circumferential wave spring around the outside diameter to load the piston ring against the housing sealing surface for improved sealing. The wave spring was 0.0000762 m (0.003 in.) brass shim stock.

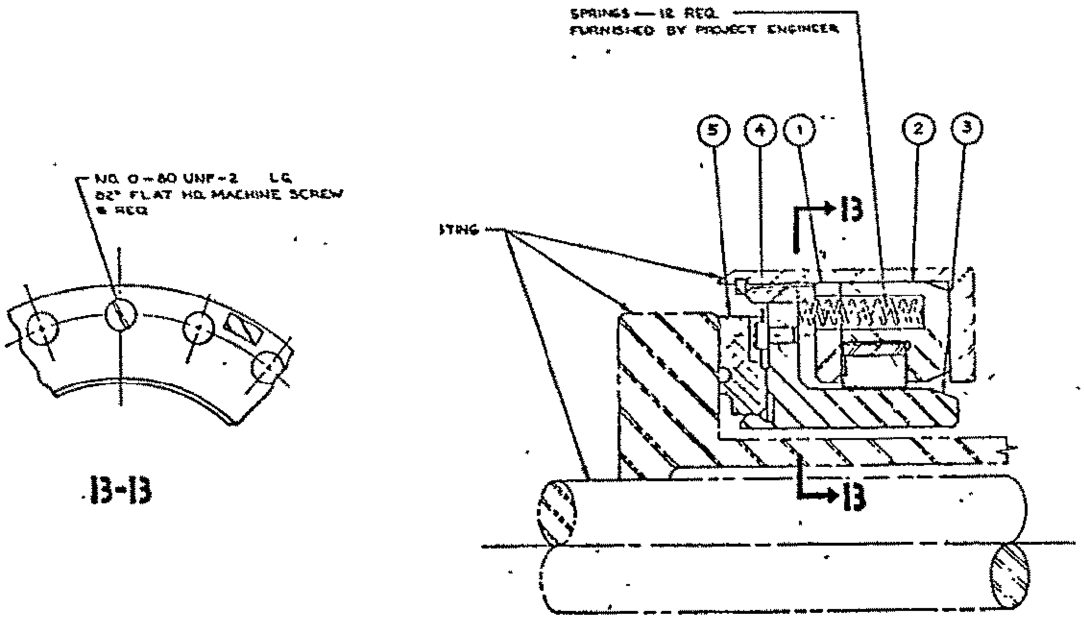
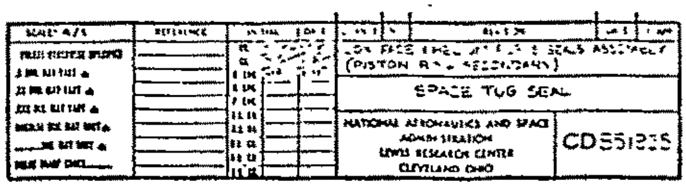


Figure 22. NASA-Designed Oxygen Face Seal With Composite Piston Ring



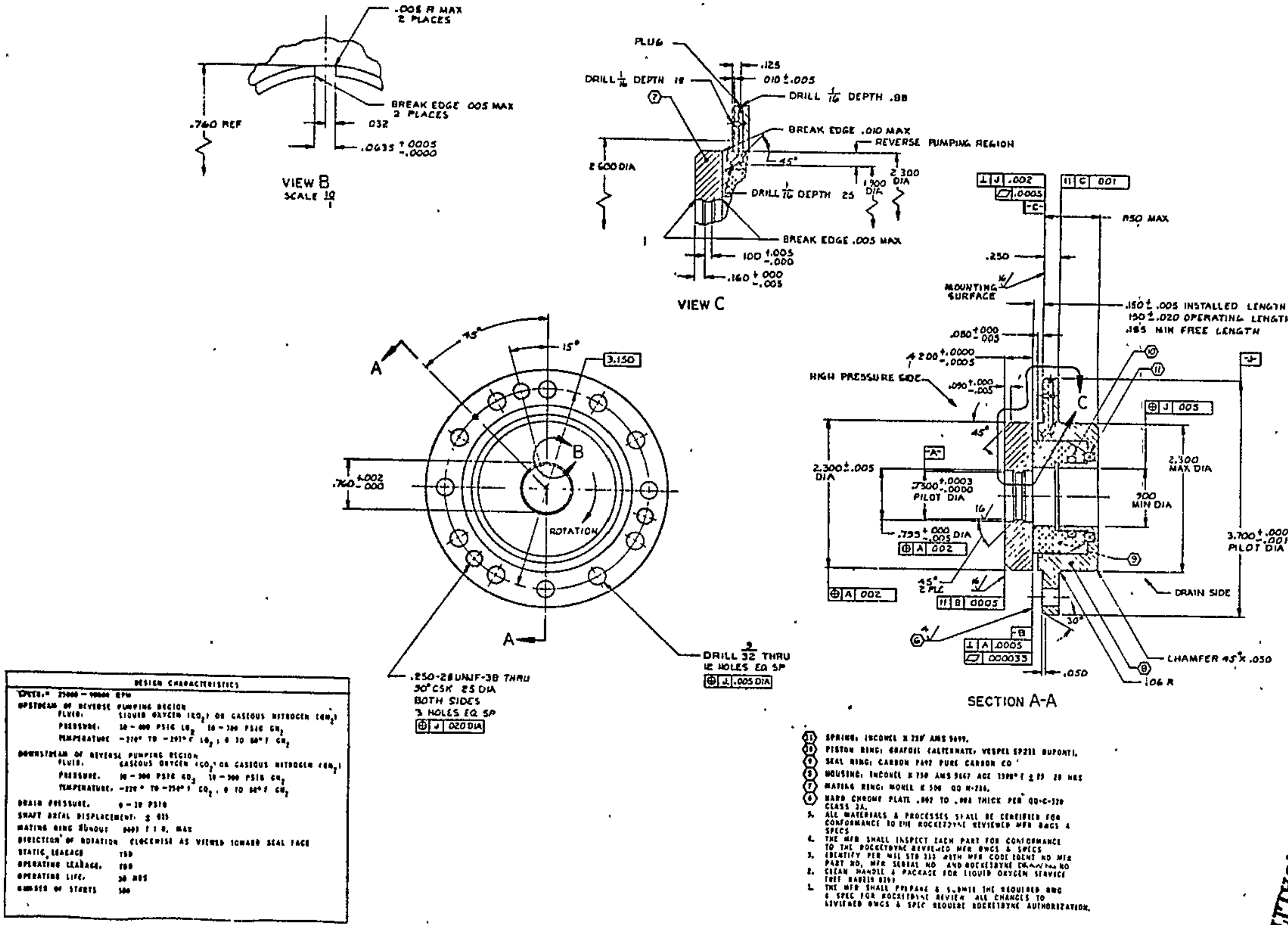


Figure 23. Alternate Spiral Groove LOX Seal Design Specification Drawing

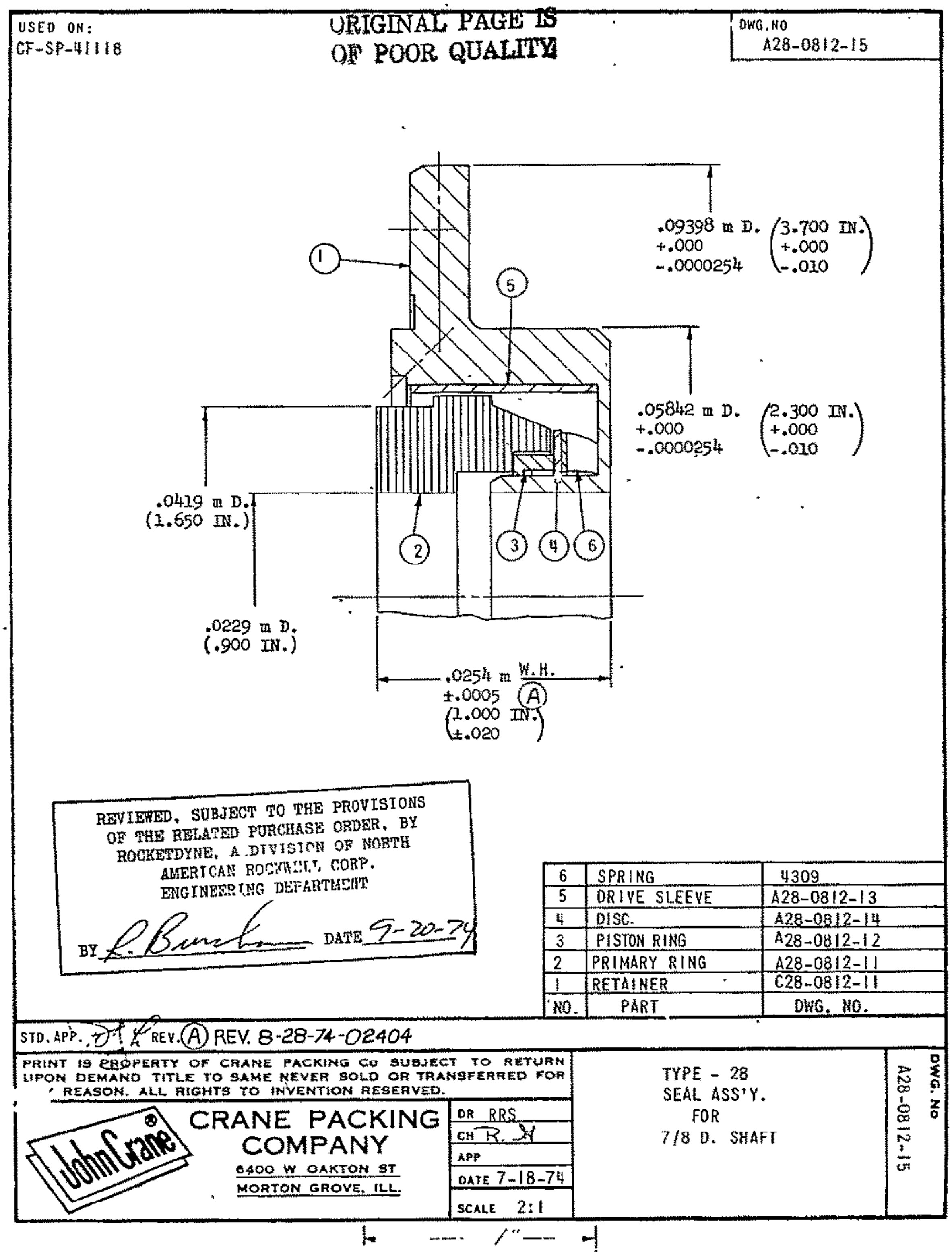


Figure 24. Spiral Groove LOX Seal Assembly

```
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ratio=1. sload=6. rrad=0. thexco=.0000033 flen=.75 elen=-.406 olen=-.156 ymod=3800000. sid=.9 ood=1.65 cutod=1.437 cutoff=.25
odia=1.245 len=0. ;
MODE(1)='GAS' ;
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FINAL

```
clearx=.0001 ;
alpha1=-.000015240531088657 mtoll=-1.1384004620584 fopen=*** fclose=177.56925445169 ;
clearx=.0001 ;
alpha1=-.000015146655730954 mtoll=-1.1313883868254 fopen=*** fclose=177.56925445169 ;
clearx=.00005 ;
alpha1=-.000017739205277463 mtoll=-1.3250404048874 fopen=172.59565902396 fclose=177.56925445169 ;
clearx=.000075 ;
alpha1=-.000016311368551155 mtoll=-1.2183872981474 fopen=186.47695716509 fclose=177.56925445169 ;
clearx=.0000875 ;
alpha1=-.000015687271173036 mtoll=-1.1717700178814 fopen=178.67189455614 fclose=177.56925445169 ;
3
alpha1=-.000015983908041335 mtoll=-1.1939274421544 fopen=175.23165895615 fclose=177.56925445169 ;
```

O.D.(in)	I.D.(in)	BAL (in)	PLUG(in)	PG LIGHT BANDS	EX.PRES.(psig)	IN.PRES.(psig)	RPM	TEMP(F)	VIS. (lb sec/ in sq)
1.6500	.9000	1.0660	3.000	.01	120.00	0.	0.	*****	.000000001290

GROOVE DEPTH (in)	GROOVE ANGLE (in)	GROOVE DIA (in)	RIDGE WIDTH/GROOVE WIDTH	SPRING LOAD
.0003500	15.0000	1.0300	1.00000	6.0000

FACE LENGTH	END LENGTH	O RING DIST.	SEAL I.D.	SEAL O.D.	CUT O.D.	CUTOFF
.7500	-.4060	-.15600	.9000	1.6500	1.4370	.250

CLOSE.FORCE	OPEN.FORCE	YOUNGS MOD.	XBAR	YBAR	MOM.OF INERTIA	TORQUE	HP	GAP (in)
177.57	177.01	3800000.00	.312	.204	.0084187	0.	0.	.0000812500

DT AXIL	DT FACE	INPUT THER.DEF.	CALTEMP(F)	GRADIENT	THERMAL EX.CO.
0.	0.	.0	0.	0.	.0000033

THERMAL DEFL.(rad)	PRES.DEFL.(rad)	PRES.MOM.(inlb/in)	SCFM	SCFH
0.	-.000015984	-1.193027	.85957	51.5741

```
cface=2.2084309723254 ccface=1.5440772042211 ctop=13.627811262093 cctop=8.2773066202907 cback=.82996629526775
ccback=2.0485070766998 cend=.14930315294433 cbot=.49271677391485 ccbot=.47524731612796 ctall=-6.1570176813593 ;
clear(1)=.000081199936547924 clear(2)=.000080902809643772 clear(3)=.000080704682739619 clear(4)=.000080506555835467
(5)=.000080308428931314 clear(6)=.000079736900015489 clear(7)=.000078791996087993 clear(8)=.000077847083160496
clear(9)=.000076902170232999 clear(10)=.000075957257305502 clear(11)=*** clear(12)=*** ;
DO YOU WISH TO FREE THE DATA CURRENTLY IN THE PROGRAM???? ANSWER MUST BE 'Y' OR 'N'!!!!
```

dod

Figure 25. Static

```
dod=1.65 did=.9 db=1.066 dpg=3. plb=.01 pog=120. pig=0. rpm=25000. temp=-297. vis= 1.2898000000000E-09 gd=.00035 ang=15.
diag=1.03 ratio=1. sload=6. grad=0. thexco=.0000033 flen=.75 elen=-.406 olen=-.156 ymod=3800000. sid=.9 ood=1.65 cutod=1.437
cutoff=.25 odia=1.245 len=0. ;
MODE(1)='GAS' ;
```

.. FINAL

```
clearx=.0001 ;
alpha1=-.00001811300326123 mtoll=-1.3529614658374 fopen=*** fclose=177.56925445169 ;
clearx=.0001 ;
alpha1=-.00001813405164l253 mtoll=-1.3545336870024 fopen=*** fclose=177.56925445169 ;
clearx=.0003 ;
alpha1=-.00001275735l859828 mtoll=-.9529179244074 fopen=193.64402175395 fclose=177.56925445169 ;
clearx=.0002 ;
alpha1=-.00001370405278532 2 mtoll=-1.0236723086204 fopen=161.4563276066 2 fclose=177.56925445169 ;
clearx=.00015 ;
alpha1=-.0000149558893261 9 mtoll=-1.1171389776634 fopen=166.86830596228 fclose=177.56925445169 ;
clearx=.000125 ;
alpha1=-.00001615476664061 3 mtoll=-1.2066898260394 fopen=174.5180839675 fclose=177.56925445169 ;
clearx=.0001375 ;
alpha1=-.00001548732872548 2 mtoll=-1.1568351571594 fopen=181.82911163066 fclose=177.56925445169 ;
```

O.D.(in)	I.D.(in)	BAL (in)	PLUG(in)	PG LIGHT BANDS	FX.PRES.(psig)	IN.PRES.(psig)	RPM	TEMP(F)	VIS. (lb sec/ in sq)
1.6500	.9000	1.0660	3.000	.01	120.00	0.	25000.	*****	.000000001290

GROOVE DEPTH (in)	GROOVE ANGLE (in)	GROOVE DIA (in)	RIDGE WIDTH/GROOVE WIDTH	SPRING LOAD
.0003500	15.0000	1.0300	1.00000	6.0000

FACE LENGTH	END LENGTH	O RING DIST.	SEAL I.D.	SEAL O.D.	CUT O.D.	CUTOFF
.7500	-.4060	-.15600	.9000	1.6500	1.4370	.250

CLOSE.FORCE	OPEN.FORCE	YOUNGS MOD.	XBAR	YBAR	MOM.OF INERTIA	TORQUE	HP	GAP (in)
177.57	177.68	3800000.00	.312	.204	.0084187	.02	.01	.0001375000

93

DT AXIL	DT FACE	INPUT THER.DEF	CALTEMP(F)	GRADIENT	THERMAL EX.CO.
0.	0.	.0	0.	0.	.0000033

THERMAL DEFL.(rad)	PRES.DEFL.(rad)	PRES.MOM.(inlb/in)	SCFM	SCFH
.00001139700	-.000015487	-1.15C835	3.07511	278.5067

```
cface=2.225642022561 ccface=1.5241959694626 ctop=13.627811262093 cctop=8.2773066202907 cback=.82996629526775
ccback=2.0485070766998 cend=.1493031529433 cbot=.49271677391485 ccbot=.47524731612706 ctall=-6.1570176813593;
clear(1)=.00013739226547881 clear(2)=.00013734670643641 clear(3)=.00013691132739402 clear(4)=.00013667585835162
clear(5)=.00013644038930922 clear(6)=.00013576115168693 clear(7)=.00013463814548473 clear(8)=.00013351513928253
clear(9)=.00013239213308034 clear(10)=.00013126932687814 clear(11)=**** clear(12)=**** ;
```


Figure 26. 25,000 rpm

```
dod=1.65 did=.9 db=1.066 dpr=3. plb=.01 por=120. plr=0. rpm=90000. temp=-297. vis= 1.2898000000000E-09 rd=.00035 anr=15.
diar=1.03 ratio=1. sload=6. rrad=0. thexco=.0000033 flen=.75 elen=-.406 olen=-.156 ymod=3800000. sid=.9 ood=1.65 cutod=1.437
cutoff=.25 odia=1.245 len=0. ;
MODE(1)='GAS' ;
```

FINAL

```
clearx=.0001 ;
alpha1=-.00002539335882409 mtol1=-1.8967719245994 fopen=*** fclose=177.56925445169 ;
clearx=.0001 ;
alpha1=-.00002586745554680 mtol1=-1.9321848546784 fopen=*** fclose=177.56925445169 ;
clearx=.0003 ;
alpha1=-.00001313861821662 mtol1=-.98139683988274 fopen=247.33311469636 fclose=177.56925445169 ;
clearx=.0003 ;
alpha1=-.00001319135718903 mtol1=-.98533620854 94 fopen=247.33311469636 fclose=177.56925445169 ;
clearx=.0002 ;
alpha1=-.00001507474129129 mtol1=-1.1260166953684 fopen=164.69576227655 fclose=177.56925445169 ;
```

O.D.(In)	I.D.(In)	BAL (In)	PLUG(In)	PG LIGHT BANDS	EX.PRES.(psig)	IN.PRES.(psig)	RPM	TEMP(F)	VIS. (lb sec/ In sq)
1.6500	.9000	1.0660	3.000	.01	120.00	0.	90000.	*****	.000000001290

GROOVE DEPTH (In)	GROOVE ANGLE (In)	GROOVE DIA (In)	RIDGE WIDTH/GROOVE WIDTH	SPRING LOAD
.0003500	15.0000	1.0300	1.00000	6.0000

FACE LENGTH	END LENGTH	O RING DIST.	SEAL I.D.	SEAL O.D.	CUT O.D.	CUTOFF
.7500	-.4060	-.15600	.9000	1.6500	1.4370	.250

CLOSE.FORCE	OPEN.FORCE	YOUNGS MOD.	XBAR	YBAR	MOM.OF INERTIA	TORQUE	HP	GAP (In)
177.57	177.39	3800000.00	.312	.204	.0084187	.04	.06	.0002000000

DT AXIL	DT FACE	INPUT THER.DEF	CALTEMP(F)	GRADIENT	THERMAL EX.CO.
0.	0.	.0	0.	0.	.0000033

THERMAL DEFL.(rad)	PRES.DEFL.(rad)	PRES.MOM.(Inlb/In)	SCFM	SCFH
.00010036015	-.000015075	-1.126017	11.68970	701.3822

```
cface=2.2334408824089 ccface=1.5011763675183 ctop=13.627811262093 ccton=8.2773068202907 cback=.82996629526775
ccback=2.0485070766998 cend=.1493031529433 cbot=.49271677391445 ccbot=.47524731612706 ctall=-6.1570176813593 ;
clear(1)=.00019991459898 16 clear(2)=.00019974379694478 clear(3)=.00019957299490796 clear(4)=.00019940219287115
clear(5)=.00019923139083433 clear(6)=.00019873869265321 clear(7)=.00019792409832178 clear(8)=.00019710950309235
clear(9)=.00019629490966292 clear(10)=.00019548031537349 clear(11)=*** clear(12)=*** ;
DO YOU WISH TO FREE THE DATA CURRENTLY IN THE PROGRAM???? ANSWER MUST BE 'Y' OR 'N'!!!!
N
```


Figure 27. 90,000 rpm

RAYLEIGH PAD FLOATING RING HELIUM SEAL

The design features shrouded Rayleigh step hydrogynamic lift pads on the floatint seal ring inside diameter to center the rings on the rotating mating ring with minimum wear and leakage. The rings are separated by a spring loading the rings against the radial seal faces.

The final design is shown in Fig. 28. The NASA supplied design is shown in Fig. 29. The changes from the NASA design are listed below:

1. Use of a bolted, flanged mounting with positive static sealing of the helium purge
2. Use of composite metal-banded carbon rings
3. Use of two antirotation tangs on the outside diameter of the metal band and slots in the housing
4. Use of a wave spring separating carbon rings
5. Full pilot under sealing surface of mate sleeve

The materials used in the design are shown in Fig. 30.

The predicted performance at maximum operating conditions of the helium purged shrouded Rayleigh lift pads and seal dam is shown in Fig. 31. The self-acting lift pad characteristics of increased lift and power with reduced film thickness is shown. Leakage also decreases with reduced film thickness.

The thermal analysis results for the helium purge seal components are shown in Fig. 32 and 33. The average temperature at maximum operating conditions was 216.7 K (-70 F.) The results were used in the stress analyses of seal components.

The floating rings are pressure blanaced as close as possible. The forces, pressures, and moments on the floating rings are shown in Fig. 34. The rings are pressure balanced except at the seal dam and seal face. The separating spring force was 3.781 N (90.85 pounds).

The design of the helium-purged seal carbon rings was completed after the diameter characteristics of the rotating mating sleeve as a function of geometry, pilot fits, axial preload, temperature, and speed were evaluated.

Three floating ring configurations were evaluated: solid carbon ring (Fig. 35); composite metal-banded carbon ring (Fig. 36); and segmented or split ring.

The NASA-designed, helium-purged seal, solid carbon ring was compared with a metal-banded carbon composite ring design. Relative radial deflections of the seal rings and the rotating mating sleeve were compared (Table 2) to determine the changes in diametral clearances from the installed-to-static chilled conditions and installed-to-maximum operating conditions at 9425 rad/s (90,000 rpm.) The analysis considered the effects of temperature and pressure on the

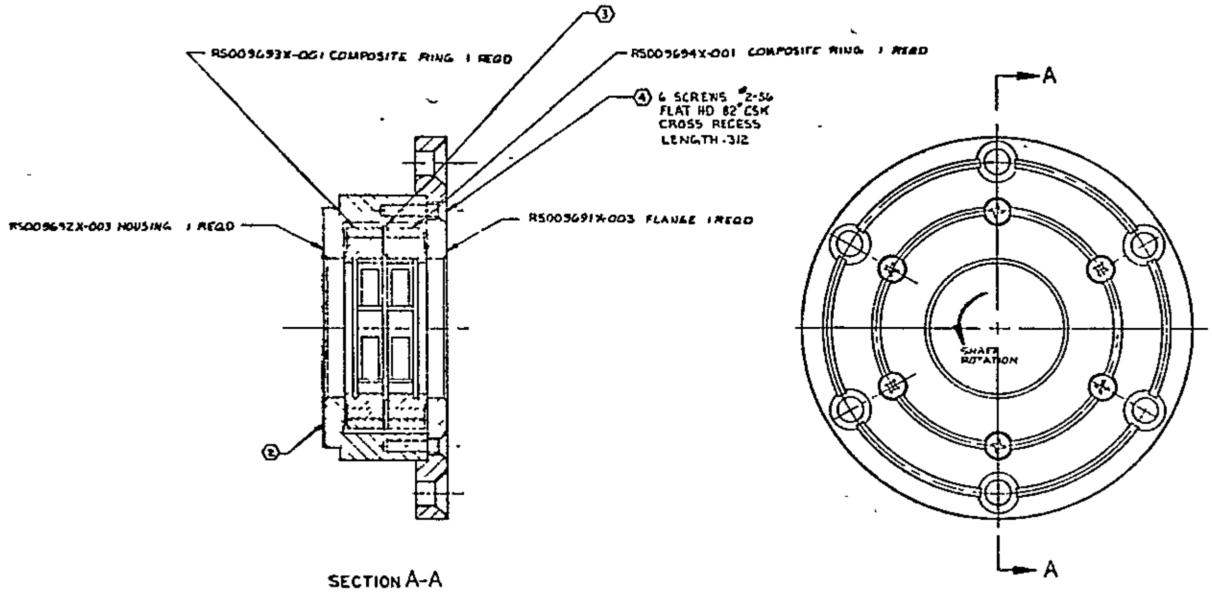


Figure 28. Final Helium Purged Seal Assembly

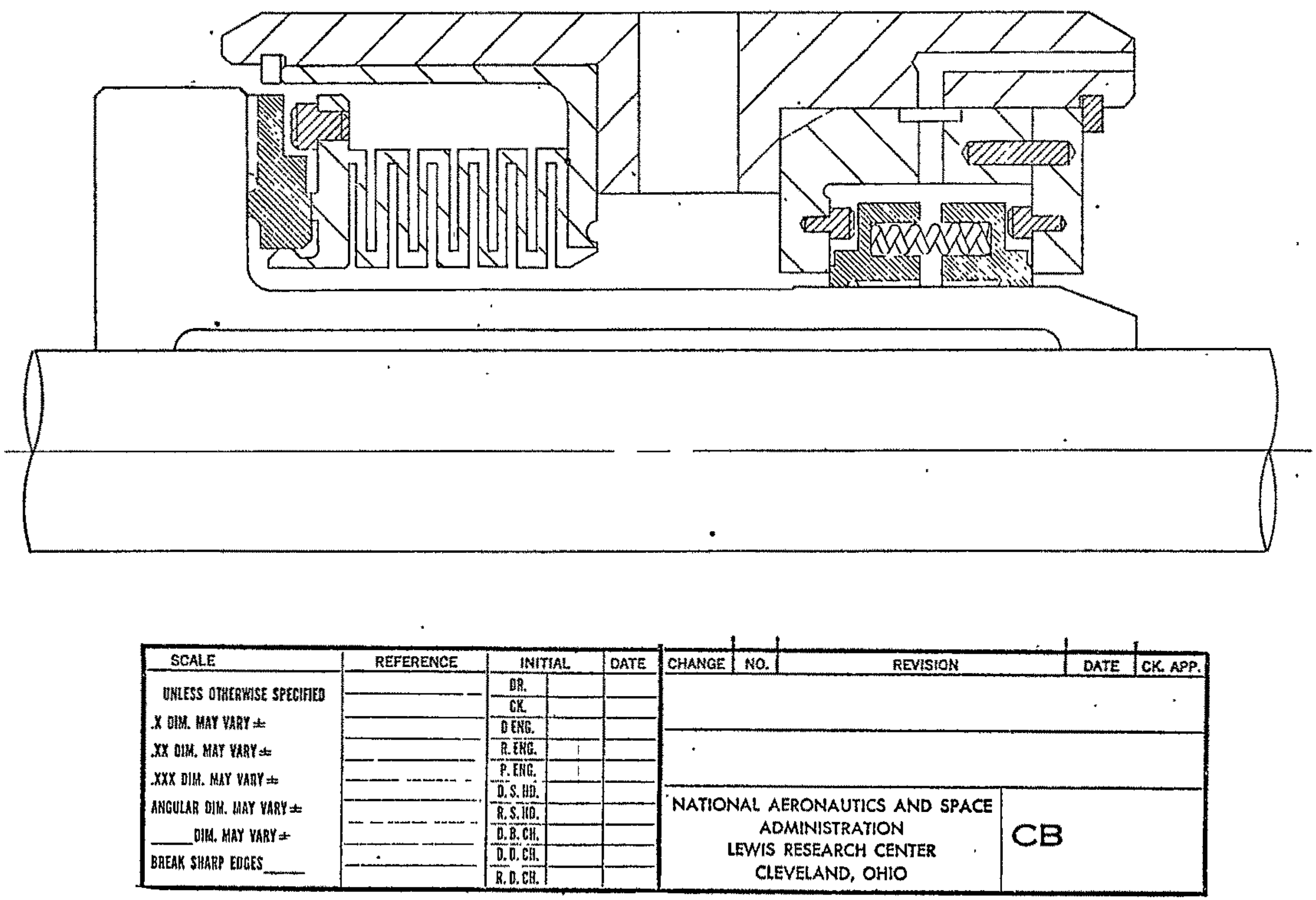


Figure 29. NASA Sketch of LOX Face Seal and Helium Purge Seal

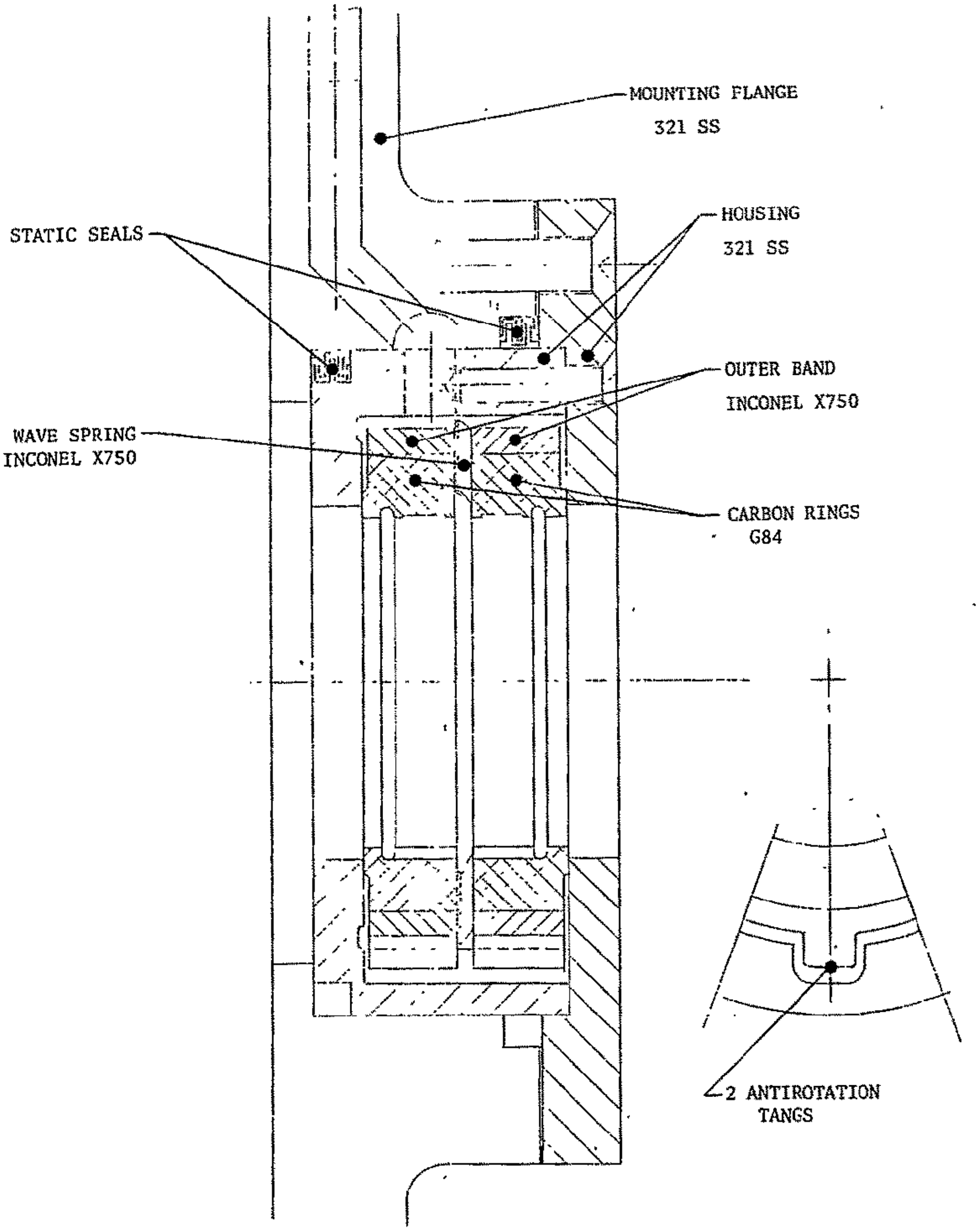


Figure 30. Composite Ring Helium Seal Layout

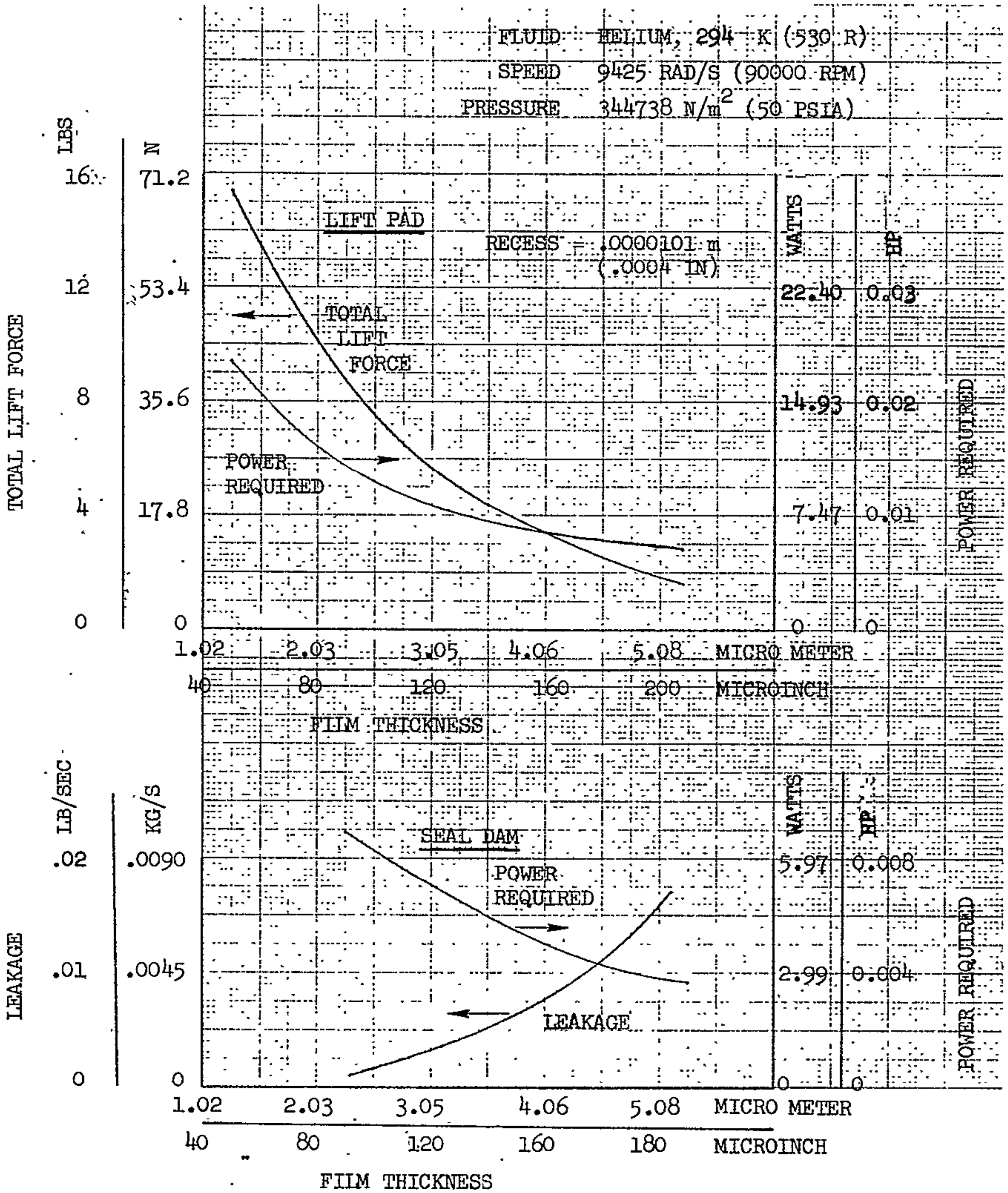
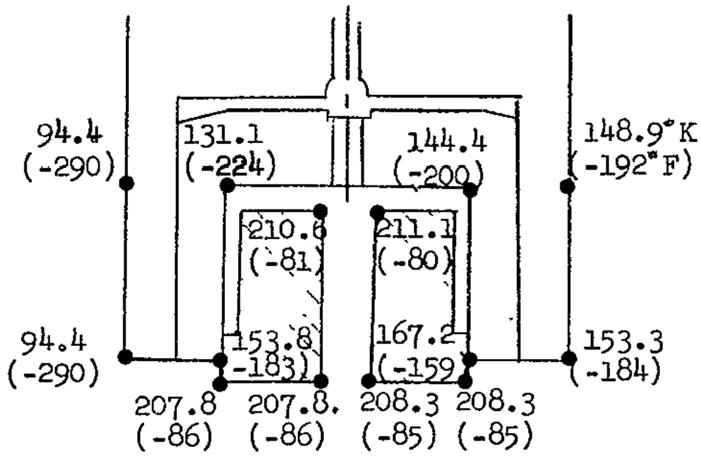


Figure 31. NASA Helium Purge Seal Performance

AT ZERO RAD/S (ZERO RPM)



AT 9425 RAD/S (90000 RPM)

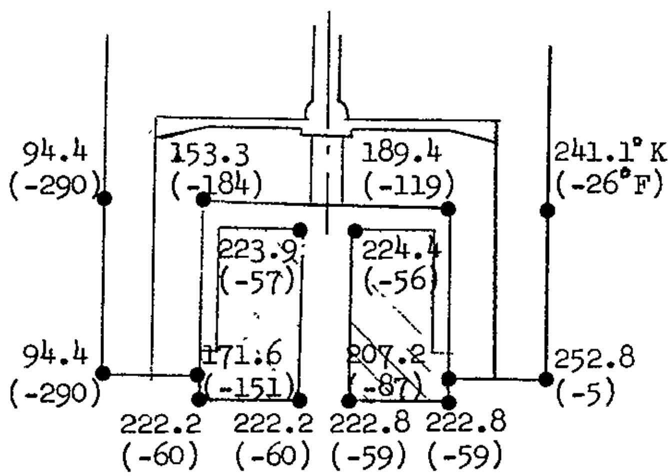


Figure 32. Temperature Profile in Helium Purge Seal Assembly

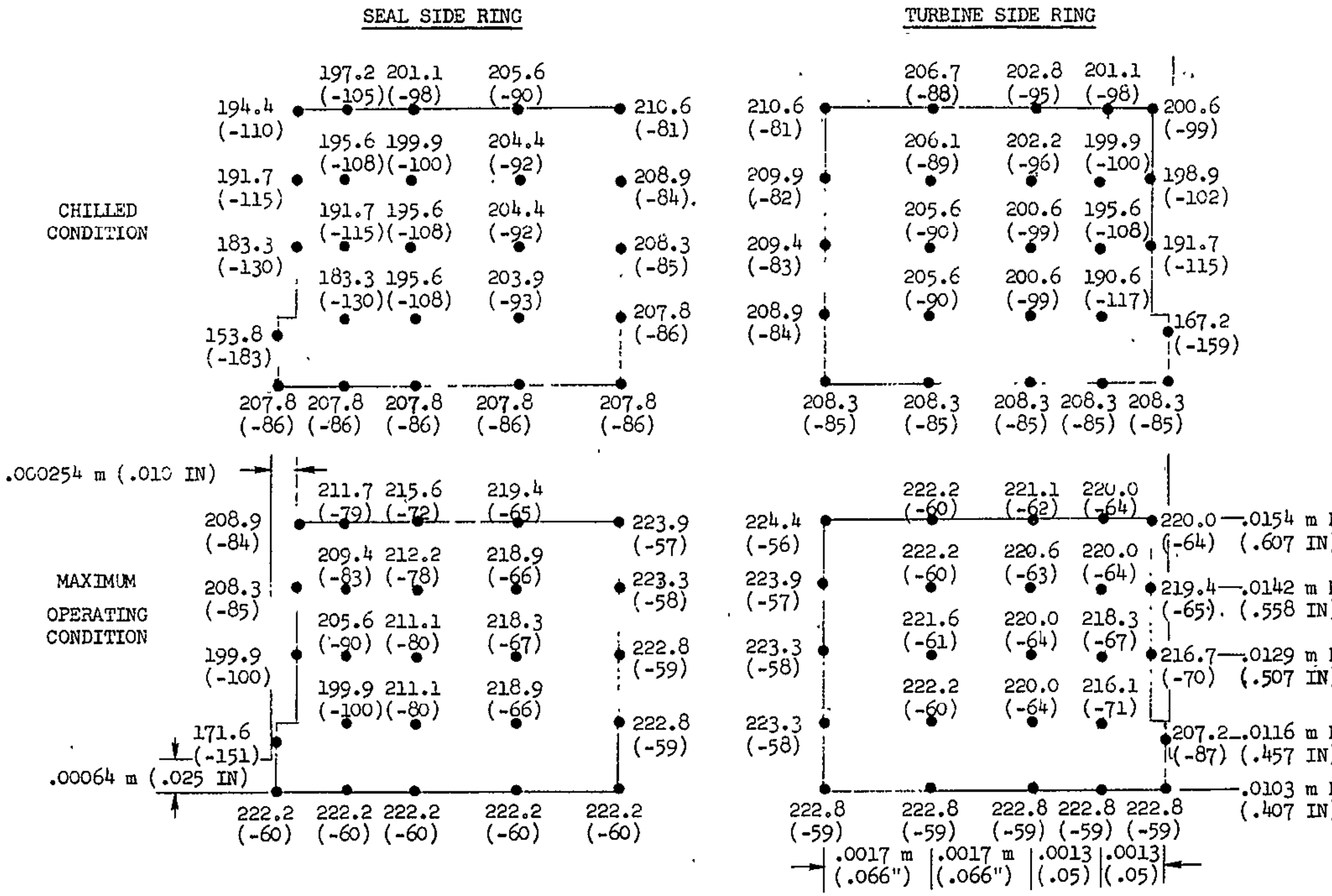
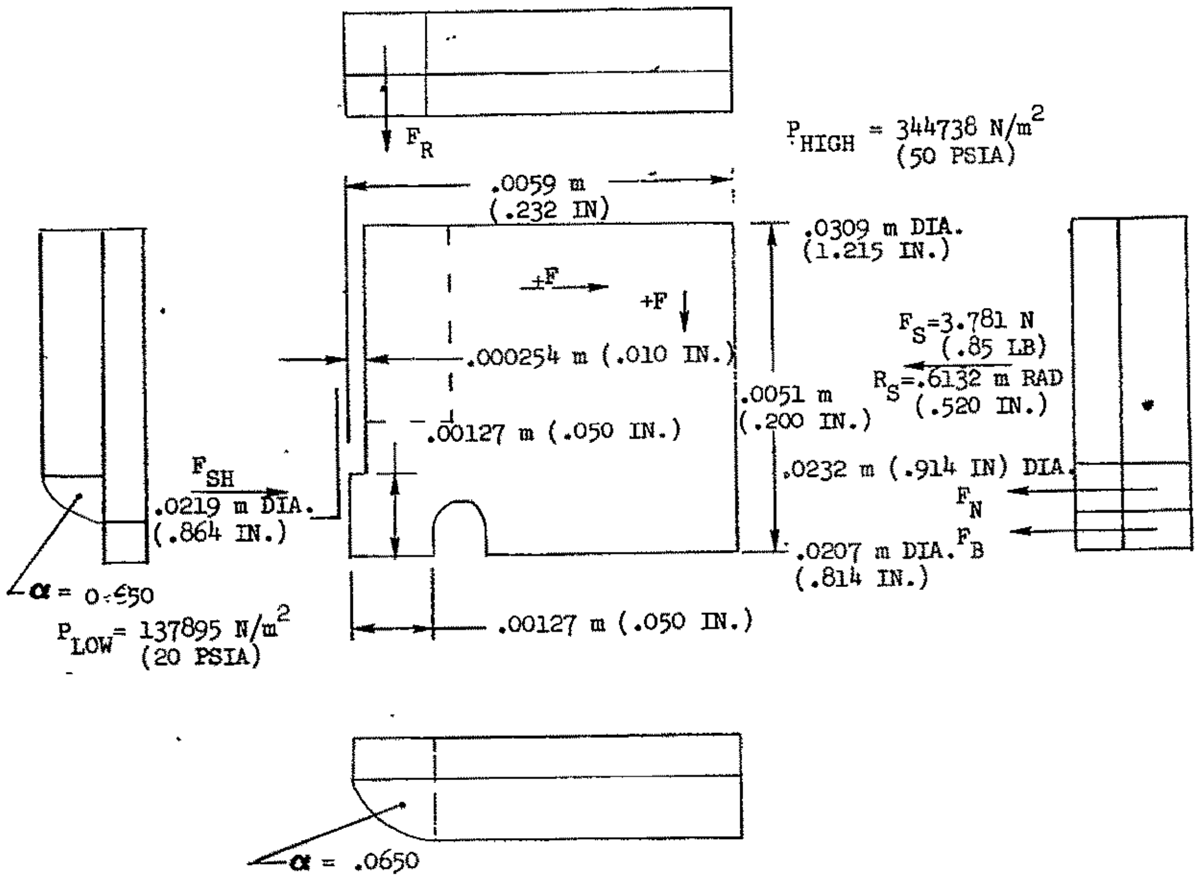


Figure 33. Helium Purged Seal Rings Predicted Temperature Distribution K (F)



F_S = 3.781 N (.85 LB)

F_N = 3.26 N (.733 LB)

F_B = 8.794 N (1.977 LB)

F_{SH} = 15.835 N (3.560 LB)

F_R = 14.376 N (3.232 LB)

Figure 34. Preliminary Force and Moment Balance Free Body of Carbon Ring - Scale: 10X

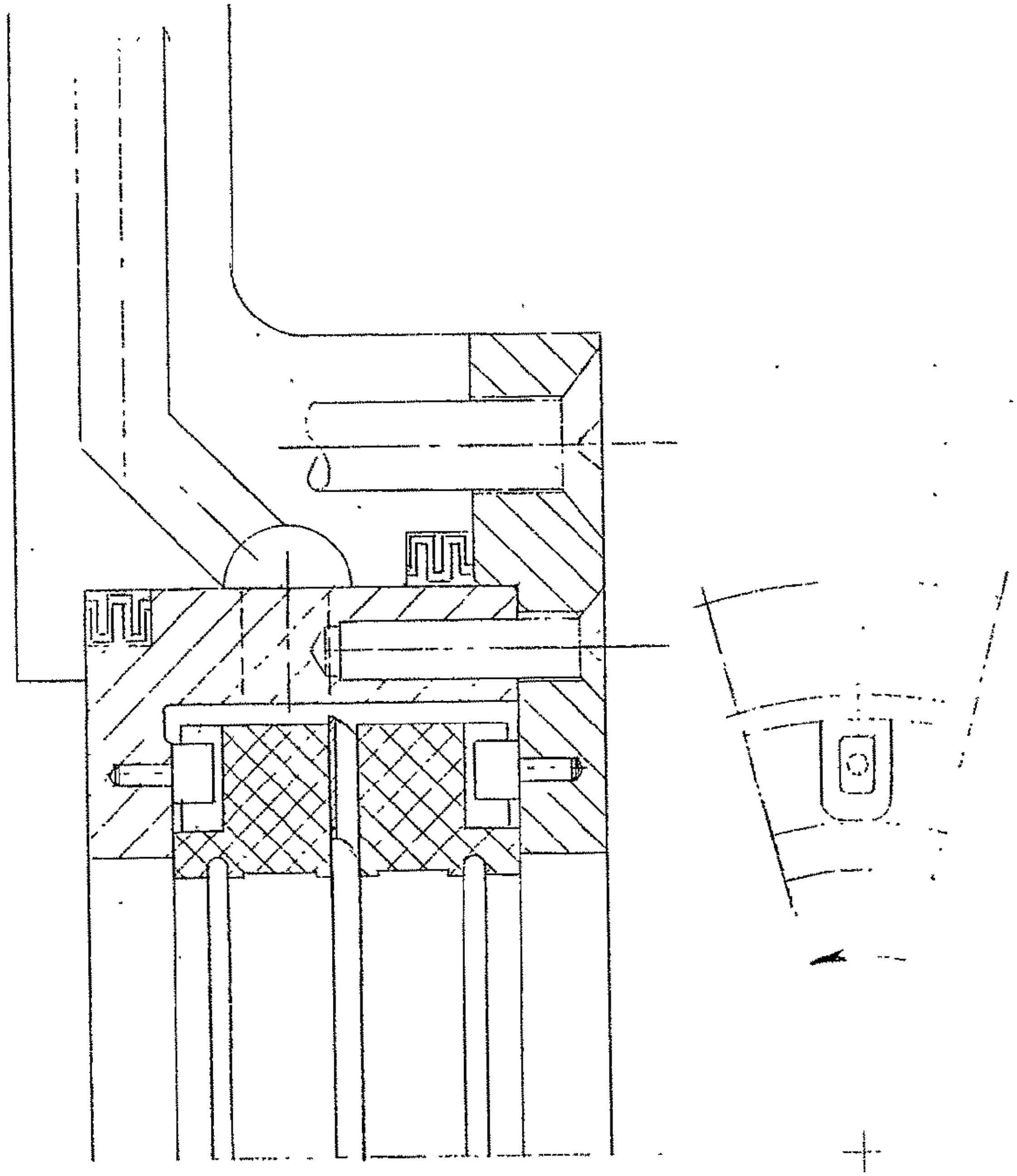


Figure 35. Solid Carbon Ring Helium Seal Layout

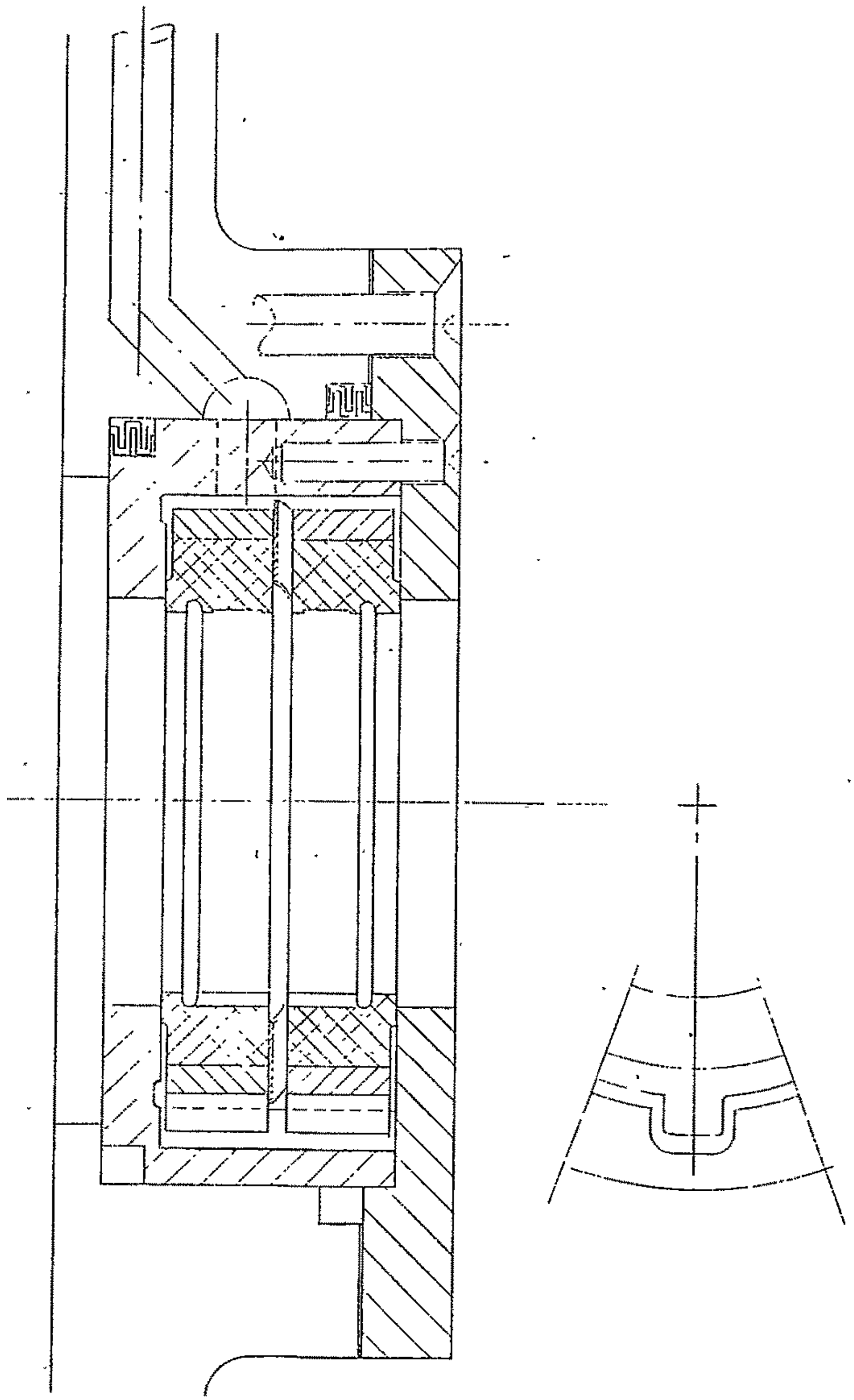


Figure 36. Composite Ring Helium Seal Layout

TABLE 2. SMALL, HIGH-SPEED SEAL TECHNOLOGY HELIUM-PURGED SEAL RINGS; COMPARISON OF SOLID AND COMPOSITE RINGS

(Reference: Ambient Installed Condition
Note: Dimensions: centimeters (inches))

	Chilled Condition		Maximum Operating Condition	
	Solid Ring	Composite Ring	Solid Ring	Composite Ring
LOX Side Seal				
Outer Diameter, Seal Ring ΔRadius	-0.000409 (-0.000161)	-0.001273 (-0.000501)	-0.000345 (-0.000136)	0.001095 (-0.000431)
Inner Diameter, Shaft Sleeve ΔRadius	-0.002096 (-0.000825)	-0.002096 (-0.000825)	-0.000958 (-0.000377)	0.000958 (-0.000377)
ΔClearance, radial	-0.001687 (+0.000664)	-0.000823 (+0.000324)	0.000612 (+0.000241)	0.000137 (-0.000054)
ΔClearance, diametral	-0.003373 (+0.001328)	-0.001646 (+0.000648)	0.001224 (+0.000482)	0.000274 (-0.000108)
Turbine Side Seal				
Outer Diameter, Seal Ring ΔRadius	-0.000394 (-0.000155)	-0.001229 (-0.000484)	-0.000318 (-0.000125)	-0.001011 (-0.000398)
Inner Diameter, Shaft Sleeve ΔRadius	-0.002096 (-0.000825)	-0.002096 (-0.000825)	-0.000739 (-0.000291)	-0.000739 (-0.000291)
ΔClearance, radial	-0.001702 (+0.000670)	0.000866 (+0.000341)	-0.000422 (+0.000166)	-0.000272 (-0.000107)
ΔClearance, diametral	-0.003404 (+0.001340)	0.001732 (+0.000682)	-0.000843 (+0.000332)	-0.000544 (-0.000214)

seal rings and temperature, pressure, rotation, axial bolt load, and pilot press fits on the mating sleeve. The change in diametral clearance for the solid ring was nearly twice that for the composite ring at the chilled conditions. The relative diametral clearance was larger for the solid ring than for the composite ring at the 9425 rad/s (90,000 rpm) maximum operating condition. The composite ring design was selected on the basis of improved clearance control for lower helium leakage and increased hydrodynamic lift potential.

The predicted range of film thickness at maximum operating conditions in the tester is 0.00066 to 0.00173 cm (0.00026 to 0.00068 in.).

The helium seal mating ring was designed to have a constant diameter at maximum operating conditions. Thermal and stress analyses including finite element modules indicated a full pilot was required under the sealing area for dimensional control. Mating sleeve deflections due to rotation, temperature, axial bolt load, and pilot fits are summarized in Table 3. Mating sleeve material is K-monel for oxidation resistance and hard chrome plate for the sealing surface. Provisions were made on the sleeve for Bently depressions, puller holes, and LOX mate ring clamping shoulder.

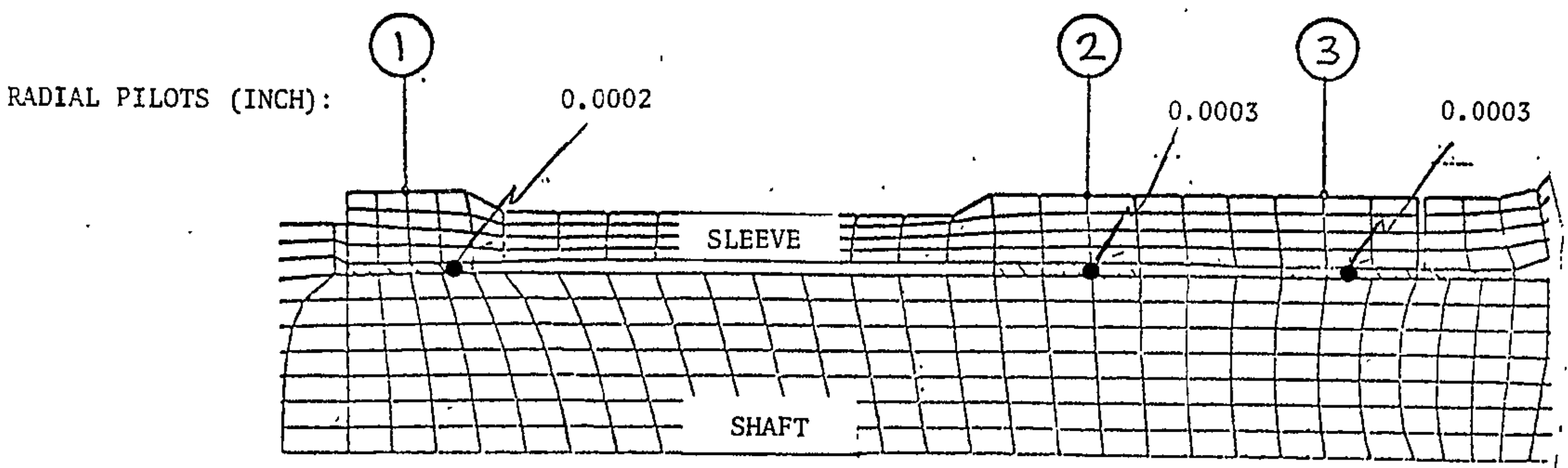
The helium seal housing has a single feed hole for the helium purge flow. Flat, smooth surface finish faces are provided for seal ring faces and the static seal faces. The housing outer inside diameter corners are chamfered to facilitate seal installation. The housing-to-mating ring radial clearance is 0.076 cm (0.030 in.), which would result in a 7.22/m^3/minute (255 scfm) helium flow at 344,738 N/m^2 (50 psi) in case of a catastrophic seal failure.

TABLE 3. HELIUM PURGED SEAL ROTATING MATING SLEEVE RADIAL DISPLACEMENTS SUMMARY

Location / Condition	① At Mating Ring Shoulder (Inch)	② At Seal Side Ring (Inch)	③ At Turbine Side Ring (Inch)
Sleeve *	+.000148	+.000218	+.000207
Sleeve + Assembly **	+.000168	+.000221	+.000213
Childown	-.000658	-.000604	-.000612
Temperature + Speed	-.000585	-.000156	-.000078

* Values shown are installed with radial interference, pre-installation values are all equal to 0.00.

** Assembly indicates a preload of 3500 lbs.



TESTER DESIGN

The seal tester assembly is shown in Fig. 37. The tester is a modification of an existing LOX seal tester designed to simulate, as closely as possible, the operating conditions in a liquid oxygen turbopump including an acceleration rate of 4189 rad/s/s (40,000 rpm/sec) with the liquid oxygen pressure increase proportional to the square of the speed. A braking system is also provided to decelerate the tester from full speed to zero rpm in 4 seconds. The tester consists of a simulated turbopump overhung rotating shaft, mounted in two preloaded angular contact bearings. The tester bearing size was minimized consistent with the load, life, stiffness, and critical speed requirements to provide the minimum DN value for safe operation in liquid oxygen. The DN value for the selected 15-mm bearings at the 9425 rad/s (90,000 rpm) operating point is 1.35 million. The bearing design is shown in Fig. 38, and predicted bearing B_1 life is shown in Fig. 39. The bearings are lubricated and cooled by liquid oxygen which flows inward through each bearing with a drain located in the cavity between the bearings. LOX flow to each bearing is 0.0189 m^3/minute (5 gpm) and is entirely separate from the flow to the test seals.

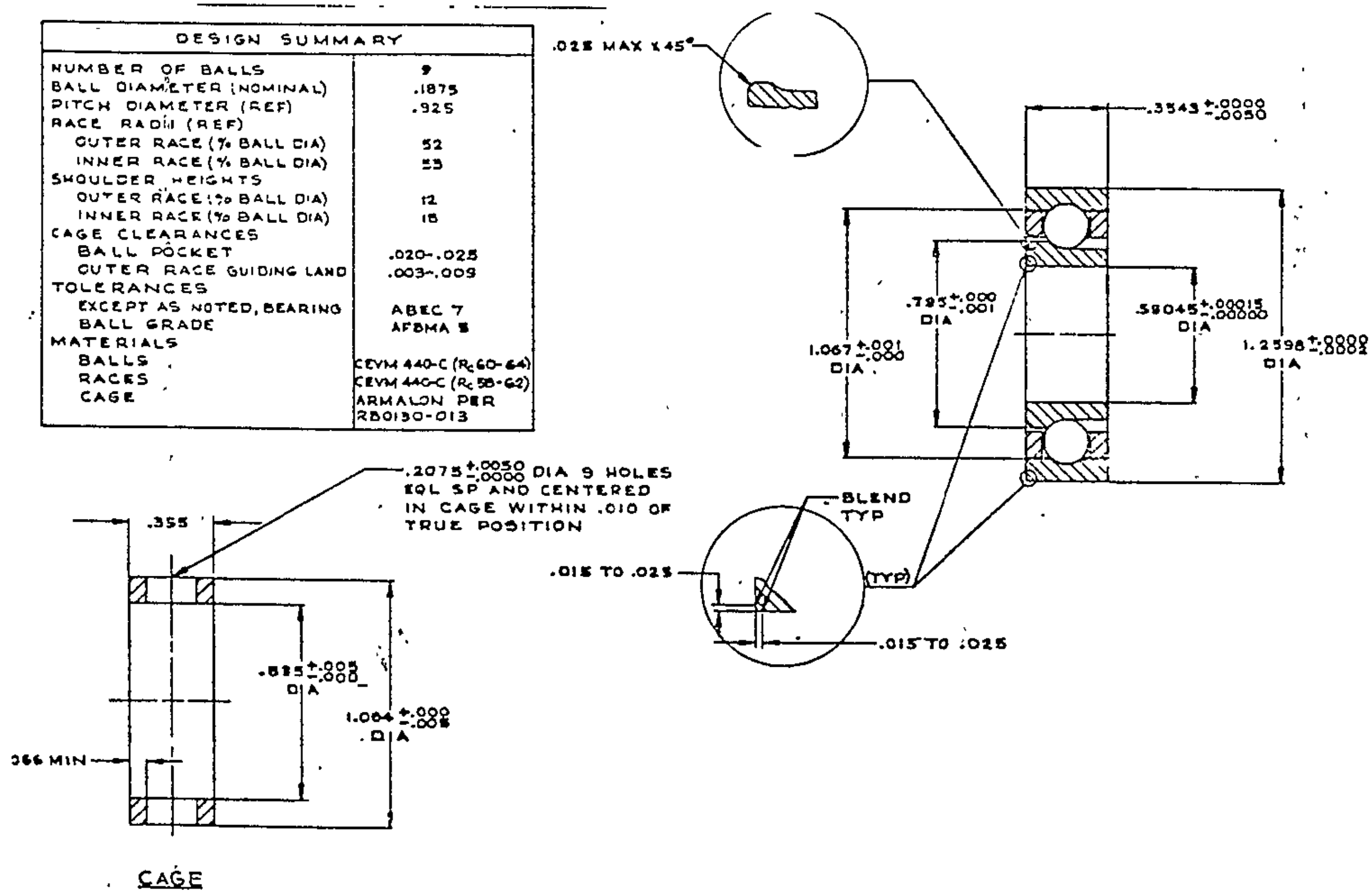
The tester shaft is accelerated and driven at the design speed of 9425 rad/s (90,000 rpm) by a 0.064 m (2-1/2 in.) diameter radial inflow turbine mounted on the overhung end of the shaft. Drive gas for the turbine is ambient nitrogen which is supplied to the rotor by four 0.0064 m (0.25 in.) diameter forward and two 0.0064 m (0.25 in.) reversing nozzles. Performance characteristics of the turbine are shown in Fig. 40. A close clearance Kel-F labyrinth seal was incorporated at the turbine rotor OD to lower the pressure in the adjacent seal drain area. The test seals (two) are located on the overhung portion of the shaft between the turbine and the bearing to stimulate, as close as possible, the actual turbopump installation.

An additional labyrinth seal is located between the test seals and the outward turbine bearing and serves two purposes:

1. It separates the upstream seal cavity from the bearing cavity.
2. The diameter is sized to help balance the tester thrust loads.

Drains are provided in the tester housing in the cavities on either side of the purged helium seal. Helium purge gas fed to the helium seal is allowed to leak to both cavities where, on one side, it sweeps any simulated turbine leakage gases out through a drain port, and on the opposite side, it sweeps any leakage from the LOX fluid film face seal out through a separate drain port.

Critical speed analysis was performed on several reiterations of tester shaft designs to provide safe operation at the required test speeds. The final design has a weight added between the bearings to shift the second critical speed further from the nominal operating speed. The first critical 1780 rad/s (17,000 rpm) is below the minimum 2618 rad/s (25000 rpm) test speed, and the third critical 5136 rad/s (115,000 rpm) is above the maximum 9425 rad/s (90,000 rpm) test speed. Other test speed was selected at 6279 rad/s (60,000 rpm) to maintain adequate margin once the 4919 rad/s (47,000 rpm) second critical



DESIGN SUMMARY	
NUMBER OF BALLS	9
BALL DIAMETER (NOMINAL)	.1875
PITCH DIAMETER (REF)	.925
RACE RADII (REF)	
OUTER RACE (% BALL DIA)	52
INNER RACE (% BALL DIA)	55
SHOULDER HEIGHTS	
OUTER RACE (% BALL DIA)	12
INNER RACE (% BALL DIA)	18
CAGE CLEARANCES	
BALL POCKET	.020-.025
OUTER RACE GUIDING LAND	.003-.009
TOLERANCES	
EXCEPT AS NOTED, BEARING	ABEC 7
BALL GRADE	AFBMA 5
MATERIALS	
BALLS	CEVM 440-C (R_c 60-64)
RACES	CEVM 440-C (R_c 58-62)
CAGE	ARMALON PER RB0130-013

Figure 38. Tester Bearing

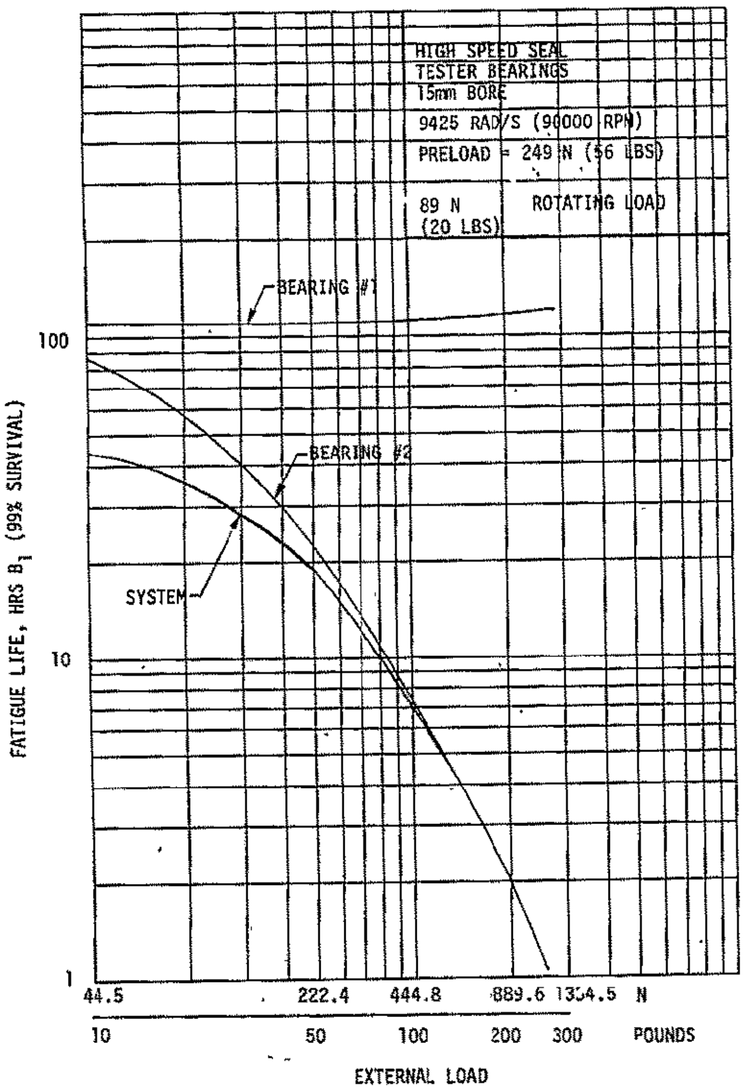


Figure 39. Bearing B_1 Life

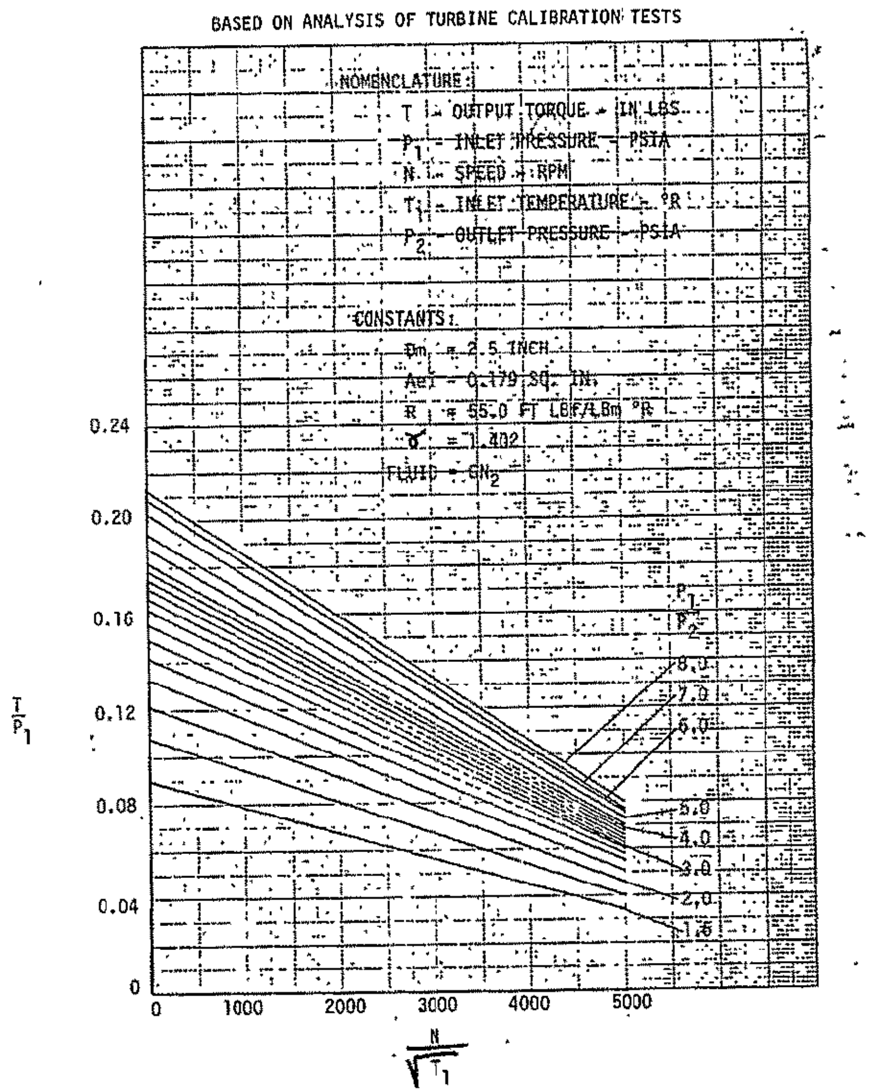


Figure 40. Mark 36 Turbine Performance Map

speed. Results of the critical speed analysis are shown in Fig. 41 where critical speeds are plotted against bearing stiffness.

THERMAL ANALYSIS

A thermal analysis was made of the seal tester for chilled zero speed conditions and also the design operating conditions at 9425 rad/s (90,000 rpm). The analysis indicated the bearing and LOX seal cavities were maintained at LOX temperature 90 K (-296 F) during operation. The LOX side of the helium seal housing also remained at essentially LOX temperature at operating conditions. The helium mating ring sleeve temperature increased from 201 K (-96 F) at chill to approximately 222 K (-60 F) at the 9425 rad/s (90,000 rpm) operating condition. The turbine rotor also increased in temperature from 197 K (-105 F) at chill to 284.8 K (+53 F) at operating conditions.

THRUST BALANCE

To achieve the required minimum 10-hour life of the tester bearings, the thrust load on the bearings had to be maintained at a maximum of approximately 334 N (75 pounds) a total shaft thrust load at 9425 rad/s (90,000 rpm) was achieved by pressure balancing the system. Bladed housings were incorporated on either side of the shaft weight to balance pressure across the rotating element, and the diameter of the labyrinth between the bearing and the test seal was sized to achieve a total thrust load of 334 N (75 pounds) toward the turbine. Fig. 42 is a summary of the calculated thrust loads in the tester.

MATERIALS

The materials selected for the tester are shown in Fig. 43. The stainless and nickel steels were selected because of their LOX compatibility, resistance to oxidation and their strength, ductibility, and hardness in the required operating environment. The 321 stainless steel used in the bearing housing, bearing carriers, and helium seal housing exhibits high ductility and adequate strength at cryogenic temperatures. Inconnel 718 was used for the turbine rotor, shaft, shaft weight, LOX seal mounting ring and LOX seal housing. The K-monel used in the LOX seal mating ring and the helium seal mating sleeve has high resistance to oxidation and can be chrome plated.

A286 stainless steel is used for the bearing end shaft nut and seal end bearing carrier nut. The 6061 aluminum drive turbine manifold was an existing part and required special Invar washers for mounting to provide gasket sealing with the high thermal contraction of aluminum.

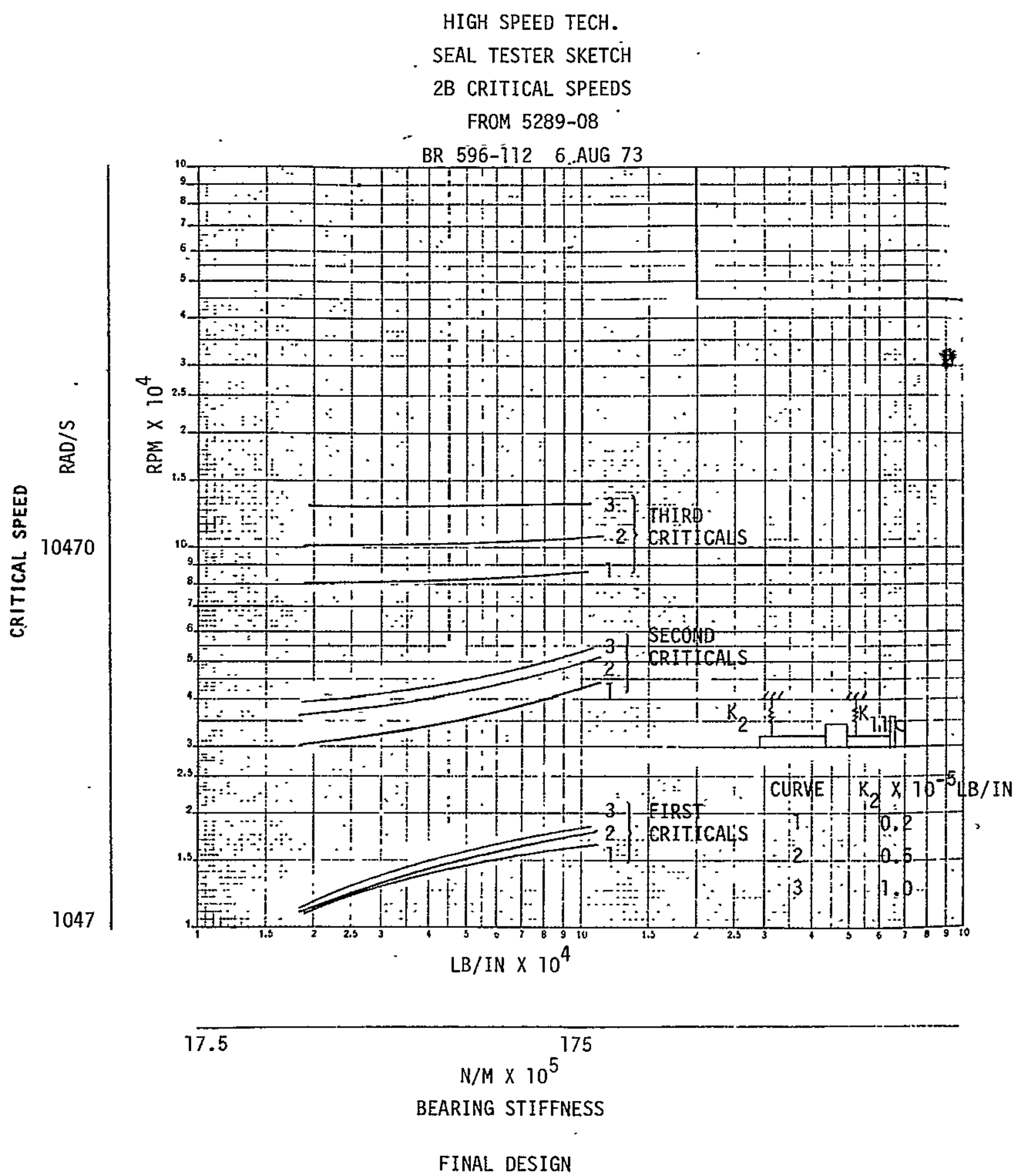


Figure 41. Critical Speeds

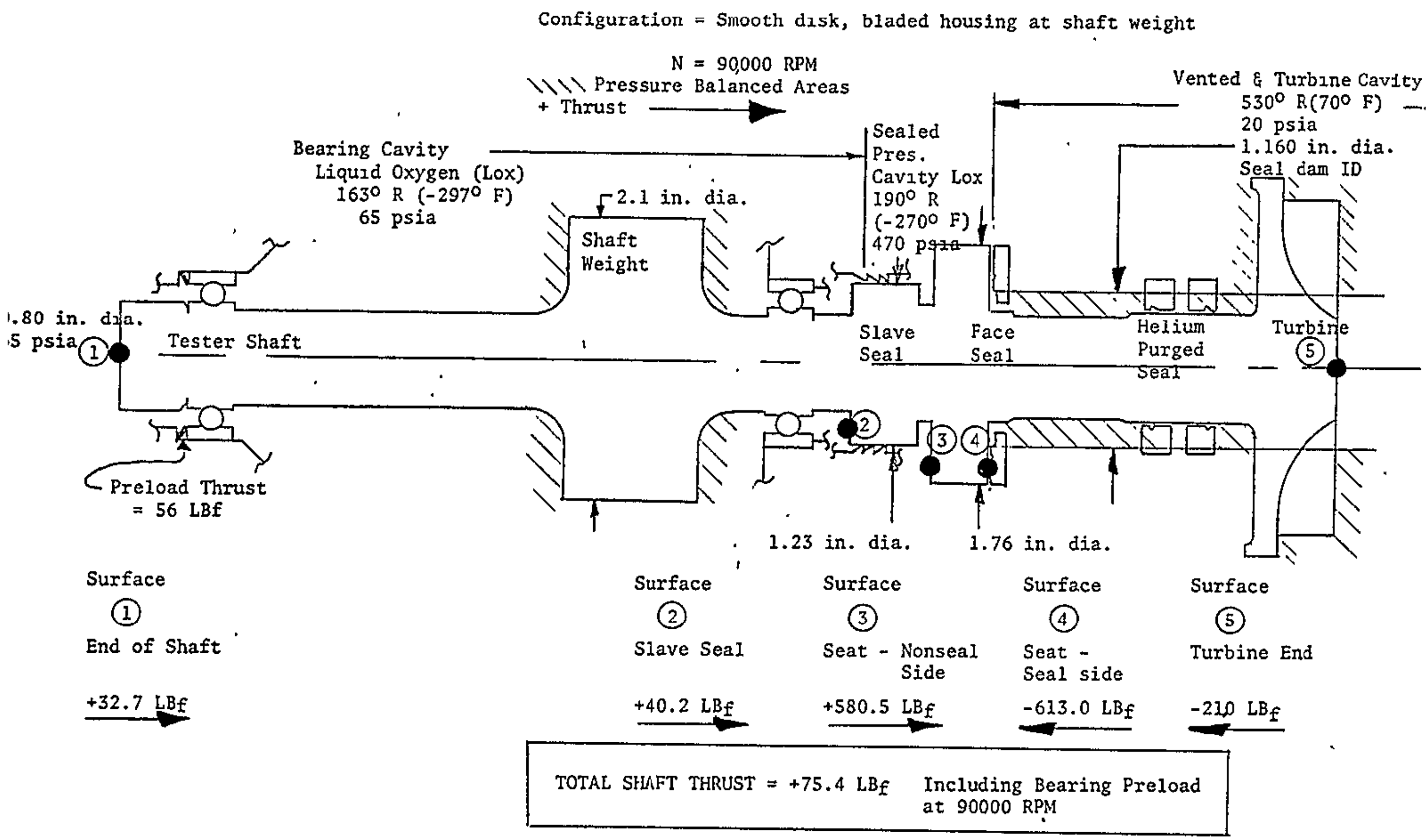
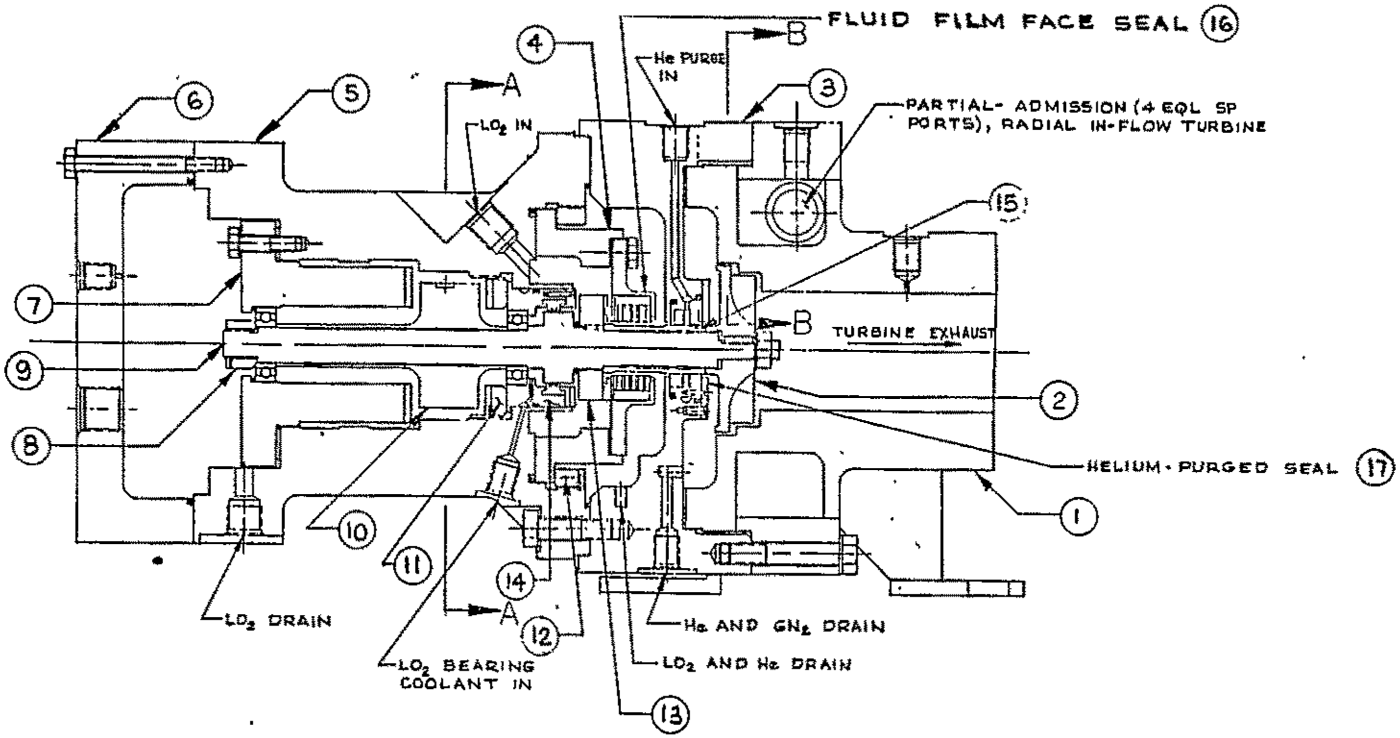


Figure 42. Small, High-Speed Seal Tester Shaft Axial Thrust Summary



LEGEND	MATERIAL
1	6061 ALUM
2	INCO 718
3	321 CRES
4	INCO 718
5	321 CRES
6	321 CRES
7	321 CRES
8	A286 CRES
9	INCO 718
10	INCO 718
11	A286 CRES
12	A286 CRES
13	K-MONEL
14	321 CRES
15	K-MONEL
16	INCO 718
17	321 CRES

Figure 43. Small High Speed Seal Tester Materials

FOLDOUT FRAME 1

FOLDOUT FRAME 2

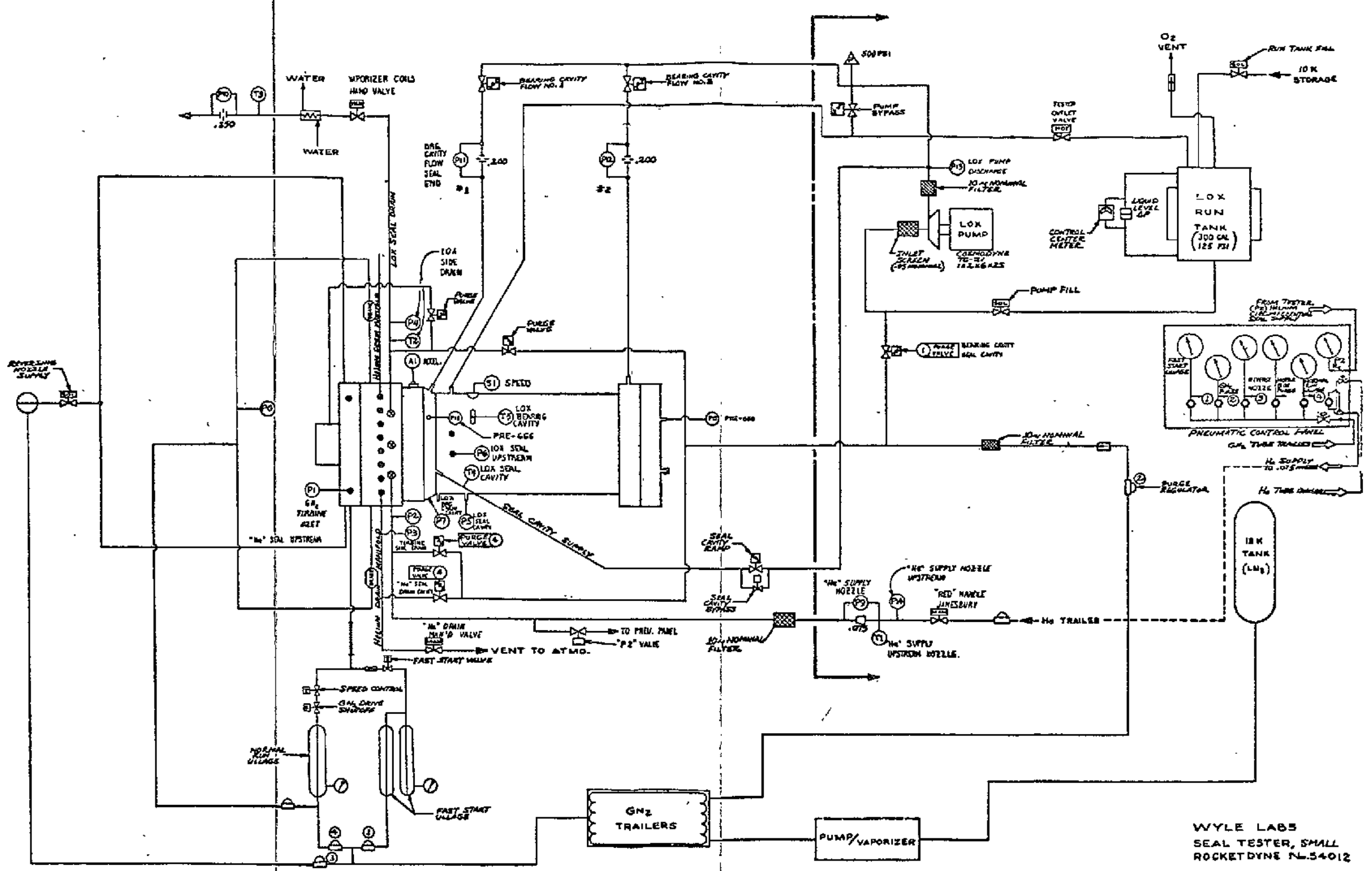


Figure 44. Seal Tester Flow Schematic

TEST FACILITY

DESCRIPTION

Seal testing was accomplished at Wyle Laboratories, Norco, California. Capabilities include 106 m^3 (28,000 gallons) and 49.2 m^3 (13,000 gallons) vacuum-jacketed LH_2 and LOX storage with steady-state flow to 41.63 m^3/minute (11,000 gpm); 49.2 m^3 (13,000 gallons) and 37.85 m^3 (10,000 gallons) vacuum storage tanks for LOX and LN_2 with ready-state flows to 37.85 m^3/minute (10,000 gpm); and high-pressure pneumatic systems with air/nitrogen flowrates to 45.35 kg/s (100 lb/sec), and helium flowrates to 6.8 kg/s (15 lb/sec). A schematic of the seal test setup is shown in Fig. 44.

Liquid oxygen was supplied to the tester from a 1.14 m^3 (300 gallons) tank by a Cosmodyne Model TC-21 pump through a 10-micron filter. The flow was split into bearing coolant flow and LOX seal flow.

Flow to each of the two bearings was measured by calibrated orfices and controlled by motorized valves. LOX seal pressurization was also controlled by an upstream motorized valve. For the ramp test, seal cavity pressure rise from 88.96 N/m^2g (20 psig) to 178 N/m^2g (400 psig) at a rate proportional to the square of the rotational speed, a bypass in conjunction with a solenoid valve was used. A preramp pressure was established with the bypass valve; the solenoid was then actuated to supply the 1780 N/m^2g (400 psig) at the required rate. Helium purge flow was supplied from a pressurized tank and regulated to provide 133.45 N/m^2a (30 psia) at the tester.

Gaseous nitrogen for the tester drive turbine was supplied from a pressurized tank. Solenoid and motorized valves were used to control the GN_2 pressure to achieve the desired test speed. For the fast-start tests, an acceleration rate of 4189 rad/s/s (40,000 rpm/sec) additional GN_2 tank was plumbed into the drive system. The additional GN_2 supply was cut in at turbine start and automatically deactivated when the tester operating speed was reached. Fast-start ramp rate was controlled by varying the fast-start tank pressure.

The requirement to decelerate the tester from operating speed to zero speed in 4 seconds was achieved by simultaneously closing the LOX seal supply and turbine solenoid valves and actuating the solenoid valve to supply GN_2 to the two turbine reversing nozzles for 2 seconds, and then the tester brake actuators for 1.5 seconds. The valve opening times were controlled by a cam timer activated at shutdown. The turbine reversing nozzles and brake actuators were each supplied by separate GN_2 tanks and tank pressures were varied to set deceleration rates. During checkout, it was found that the reversing nozzles provided sufficient power to meet the deceleration time and the use of the brake system was discontinued.

Gaseous nitrogen purges were used both before and after each test to prevent moisture contamination of the tester. The purges were also activated between tests whenever a significant delay resulted in LOX pump shutdown. Purge gas was supplied to the bearing cavity, LOX seal upstream and downstream cavities, and the helium seal upstream and downstream cavities. The tester installed in the facility is shown in Fig. 45 through 48. Figure 45 is a photograph of the facility showing the overall layout of the test site and the relationship of the tester to the facility main fluid supply systems. Figure 46 is a view of the tester looking into the turbine exhaust and shows the location of the main flow control valve. Figure 47 is a closeup view of the tester showing the LOX seal supply line and the bearing drain line. Figure 48 illustrates the location of the bank of pressure transducers and also shows the location of the orifice used to measure LOX seal drain cavity leakage. Figure 49 is a photograph of the control panel and the strip charts used to record some of the data.

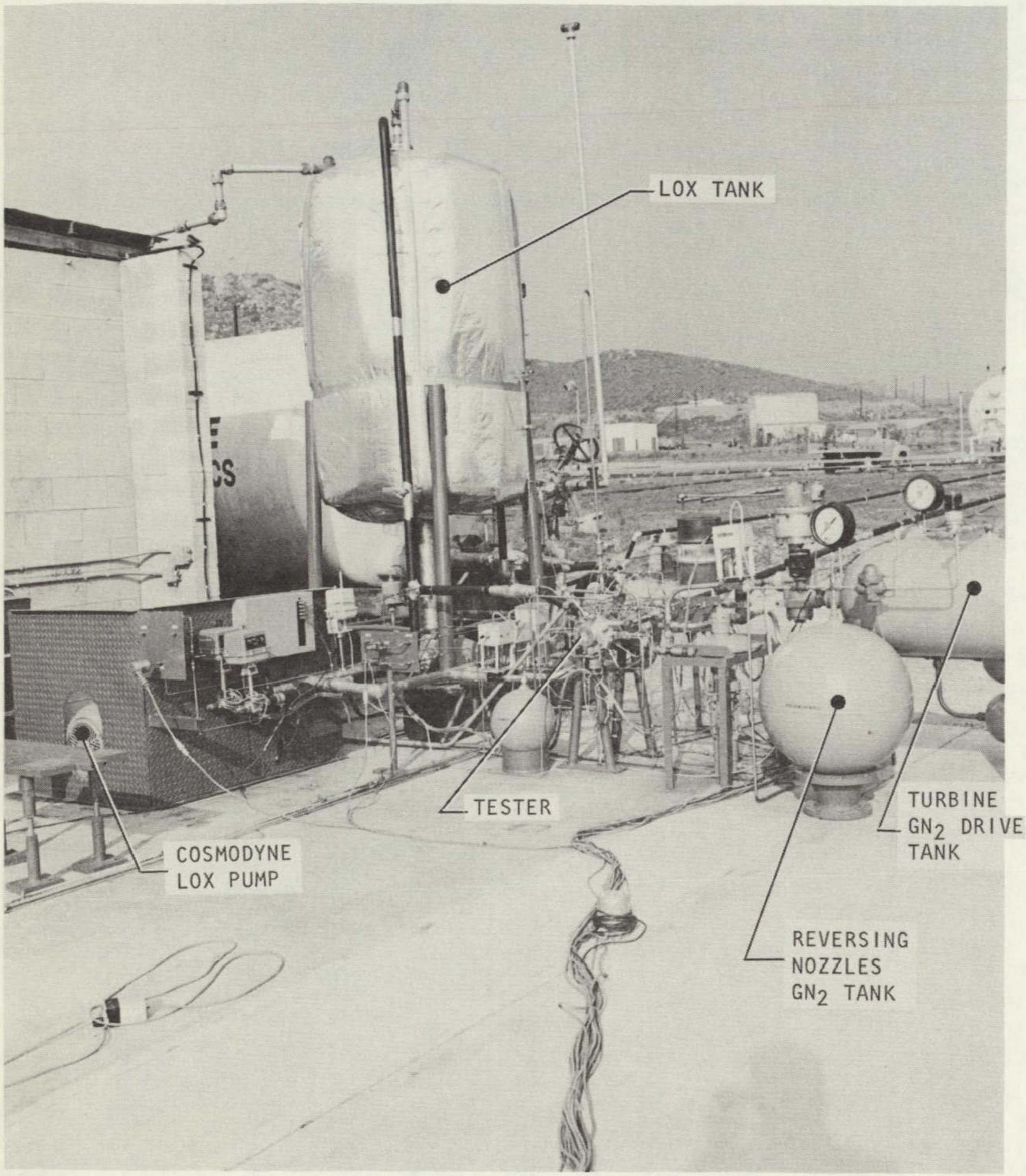


Figure 45. Test Facility (overall)

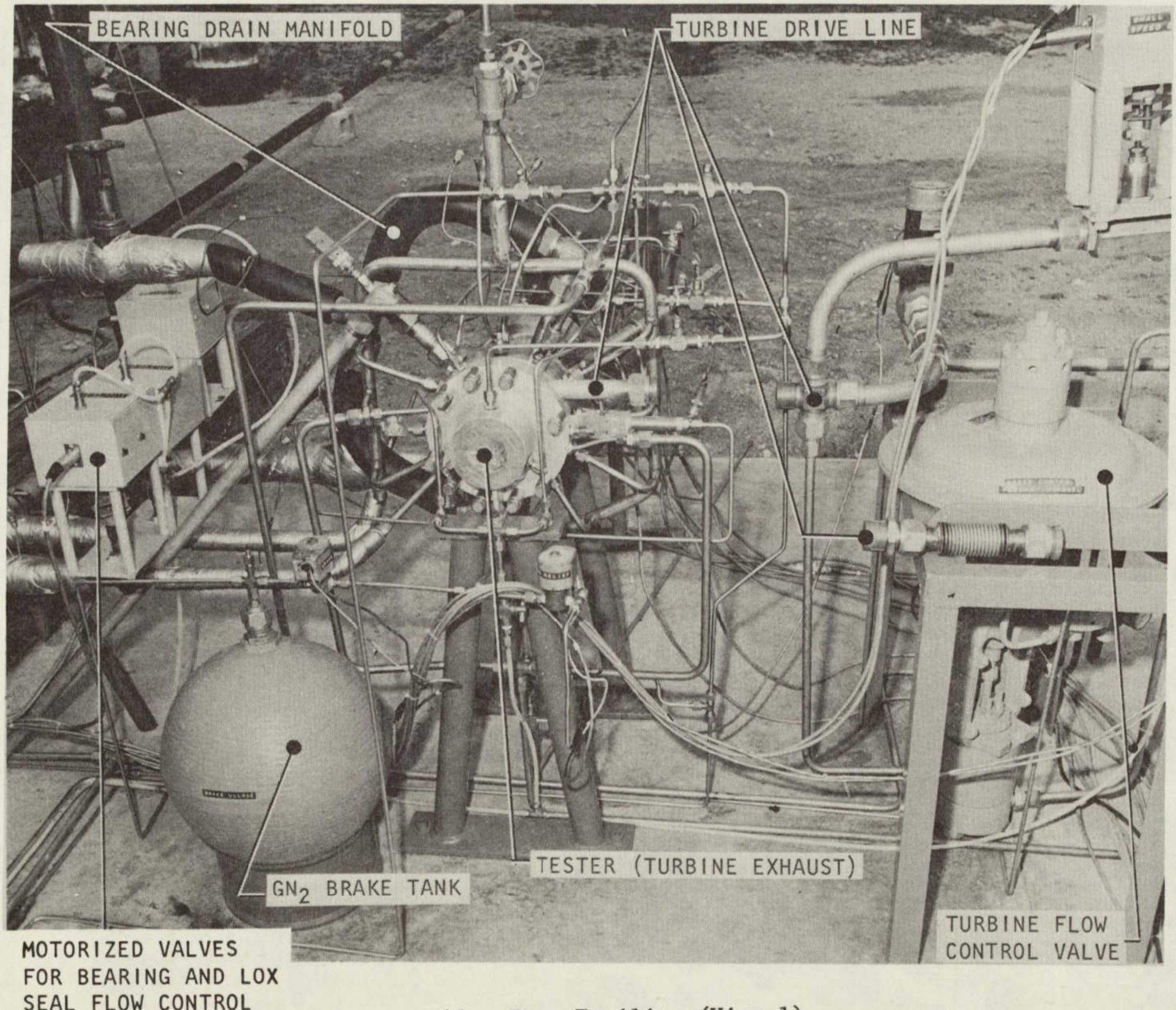


Figure. 46. Test Facility (View 1)

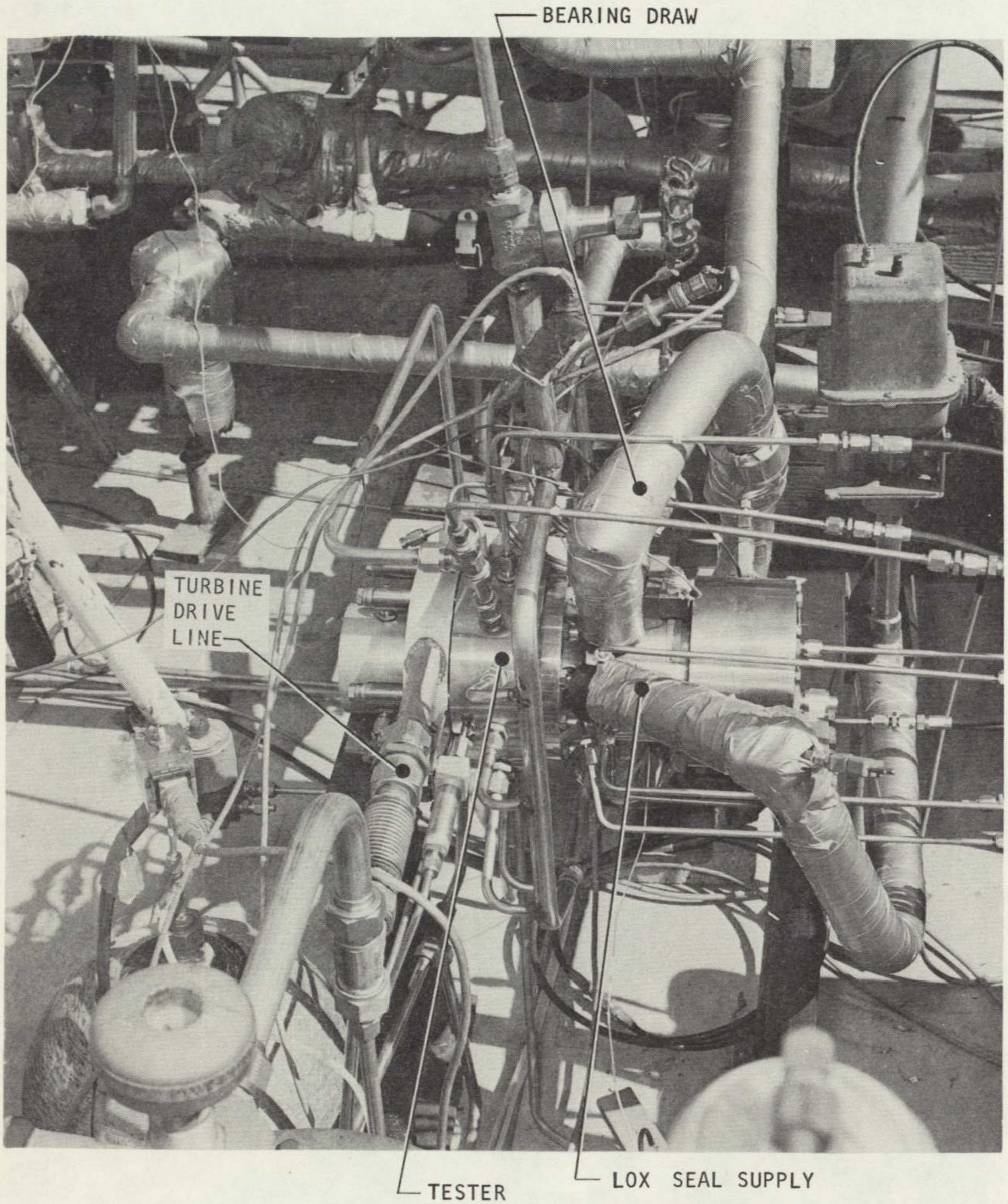


Figure 47. Test Facility (view 2)

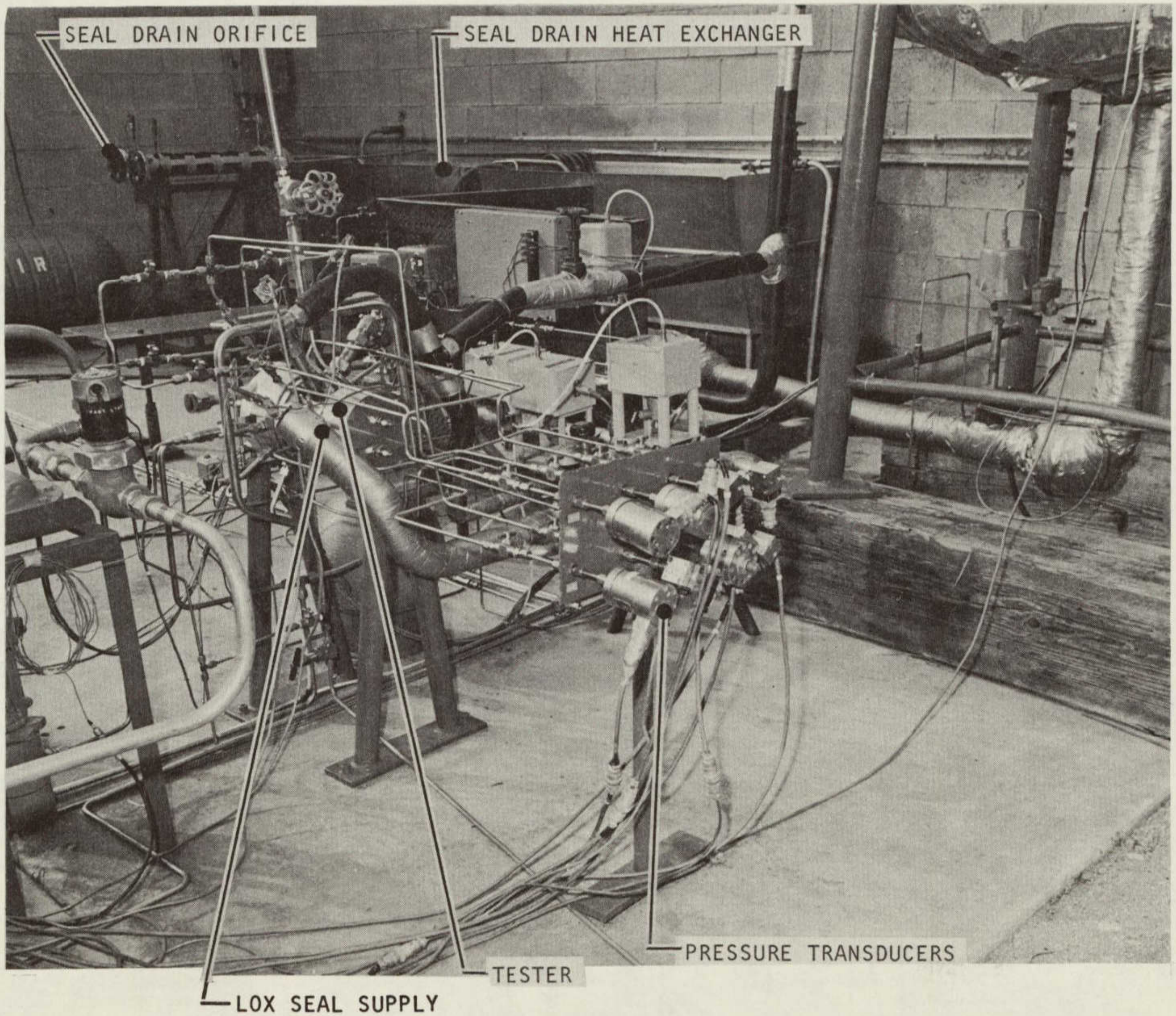


Figure 48. Test Facility (View 3)

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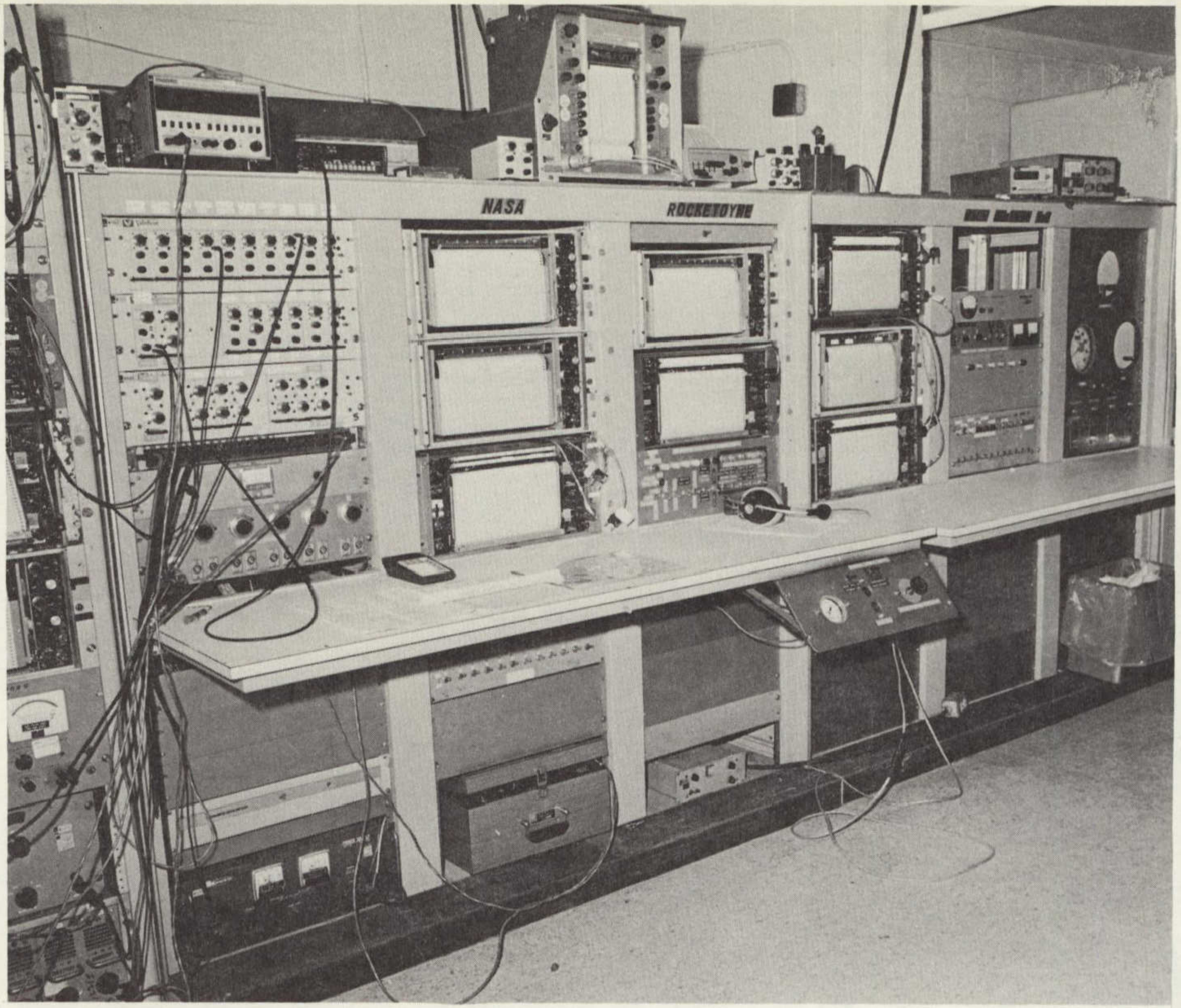

Figure 49. Control Panel

TEST HARDWARE

TESTER HARDWARE

The seal tester (Fig. 50), part number RS009661X, was assembled by Rocketdyne and supplied to the test site ready for installation. The tester assembly was driven by a built-in GN_2 turbine. Instrumentation provided with the tester included a speed pickup which senses the passing of three holes per shaft revolution, a LO_2 temperature bulb to measure bearing cavity temperatures, and two Bently probes to measure shaft deflection.

The tester hardware is shown in Fig. 50. Components shown in the photograph include: (1) the shaft assembly, (2) the slotted cover end bearing carrier, (3) the bearing housing, (4) LOX seal assembly, (5) helium seal housing and seal assembly, and (6) the turbine manifold.

SEAL HARDWARE

The machined metal bellows LOX face seal assembly is shown in Fig. 51. The helium purged seal assembly is shown in Fig. 52.

Figure 53 is a photograph of the piston ring LOX face seal assembly. The spiral groove LOX face seal assembly is shown in Fig. 54.

TEST REQUIREMENTS

INSTRUMENTATION

Instrumentation requirements including the redline limits are listed in Table 4. Data were recorded continuously on direct inking graphic recorder charts and/or FM tape. Location of instrumentation taps on tester is shown in Fig. 55.

The seal leakage measurements were recorded with calibrated orifice ΔP measurements. The LO_2 seal leakage was drained through a heat exchanger to vaporize the fluid and raise the temperature to approximately atmospheric prior to the flow measurement.

The helium purge flow was measured continuously upstream of the circumferential seal. The helium leakage into the LO_2 side seal drain was assumed to be half of the total purge flow in.

Prior to conducting the two test schedules, two operational checkout tests of 6 minutes duration each were conducted to measure shaft deflections using the Bently transducers (2 each) in place of the helium seal. The testing included a slow acceleration test of 4189 rad/s/minute (40,000 rpm/minute) and a fast acceleration test of 4189 rad/s/s (40,000 rpm/sec) from 0 to 9425 rad/s (90,000 rpm). Data obtained were analyzed to ensure that shaft deflections are within the operating limits prior to commencing the test schedule I preliminary checkout tests. The speed, accelerometer, and Bently data were recorded on FM tape. All other data were recorded on graphic recorder charts.

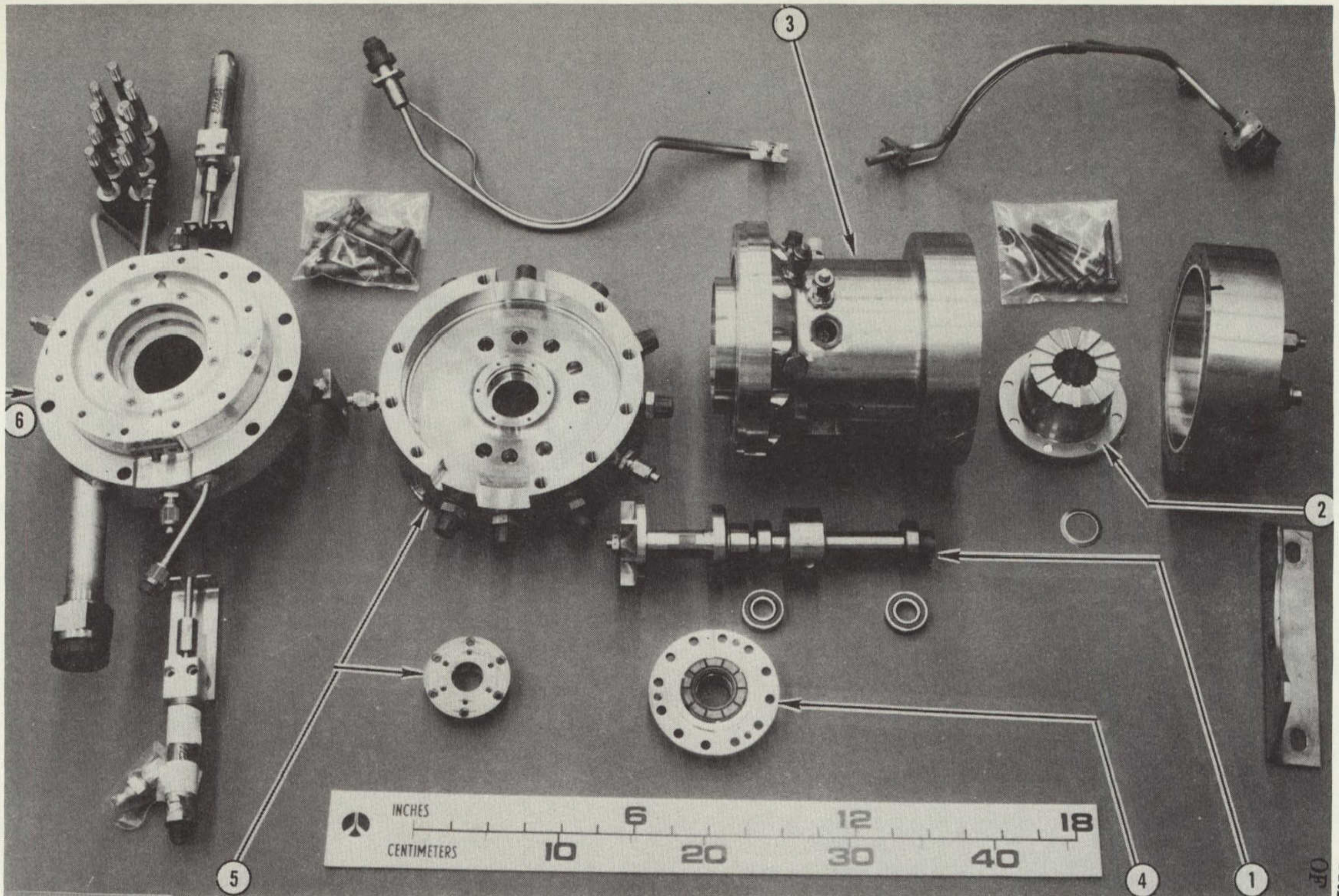

Figure 50. Seal Tester Components

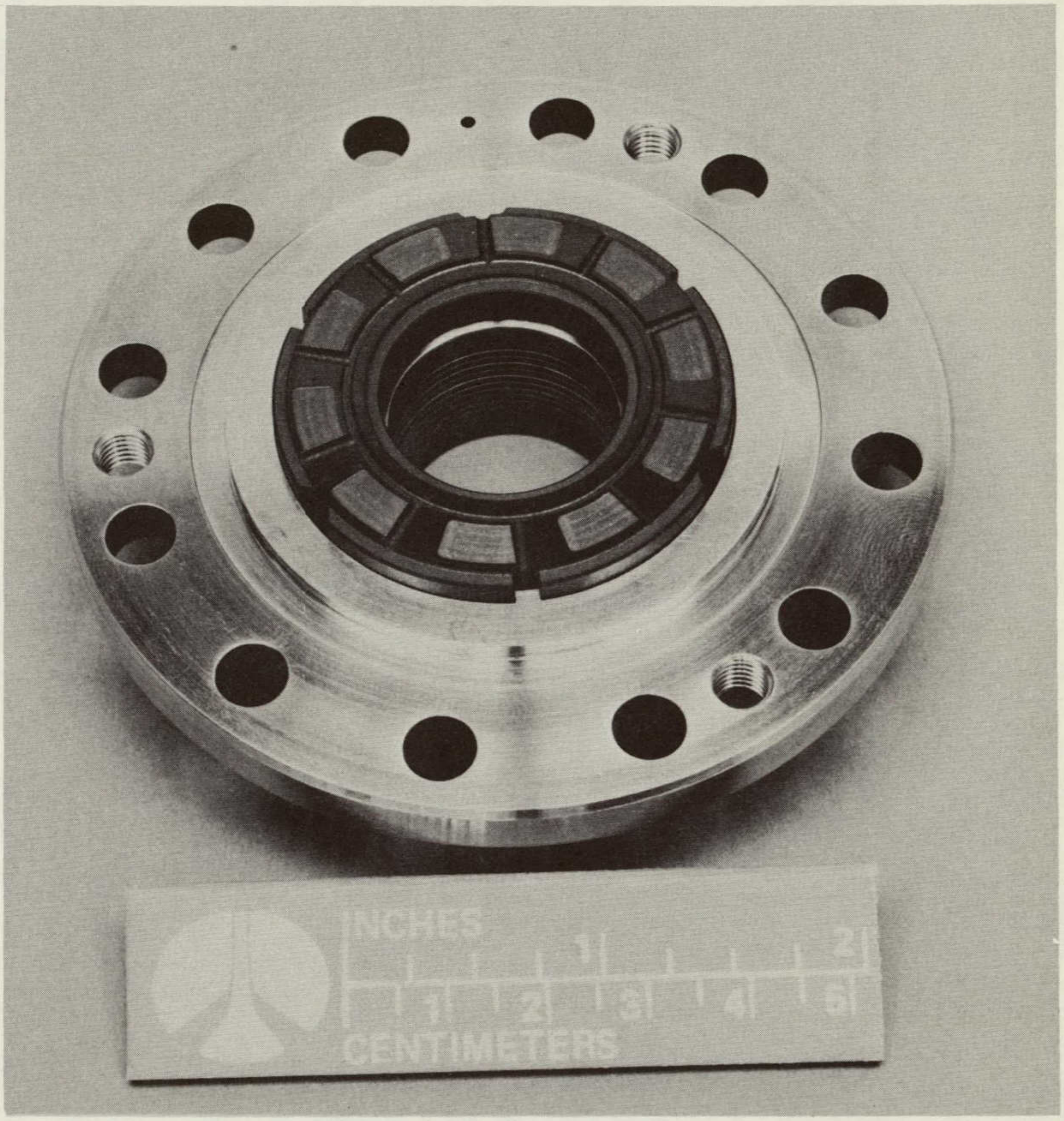

Figure 51. Machined Metal Bellows
Lox Face Seal Assembly

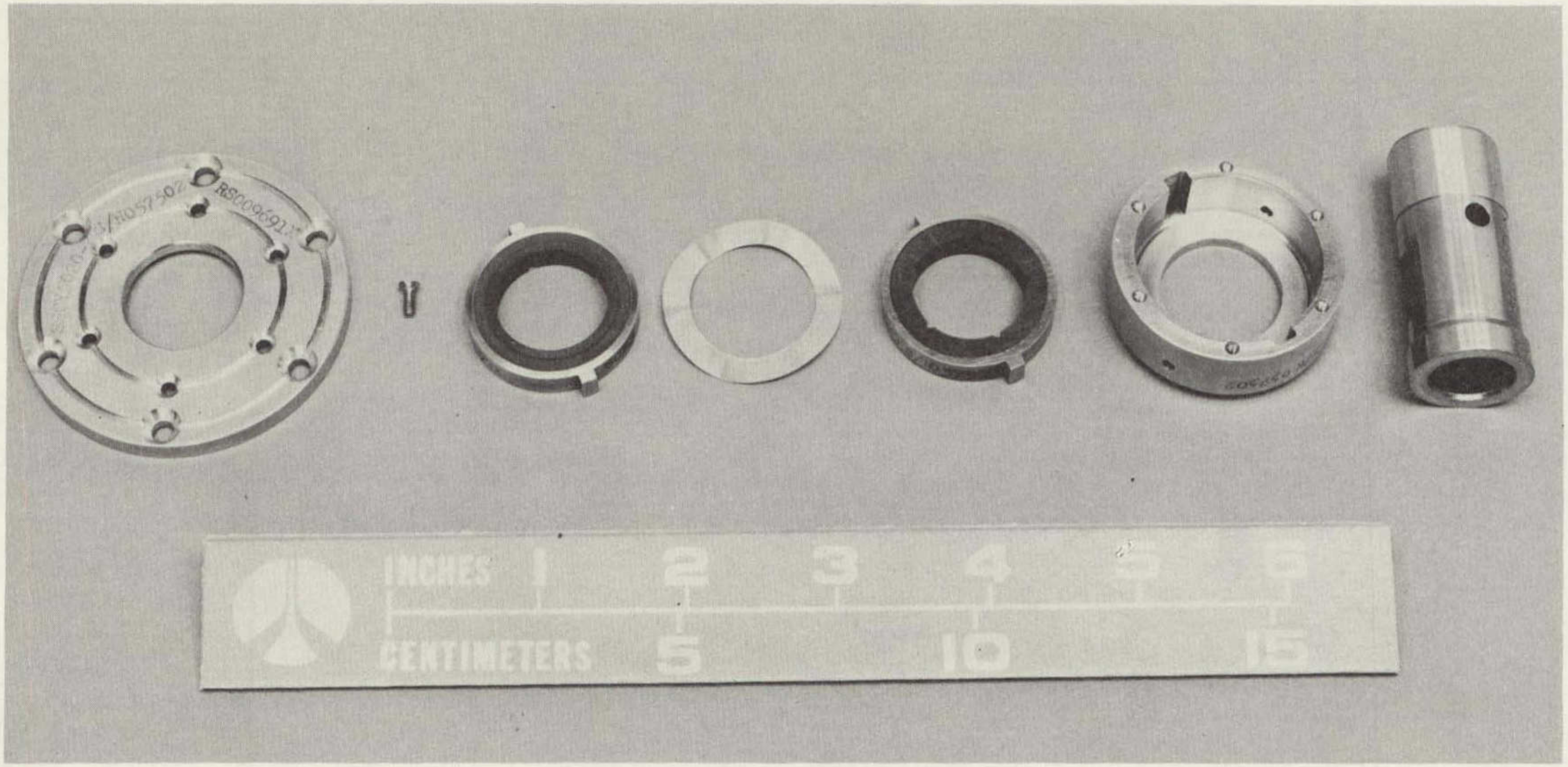

Figure 52. Helium Purged Seal Assembly

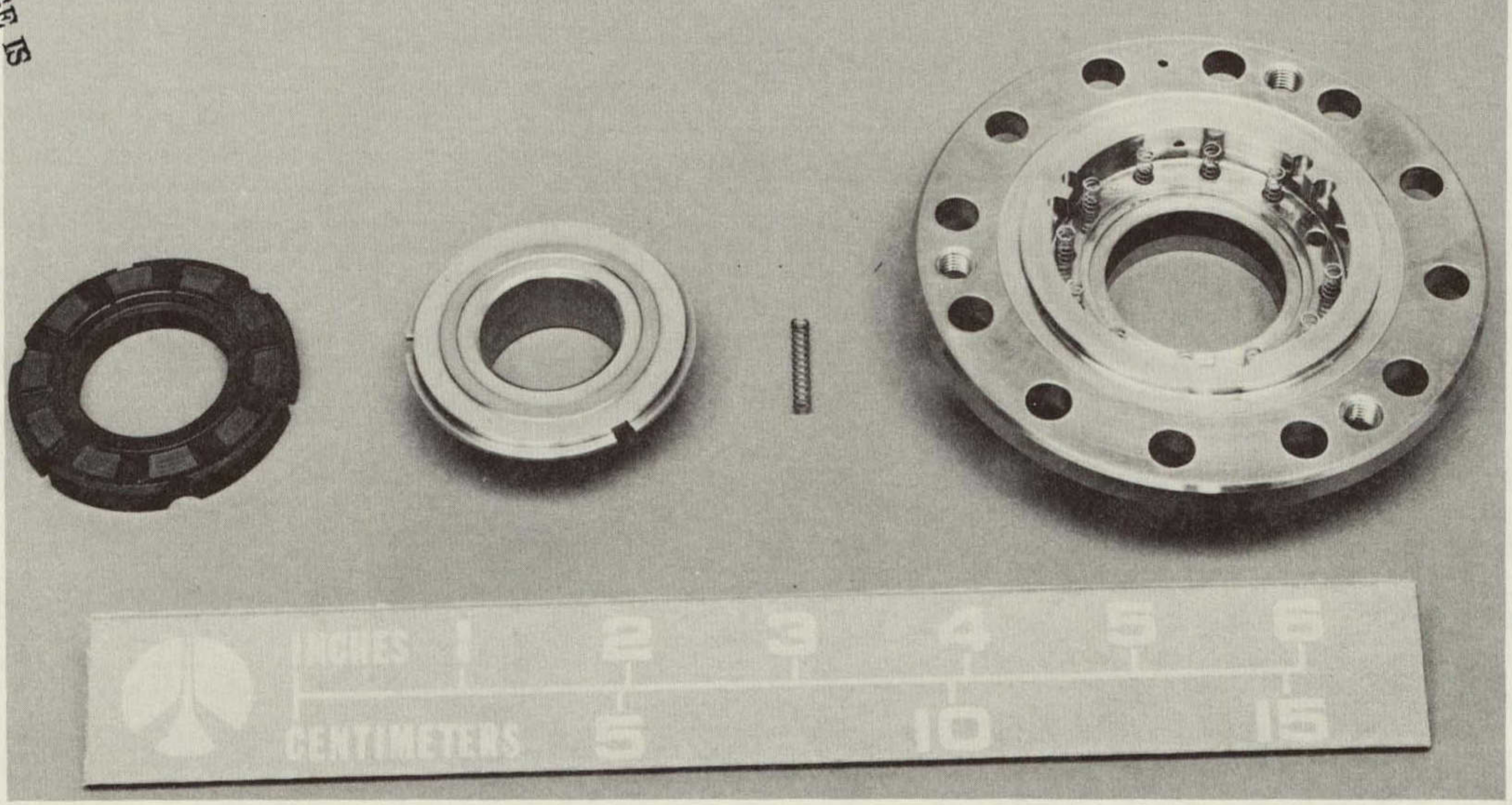

Figure 53. Piston Ring LOX Face Seal Assembly

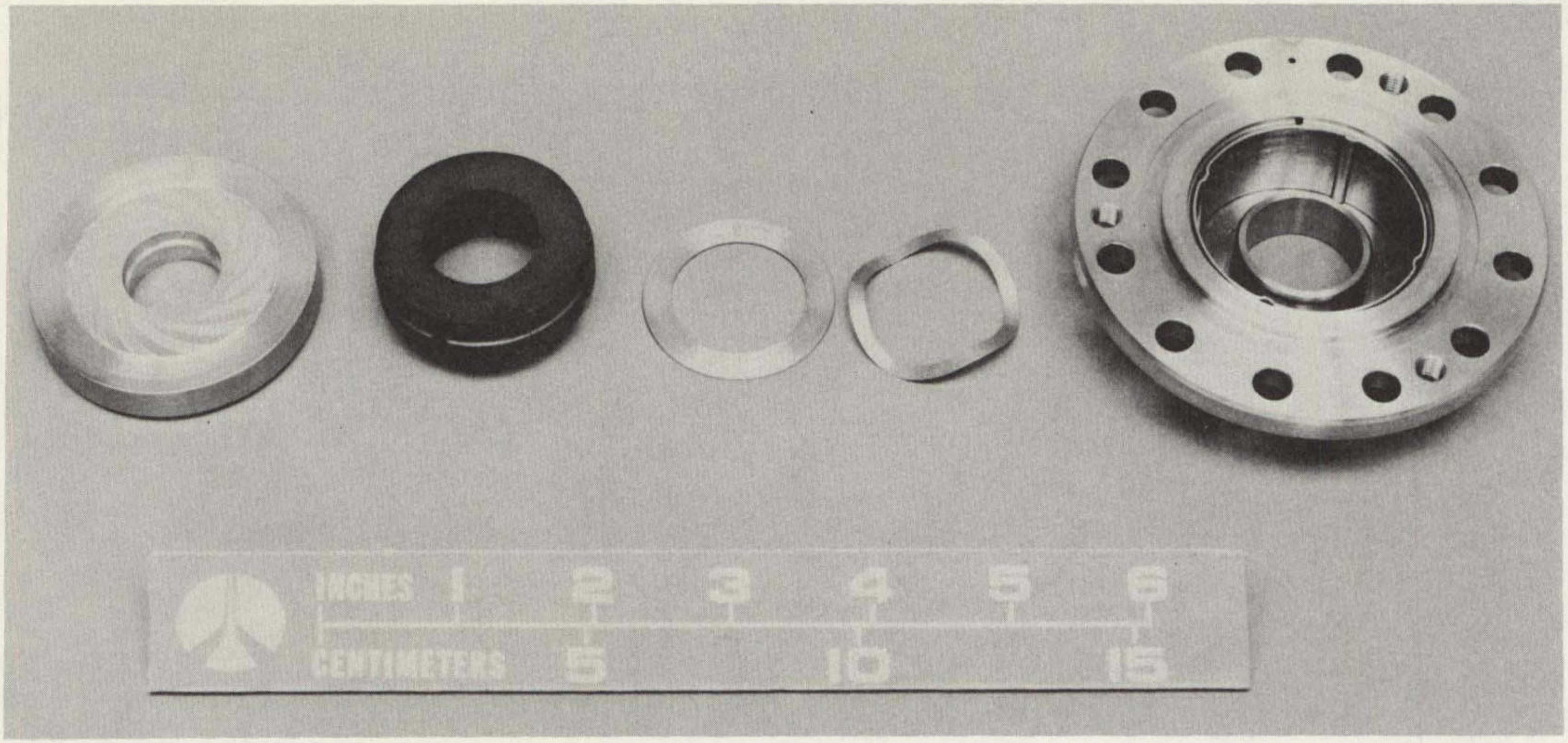

Figure 54. Spiral Groove LOX Face Seal Assembly

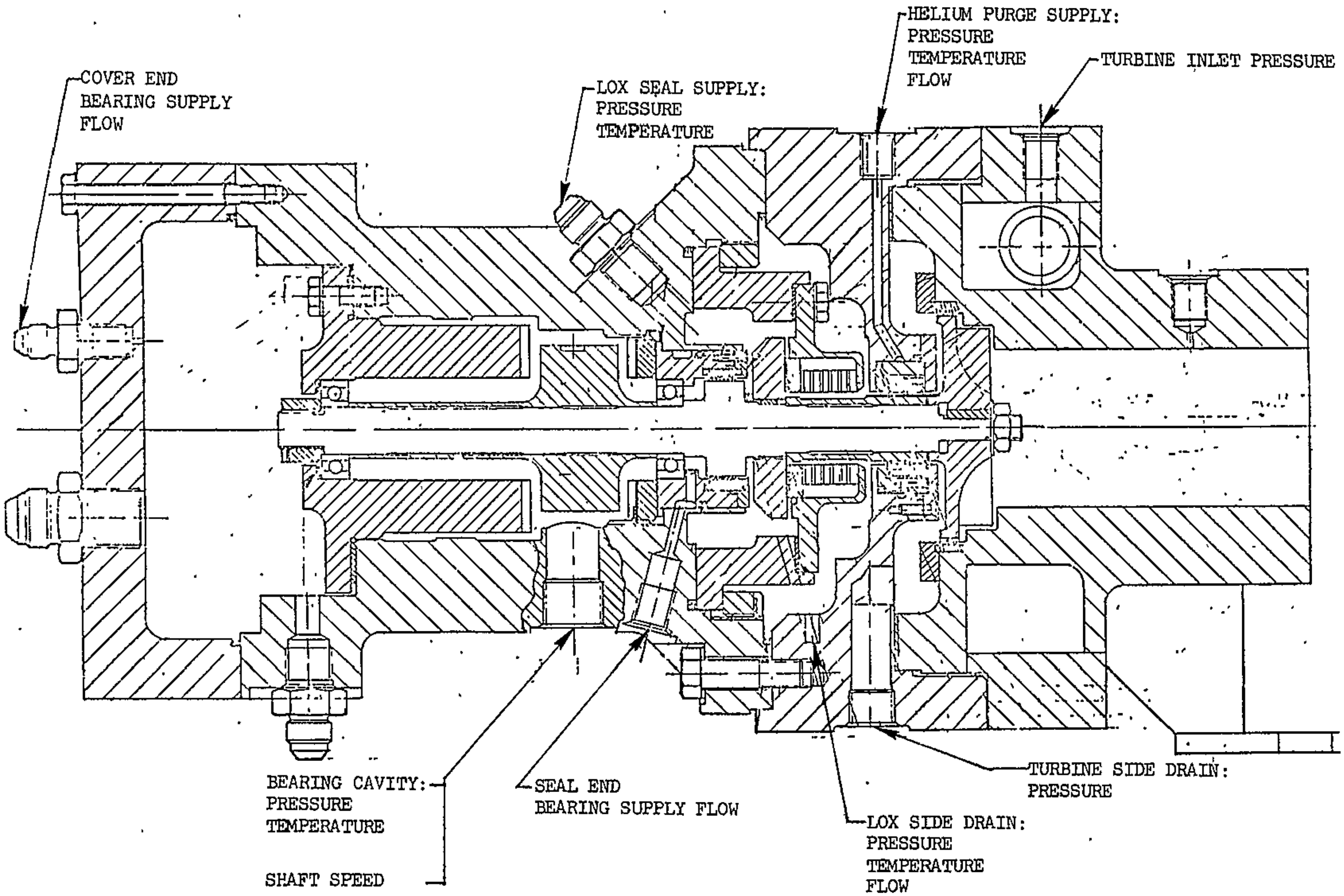

Figure 55. Instrumentation Tap Location

TEST SCHEDULE I PRELIMINARY CHECKOUT

Preliminary checkout tests were conducted on each seal assembly using clean, dry, gaseous nitrogen at room temperature at the test conditions shown in Table 5. The LOX seal GN_2 pressure and the helium seal purge pressure were applied prior to start of rotation.

TEST 5. TEST CONDITIONS

Test Point Number	Shaft Speed, rad/s (rpm)	Face Seal Pressure, N/m^2d (psia	Circumferential Seal Pressure, N/cm^2d (psia)	Time minutes
1	2618 ±524 (25,000 ±500)	275,790 ±34.474 (40 ±5)	206,843 ±34.474 (30 ±5)	6
2	6282 (60,000)	1.034,214 ±103,421 (150 ±15	206,843 (30)	↓
3	6282 (60,000)	1,723,689 (250)	↓	↓
4	7329 (70,000)	↓	↓	↓
5	8376 (80,000)	↓	↓	↓
6	9425 (90,000)	↓	↓	↓
7	8376 (80,000)	2,068,429 (300)	↓	↓
8	9425 (90,000)	1,378,951 (200)	↓	↓
9	↓	2,068,429 (300)	↓	↓
10	↓	↓	68,948 (10)	↓
11	↓	↓	137,895 (20)	↓
12	9425 (90,000 ±500)	2,068,427 ±10,321 (300 ±15	206,843 ±34,474 (30 ±5)	6

TEST SCHEDULE II LO_2 TESTING

LO_2 tests were conducted on each seal assembly using LO_2 as the sealed fluid. Each of the seal designs was tested at the following test conditions:

Test Point Number	Shaft Speed, rad/s (rpm)	LOX Seal Pressure, N/m^2d (psid)	Helium Seal Pressure, N/m^2d (psid)	Time, minutes
1	0 to 8062 ±105 (0 to 77,000 ±1000)	137,895 to 2,757,903 ±103,421	206,843 ± 34,474 (30 ±5)	3
Repeat test point 1 300 times for a total time of 10 hours. Inspect each 5 hours, or as required for bearing inspection.				

The LOX face seal pressure values above are during LO_2 seal operation at the maximum shaft operating speed. During acceleration, the LOX face seal pressure was obtained by ramping the LO_2 seal cavity pressure as a function of the shaft speed squared. During deceleration, the LOX face seal pressure was vented. The helium circumferential seal pressure will be applied prior to start of rotation and will remain on until after rotation stops.

The turbine forward, reverse, and brake actuator valves were adjusted to permit an acceleration rate of 4188 rad/s (40,000 rpm/sec) and deceleration to 0 rpm within 4 seconds as shown in Fig. 56. The forward turbine valve was opened to supply drive GN_2 to the turbine at the ramp rate of 4188 rad/s (40,000 rpm/sec). After operating the tester at 8062 rad/s (77,000 rpm) for 3 minutes, the forward valve closes and the reversing valve opens which supplies GN_2 to the turbine in the reverse direction. When the speed has been reduced to about 1047 rad/s (10,000 rpm), in about 2 seconds, the reversing valve closes and the brake actuator valve opens. The brake actuator pressure was adjusted to provide stopping of the shaft rotation in about 1.5 seconds.

PRETEST PROCEDURES

Prior to the start of the preliminary checkout and liquid oxygen testing, and after each seal modification or rework, the following information was obtained on each seal assembly to be tested:

1. Static seal leakage at differential pressures across the face seal of 172,369, 344,738, 689,476, 1,378,951, and 2,068,427 $N/m^2/d$ (25, 50, 100, 200, and 300 psid) in the test rig.
2. Dam heights, pad depths, and/or other pertinent dimensions measured by surface profile traces.
3. Surface profile traces and optical readings of flatness of seal mating surfaces.
4. Torque required to overcome the static friction of the seal assembly to initiate rotational motion of the shaft.

POSTTEST PROCEDURES

All items in the pretest procedure, as described above, were determined at the completion of each seal assembly testing for each test schedule. A careful visual examination was made of each seal (e.g., for cracks, excessive wear, distortions). Photographs of normal and unusual posttest conditions were taken.

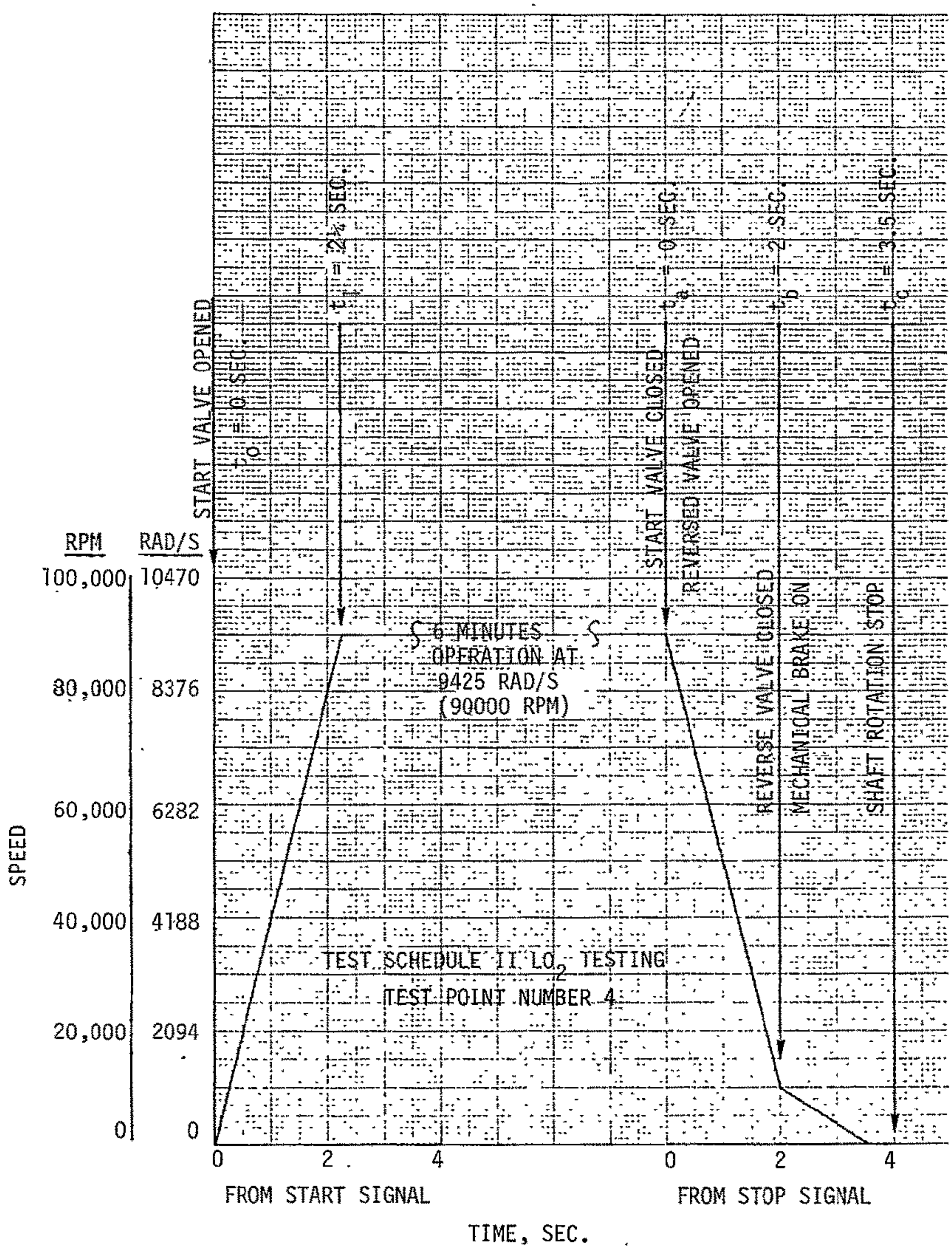

Figure 56. Typical Seal Acceleration and Deceleration Ramp Rates

RESULTS AND DISCUSSION

TEST SUMMARY

The test summary is given in Table 6.

HARDWARE AND INSPECTION SUMMARY

The LOX seal hardware summary is given in Table 7. The helium seal hardware summary is given in Table 8. The LOX seal inspection summary is given in Table 9 for English units and Table 10 for SI units. The helium seal inspection summary is given in Table 11 for English units and Table 12 for SI units.

DATA SUMMARY

The test data summary is given in Table 13 for English units and Table 14 for SI units.

TABLE 6. SMALL HIGH SPEED SEAL TEST SUMMARY

Build	Tests	Starts	Time, Minutes	Objective	LOX Seal	Helium Seal	Remarks
1	035-045	11	2.7	GN_2 Checkout 2618 rad/s (25,000 rpm), 275,790 N/m^2 (40 psi) at LOX seal	Rayleigh, bellows, new, S/N 01	Floating ring, new, S/N 01	Completed on test at 2618 rad/s (25,000 rpm), 461,949 N/m^2, (67 psi) LOX seal pressure, 6 minutes, tried for 6282 rad/s (60,000 rpm), 1,034,214 N/m^2 (150 psi) LOX seal pressure when excessive leakage occurred
2	045-054	9	10.6	GN_2 checkout	Rayleigh, piston ring, new S/N 01	Floating ring, no rework, S/N 01	Completed 6-minute test at 9425 rad/s (90,000 rpm), 1,075,582 N/m^2 (156 psig) LOX seal pressure; found bearing failure at disassembly; seals good condition
3	055-077	23	73.8	GN_2 checkout	Rayleigh, piston ring, S/N 01 new carbon and mate	Floaring ring, no rework, S/N 01	New bearing preload spring design, completed GN_2 checkout on Rayleigh LOX seal
4	078-088	11	20.4	GN_2 checkout	Spiral groove, new, S/N 01	Floating ring, no rework, S/N 01	Scheduled inspection, seals good condition
5	089-092	4	13.5	GN_2 checkout	Spiral groove, no rework, S/N 01	Floating ring, no rework, S/N 01	Bearing failure damaged seals; seal performance good before failure
6	093-111	19	66.4	GN_2 checkout	Spiral groove, new, S/N 02	Floating ring, new, S/N 04	Test speed reduced to 8062 rad/s (77,000 rpm); used 0.000013 m (0.0005 in.) smaller bearing balls; completed GN_2 checkout on spiral groove LOX seal; seals and tester good condition
7	112-186	76	84.4	LOX checkout	Spiral groove, carbon and mate lapped flat, S/N 02	Floating ring, new, S/N 03	Posttest dry spin failed bearings and damaged seals, seal performance good before failure
8	187-332	146	268.4	LOX accelerations tests	Spiral groove, new	Floating ring, new, S/N 02	Bearing failure, seals damaged, seal performance good before failure
9	333-412	80	150.0	LOX acceleration tests	Rayleigh, piston ring, new, S/N 02	Floating ring, from build 6, no rework S/N 04	Scheduled inspection, excellent condition, helium seal pads worn away
10	413-517	105	157.7	LOX acceleration tests	Rayleigh, piston ring, no rework, S/N 02	Floating ring, no rework, S/N 04	Scheduled inspection, LOX seal in excellent condition
11	518-559	42	72.9	LOX acceleration tests	Rayleigh, piston ring, no rework,	Floating ring, no rework, S/N 04	Inspection due to high vibration level, LOX seal in excellent condition
12	560-632	72	155.1	LOX acceleration tests	Rayleigh, piston ring, no rework, S/N 02	Floating ring, no rework S/N 04	Scheduled inspection, LOX seal in excellent condition
13	633-665	33	72.6	LOX acceleration tests	Rayleigh, piston ring, no rework, S/N 02	Floating ring, no rework, S/N 04	Completed 10 hours with 300 starts on Rayleigh LOX seal, LOX seal condition
14	666-749	84	249.7	LOX acceleration tests	Spiral groove, carbon, new S/N 04 housing, S/N 03, from build 8, mate lapped	Floating ring, seal, new, S/N 05	Scheduled inspection, completed total of 10 hours with 300 starts on spiral groove LOX seal, both seals in excellent condition

TABLE 7. LOX SEAL HARDWARE SUMMARY

Build No.	Seal Assembly, Type Part No., Serial No.	Seal Ring Serial No., Lox/Turbine Material	Mating Ring Part No., Serial No., Material	Hardware Condition	
				Pretest	Posttest
1	Floating Ring RS009690X 01	01/01 Carbon G84 Inconel X	RS009667X 02 Chrome/Honel	New	Good condition; carbon polished; no visible wear, mate had slight trace of contact
2				Same as build 1; no rework	Good condition; carbon recess pads worn 0.00001 to 0.00002 m (0.0002 to 0.0004 in.). Mate had slight contract pattern; tester bearing failed
3				Same as build 2; no rework	Good condition; no wear; mate had slight trace of contact
4				Same as build 3; no rework	Good condition; carbon recess pads worn 0.00003 m (0.0001 in.); carbon polished; mate had slight trace of contact
5				Same as build 4, no rework	Seal damaged by tester bearing failure, carbon severly worn and scored, end plate rubbed mate slightly; mate had grooves worn into surface at seal rings
6	Floating Ring RS009690X 04	04/04 Carbon G84 Inconel X	RS009667X 001 Chrome/Honel	New	Lox carbon wear 0.000013 to 0.000020 m) (0.0005 to 0.0008 in.) Turbine carbon wear 0.000010 to 0.000018 m (0.0004 to 0 0007 in.) Mate slight traces of wear maximum depth 0.00004 m (0.000150 in.) on one side
7	Floating Ring RS009690X 03	03/03 Carbon G84 Inconel X	RS009667X 003 Chrome/Honel	New	Seal severely damaged by dry spinup; carbon rings broken, mate ring grooved by rubbing on housing
8	Floating Ring RS009690X 02	02/02 Carbon G84 Inconel X	RS009667X 004 Chrome/Honel	New	Seal damaged by bearing failure; carbon lift pads worn away; mate grooved by housing
9	Floating Ring RS009690X 04	04/04 Carbon G84 Inconel X	RS009667X 001 Chrome/Honel	Same as build 6; no rework	Lift pads worn away; seal rings worn 0.000056 to 0.000064 m (0 0022 to 0.0025 in.); mate had contact pattern heavier on one side
10	Floating Ring RS009690X 04	04/04 Carbon G84 Inconel X	RS009667X 001 Chrome/Honel	Lift pads worn away. Same as build 9, no rework	Carbon polished, no additional wear, heavy contact pattern on mating ring
11				Same as build 10; no rework	Same as build 10
12				Same as build 11; no rework	Carbon worn additional (0 008 in.) diameter on lox side and 0.00028 m (0.011 in.) diameter on turbine side; mating ring grooved 0.00005 m (0.0002 in.) deep on lox side and 0.00003 m (0.001 in.) and on turbine side
13				Same as build 12, no rework	Carbon chipped at edge of dam; carbon and mating ring worn, no additional wear since build 12
14	Floating Ring RS009690X Clevite 05	05/05 Carbon G84 Inconel X	RSS009667X 001-1 Replated Chrome/Honel	Seal new, mating ring replated	Lox side carbon ring worn 0.000043 m (0.0017 in.) diameter; turbine side carbon ring worn 0.00066 m (0.0026 in.) diameter, most of lift pads worn off; mating ring had heavy contact pattern, no wear

TABLE 8. HELIUM SEAL HARDWARE SUMMARY

Build No.	Seal Assembly, Type Part No., Serial No.	Seal Ring Part No. Serial No., Material	Piston Ring Part No., Serial No., Material	Mating Ring Part No., Serial No., Material	Hardware Condition	
					Pretest	Posttest
1	Bellows RS009844X 01	RS009697X 08 Carbon P692	--	RS009698X 04 Chrome/Monel	New	Dam worn 0.000038 to 0.000061 m (0.0015 to 0.0024 in.); recess pads worn off; mate had irregular contact pattern with worn spots
2	Piston Ring RS-09849X 01	RS009697X 05 Carbon P692	SSCY5097X 05 Carbon P5NR2	RS009698X 01 Chrome/Monel	New	Dam and recess pads worn even 0.000005 m (0.0002 in.); mate had uniform contact pattern with one worn spot; tester bearing failed
3	Piston Ring RS009849X 01	RS009697X 07 Carbon P692	SSCY5097X 01 Carbon P5NR2	RS009698X 02 Chrome/Monel	New carbon and mate; same housing, pilot ring and piston ring	Dam and recess pads worn even 0.000013 m (0.0005 in.); pilot ring chrome flaked at pilot; mate had uniform contact pattern with one worn spot
4	Spiral Groove RS009695X 01	A28-0812-11 01 Carbon P692	A28-0812-12 01 Vespel SP211	C28-0812-10 01 Chrome/Monel	New; installed wave spring around piston ring	Good condition; no rubbing contact
5	↓	↓	↓	↓	Same as build 4; no rework	Seal damaged by tester bearing failure; carbon seal ring broken; face polished; mate spiral grooves worn slightly on one side; housing rubbed mate slightly
6	↓	A28-0812-11 02 Carbon P692	↓	A28-0812-10 02 Chrome/Monel	New carbon and mate, same housing, piston ring, wave spring around piston ring	Good condition; carbon face rubbed slightly; mate ring very slight rub marks; piston ring two slightscore marks on ID
7	↓	↓	↓	↓	Same as build 6; carbon lapped flat; mate lapped clean	Seal severly damaged by dry spinup; mate ring rubbed against housing and rotated on shaft
8	Spiral Groove RS009695X 03	A28-0812-11 03 Carbon P692	A28-0812-12 02 Vespel SP211	A28-0812-10 03 Chrome/Monel	New, wave spring around piston ring. Mating ring nicked slightly in dam area	Seal damaged by tester bearing failure; carbon ring broken, carbon surface polished; mate surface scored and rubbed
9	Piston Ring RS009849X 02	RS009697X 01 Carbon P692	SSCY5097-8 02 Carbon P5NR2	RS009698X 03 Chrome/Monel	New	Excellent condition; slight trace of contact on mate ring; carbon as-new
10	↓	↓	↓	↓	Excellent; same as build 9; no rework	Excellent condition; slight trace of contact on mate ring; carbon polished; no wear
11	↓	↓	↓	↓	Same as build 10; no rework	Same as build 10
12	↓	↓	↓	↓	Same as build 11; no rework	Same as build 11
13	↓	↓	↓	↓	Same as build 12; no rework	Excellent condition; slight trace of contact on mate ring; carbon face polished; no measurable wear; piston ring and adapter in good condition with no visible deterioration
14	Spiral Groove RS009695X 03	A28-0812-11 04 Carbon P692	A28-0812-12 -7456 Rev. C 03 Vespel SP211	C28-0812-10 03 Chrome/Monel	Carbon seal ring new; housing and mating ring same as build 8; mating ring lapped to partially clean up scoring from previous rub, new piston ring revised to eliminate vent slot; wave spring around piston ring	Satisfactory condition; mating ring rubbed slightly; no significant wear; carbon slightly scored from rubbing, piston ring in excellent condition

TABLE 9: LOX SEAL INSPECTION SUMMARY (ENGLISH UNITS)

Build No.	Spring Load, pound	Spring Rate, lb/in.	Dam Wear (Average), inch	Recess Pad Depth, inch (Pre/Posttest) — Lift Pad No. 1	2	3	Static GN_2 Leakage, scim (Pre/Posttest) — Pressure, psig 25	50	100	200	300
1	4.9	200	0.0019	0.0005 0.0000	0.0006 0.0000	0.0004 0.0000	66 770	110 1575	218 3025	455 10,540	659 16,330
2	2.86	54	0.0002	0.0005 0.0003	0.0006 0.0004	0.0006 0.0004	27 54	67 129	147 262	324 476	488 600
3	2.8	54	0.0005	0.0005 0.0001	0.0006 0.0001	0.0006 0.0001	78 650	120 1100	145 1850	272 300	410 4200
4	6.1	88.7	① 0.0000	② 0.0004 0.0004	② 0.0004 0.0004	② 0.0004 0.0004	1200 1075	2000 1700	3500 2600	11,232 5616	21,600 13,478
5	6.7	90.0	① ③	② 0.0004 ③	② 0.0004 ③	② 0.0004 ③	950 ③	1450 ③	2275 ③	5616 ③	14,515 ③
6	4.7	91.3	① 0.0000	② 0.0004 0.0004	② 0.0004 0.0004	② 0.0004 0.0004	1720 700	2450 1275	3350 1900	6560 6480	15,900 16,000
7	4.5	92.5	① ④	② 0.0004 ④	② 0.0004 ④	② 0.0004 ④	1880 ④	2350 ④	3310 ④	9330 ④	19,900 ④
8	3.7	72.5	③	② 0.0004 0.0004	② 0.0004 0.0004	② 0.0004 0.0004	2670 ③	3920 ③	4230 ③	11,060 ③	22,810 ③
9	2.0	14.0	0.0000	0.0007 0.0007	0.0006 0.0006	0.0006 0.0006	102 186	168 333	364 494	730 740	1090 1350
10	2.1	14.0	0.0000	0.0007 0.0007	0.0006 0.0006	0.0006 0.0006	95 98	220 210	518 429	1075 830	1550 1360
11	2.1	14.0	0.0000	0.0007 0.0007	0.0006 0.0006	0.0006 0.0006	100 190	235 245	535 430	1075 900	1625 1525
12	2.1	14.0	0.0000	0.0007 0.0007	0.0006 0.0006	0.0006 0.0006	75 212	150 266	300 341	900 738	1350 1163
13	2.1	14.0	0.0000	0.0007 0.0007	0.0006 0.0006	0.0006 0.0006	12 75	100 115	364 320	880 690	1420 1020
14	3.9	85	0.0000	0.0003 0.0003	0.0003 0.0003	0.0003 0.0003	325 440	545 700	1080 1370	6700 7200	12,300 18,400

① Carbon seal ring face wear

② Mating ring spiral groove depth

③ Seal damaged by tester bearing failure

④ Tester damaged by dry spin

TABLE 10. LOX SEAL INSPECTION SUMMARY

Build No.	Spring Load, N	Spring Rate, N/m	Dam Wear (Average), m	Recess Pad Depth, m			Static Leakage m^3/minute Pressure N/m^2g				
				1	2	3	172,369	344,738	689,476	1,378,951	2,068,427
1	21.80		0.000048	0.000013 0.000000	0.000015 0.000000	0.000010 0.000000	0.0011 0.0126	0.0018 0.0258	0.0036 0.0496	0.0075 0.1729	0.0108 0.2678
2	12.72		0.000005	0.000013 0.000008	0.000015 0.000010	0.000015 0.000010	0.0004 0.0009	0.0011 0.0021	0.0024 0.0043	0.0053 0.0078	0.0080 0.0098
3	12.45		0.000013	0.000014 0.000003	0.000015 0.000003	0.000015 0.000003	0.0013 0.0107	0.0020 0.0180	0.0024 0.0303	0.0045 0.0492	0.0067 0.689
4	27.13		① 0.000000	② 0.000010 0.000010	② 0.000010 0.000010	② 0.000010 0.000010	0.0197 0.0176	0.0328 0.0279	0.0574 0.0426	0.1842 0.0921	0.3542 0.2210
5	29.80		① ③	② 0.000010	② 0.000010	② 0.000010	0.0156	0.238	0.0373	0.0921	0.2380
6	20.90		① 0.000000	③ ② 0.000010 0.000010	③ ② 0.000010 0.000010	③ ② 0.000010 0.000010	③ 0.0282 0.0115	③ 0.0402 0.0209	③ 0.0549 0.0312	③ 0.1076 0.1063	③ 0.2608 0.2624
7	20.02		① ④	② 0.000010	② 0.000010	② 0.000010	0.0308	0.0385	0.0543	0.1540	0.3264
8	16.46		③	④ ② 0.000010 0.000010	④ ② 0.000010 0.000010	④ ② 0.000010 0.000010	④ 0.0438 ③	④ 0.0643 ③	④ 0.0694 ③	④ 0.1814 ③	④ 0.3741 ③
9	8.90		0.000000	0.000018 0.000018	0.000015 0.000015	0.000015 0.000015	0.0017 0.0031	0.0028 0.0055	0.0060 0.0081	0.0120 0.0121	0.0179 0.0221
10	9.34		0.000000	0.000018 0.000018	0.000015 0.000015	0.000015 0.000015	0.0016 0.0016	0.0036 0.0034	0.0085 0.0070	0.0176 0.0136	0.0254 0.0223
11	9.34		0.000000	0.000018 0.000018	0.000015 0.000015	0.000015 0.000015	0.0016 0.0031	0.0039 0.0040	0.0088 0.0071	0.0176 0.0148	0.0267 0.0250
12	9.34		0.000000	0.000018 0.000018	0.000015 0.000015	0.000015 0.000015	0.0012 0.0035	0.0025 0.0044	0.0049 0.0056	0.0148 0.0121	0.0221 0.0191
13	9.34		0.000000	0.000018 0.000018	0.000015 0.000015	0.000015 0.000015	0.0002 0.0012	0.0016 0.0019	0.0060 0.0052	0.0144 0.0113	0.0233 0.0167
14	17.35		0.000000	0.000008 0.000008	0.000008 0.000008	0.000008 0.000008	0.0053 0.0072	0.0089 0.0115	0.0177 0.0225	0.0199 0.0181	0.2017 0.3018

① Carbon seal ring face wear

② Mating ring spiral groove depth

③ Seal damaged by tester bearing failure

④ Tester damaged by dry spin

C-2

TABLE 11. HELIUM SEAL INSPECTION SUMMARY
(ENGLISH UNITS)

Build No.	Mating Ring OD, inch (Pre/Posttest)	Seal Ring ID, inch (Pre/Posttest)		Recess Pad Depth, inch (Pre/Posttest)										Static Helium Leakage (at 30 psig), scim (Pre/Posttest)	
				LOX Side Lift Pad No.					Turbine Side Lift Pad No.						
		LOX	Turbine	1	2	3	4	5	1	2	3	4	5	LOX	Turbine
1	0.8129 0.8127	0.8143 (1)	0.8145 (1)	0.0010 (1)	0.0012 (1)	0.0012 (1)	0.0013 (1)	0.0011 (1)	0.0014 (1)	0.0016 (1)	0.0015 (1)	0.0017 (1)	0.0015 (1)	4300 4060	2400 1840
2	(1) 0.8128	(1) 0.8145	(1) 0.8144	(1) 0.0006	(1) 0.0010	(1) 0.0008	(1) 0.0009	(1) 0.0008	(1) 0.0010	(1) 0.0012	(1) 0.0012	(1) 0.0013	(1) 0.0012	3970 4070	2460 2077
3	0.8128 0.8128	0.8145 0.8145	0.8144 0.8144	0.0006 0.0006	0.0010 0.0010	0.0008 0.0008	0.0009 0.0009	0.0008 0.0008	0.0010 0.0010	0.0012 0.0012	0.0012 0.0012	0.0013 0.0013	0.0012 0.0012	4550 3150	3150 2700
4	0.8128 0.8128	0.8145 0.8147	0.8144 0.8148	0.0006 0.0005	0.0010 0.0009	0.0008 0.0007	0.0009 0.0008	0.0008 0.0007	0.0010 0.0010	0.0012 0.0011	0.0012 0.0011	0.0013 0.0011	0.0012 --	4200 2900	3600 2500
5	0.8126 (2)	0.8147 (2)	0.8148 (2)	0.0005 (2)	0.0009 (2)	0.0007 (2)	0.0008 (2)	0.0007 (2)	0.0010 (2)	0.0011 (2)	0.0011 (2)	0.0011 (2)	-- (2)	3100 (2)	3950 (2)
6	(1) 0.8126	0.8143 0.8155	0.8143 0.8156	0.0007 0.0001	0.0005 0.0000	0.0007 0.0002	0.0010 0.0005	0.0010 0.0002	0.0007 0.0000	0.0007 0.0001	0.0007 0.0001	0.0007 0.0003	0.0007 0.0001	1250 3750	1650 4650
7	0.8123 (3)	0.8142 (3)	0.8139 (3)	0.0009 (3)	0.0011 (3)	0.0012 (3)	0.0009 (3)	0.0010 (3)	0.0006 (3)	0.0008 (3)	0.0007 (3)	0.0007 (3)	0.0007 (3)	1300 (3)	1500 (3)
8	0.8130 0.8123	0.8141 (2)	0.8143 (2)	0.0009 (1)	0.0012 (2)	0.0009 (2)	0.0012 (2)	0.0008 (2)	0.0008 (2)	0.0008 (2)	0.0008 (2)	0.0010 (2)	0.0007 (2)	900 9570	1880 6120
9	0.8130 0.8133	0.8151 0.8173	0.8154 0.8179	0.0002 0.0000	0.0000 0.0000	0.0002 0.0000	0.0005 0.0000	0.0002 0.0000	0.0000 0.0000	0.0001 0.0000	0.0001 0.0000	0.0003 0.0000	0.0001 0.0000	3980 9750	4900 9500
10	0.8126 0.8130	0.8173 0.8175	0.8179 0.8180	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	8068 4360	9085 5270
11	0.8130 0.8130	0.8175 0.8172	0.8180 0.8168	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	7500 7200	8900 8900
12	0.8130 0.8130	0.8172 0.8261	0.8168 0.8278	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	8750 --	7750 --
13	0.8130 0.8130	0.8261 0.8260	0.8278 0.8277	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	0.0000 0.0000	13075 14000	17000 17500
14	0.8126 0.8126	0.8140 0.8157	0.8142 0.8168	0.0012 0.0000	0.0013 0.0002	0.0001 0.0000	0.0005 0.0000	0.0006 0.0000	0.0007 0.0000	0.0010 0.0001	0.0002 0.0000	0.0003 0.0000	0.0012 0.0002	1500 3600	1150 2100

(1) No measurement
(2) Seal damaged by tester bearing failure
(3) Tester severely damaged by dry spinup

TABLE 12. HELIUM SEAL INSPECTION SUMMARY (SI UNITS)

Build No.	Mating Ring OD, m (Pre/Post Test)	Seal Ring ID, m (Pre/Post Test) LOX	Seal Ring ID, m (Pre/Post Test) Turbine	Seal Ring ID, m (Pre/Post Test) Recess Pad Depth, m LOX Side 1	LOX Side 2	LOX Side 3	LOX Side 4	LOX Side 5	Build No.	Recess Pad Depth, m Turbine Side 1	Turbine Side 2	Turbine Side 3	Turbine Side 4	Turbine Side 5	Static Helium Leakage (at 206,843 N/m²g) m³/minute	
1	0.020648 0.020643	0.020683 (1)	0.020688 (1)	0.0000251 (1)	0.000030 (1)	0.0000304 (1)	0.0000330 (1)	0.0000279 (1)	1	0.000036 (1)	0.000041 (1)	0.000038 (1)	0.000043 (1)	0.000038 (1)	0.0705 0.0666	0.0394 0.0302
2	(1) 0.20645	(1) 0.020688	(1) 0.020686	(1) 0.0000151	(1) 0.000025	(1) 0.000020	(1) 0.0000228	(1) 0.0000203	2	(1) 0.000025	(1) 0.000030	(1) 0.000030	(1) 0.000030	(1) 0.000030	0.0651 0.0667	0.0403 0.0341
3	0.20645 0.026045	0.20688 0.20688	0.20686 0.20686	0.0000151 0.0000151	0.000025 0.000025	0.000020 0.000020	0.000023 0.000023	0.000020 0.000020	3	0.000025 0.000025	0.000030 0.000030	0.000030 0.000030	0.000033 0.000033	0.000030 0.000030	0.0746 0.0517	0.0517 0.0443
4	0.020645 0.020645	0.020688 0.020693	0.20686 0.020696	0.0000152 0.000013	0.000025 0.000023	0.000020 0.000018	0.000023 0.000020	0.000020 0.000018	4	0.000025 0.000025	0.000030 0.000028	0.000030 0.000028	0.000033 0.000028	0.000030 --	0.0689 0.0476	0.0590 0.410
5	0.020640 (2)	0.020693 (2)	0.020696 (2)	0.000013 (2)	0.000023 (2)	0.000018 (2)	0.000020 (2)	0.000018 (2)	5	0.000025 (2)	0.000028 (2)	0.000028 (2)	0.000028 (2)	-- (2)	0.0508 (2)	0.648 (2)
6	(1) 0.020640	0.020683 0.020714	0.020683 0.020716	0.000018 0.000003	0.000013 0.000000	0.000018 0.000005	0.000025 0.000013	0.000025 0.000002	6	0.000018 0.000000	0.000018 0.000003	0.000018 0.000003	0.000018 0.000075	0.000018 0.000003	0.0205 0.0615	0.0271 0.0763
7	0.020632 (3)	0.020681 (3)	0.020673 (3)	0.000020 (3)	0.000028 (3)	0.000030 (3)	0.000023 (3)	0.000025 (3)	7	0.000015 (3)	0.000020 (3)	0.000018 (3)	0.000018 (3)	0.000018 (3)	0.0213 (3)	0.0246 (3)
8	0.020650 0.020632	0.020678 (2)	0.020683 (2)	0.000023 (2)	0.000030 (2)	0.000023 (2)	0.000030 (2)	0.000020 (2)	8	0.000020 (2)	0.000020 (2)	0.000020 (2)	0.000025 (2)	0.000018 (2)	0.0148 0.1569	0.0308 0.1004
9	0.020650 0.020658	0.020704 0.020759	0.020711 0.020775	0.000005 0.000000	0.000000 0.000000	0.000005 0.000000	0.000013 0.000000	0.000005 0.000000	9	0.000000 0.000000	0.000003 0.000000	0.000003 0.000000	0.000008 0.000000	0.000003 0.000000	0.0653 0.1569	0.0804 0.1558
10	0.020640 0.020650	0.020759 0.020765	0.020775 0.020777	0.000000 0.000000	0 0	0 0	0 0	0 0	10	0.000000 0	0 0	0 0	0 0	0 0	0.1323 0.0715	0.1490 0.0864
11	0.020650 0.020650	0.020765 0.020757	0.020777 0.020747	0 0	0 0	0 0	0 0	0 0	11	0 0	0 0	0 0	0 0	0 0	0.1230 0.1181	0.1460 0.1460
12	0.020650 0.020650	0.020757 0.020983	0.020747 0.021026	0 0	0 0	0 0	0 0	0 0	12	0 0	0 0	0 0	0 0	0 0	0.1435 --	0.1271 --
13	0.020650 0.020650	0.020983 0.020980	0.21026 0.021023	0 0	0 0	0 0	0 0	0 0	13	0 0	0 0	0 0	0 0	0 0	0.2144 0.2296	0.2788 0.2870
14	0.20640 0.020640	0.020676 0.020719	0.020681 0.020747	0.000030 0	0.000033 0.000005	0.000003 0	0.000013 0	0.000014 0	14	0.000018 0	0.000025 0.000003	0.000005 0	0.000008 0	0.000030 0.000005	0.0246 0.0590	0.0189 0.0344

(1) No measurement

(2) Seal damaged by tester bearing failure

(3) Tester severly damaged by dry spinlip

TABLE 13. DATA SUMMARY (ENGLISH UNITS)

TEST NO.	TIME MIN.	SPEED RPM	LOX SEAL U/S PR. CAVITY PSIG	U/S PR. SEAL PSIG	D/S PR. DRAIN PSIG	U/S TEMP CAVITY F	D/S TEMP DRAIN F	LEAKAGE SCFM	HELIUM SEAL U/S PR. PURGE PSIG	D/S PR. TUBE SIDE DRAIN PSIG	U/S TEMP PURGE F	LEAKAGE TOTAL SCFM
35	.100	******	67.5	64.0	5.00	35	42	.26	35.0	.30	73	5.20
36	.280	34000	67.5	65.2	4.20	37	16	.26	30.9	1.40	70	4.60
37	.030	32400	68.5	63.2	3.90	29	18	.20	30.4	1.40	70	4.70
38	.050	32200	67.5	62.8	4.20	20	12	.23	30.4	1.40	70	4.70
39	.070	32000	68.0	62.4	4.20	12	12	.23	30.3	1.30	70	4.70
40	6.400	25300	66.5	62.0	7.00	-35	-	(2) .51	30.0	.90	70	4.80
41	.080	37000	152.0	143.2	14.20	65	1	.69	31.5	1.50	67	4.00
42	.087	37600	151.5	143.2	15.20	63	1	.78	31.5	1.60	67	3.90
43	.250	48000	151.5	142.8	16.20	62	6	.96	32.0	2.20	67	3.70
44	.170	71200	151.5	142.0	>20.00	60	2	******	31.0	3.70	67	2.90
45	.150	66500	152.5	143.0	>20.00	60	2	******	31.0	3.40	67	2.70
46	.100	15000	146.5	140.8	3.80	82	25	.17	31.0	.44	89	4.80
47	.110	27000	152.0	143.2	4.30	83	29	.23	30.1	.96	89	4.60
48	.220	36000	150.0	143.2	4.30	92	31	.29	29.9	1.44	89	4.10
49	.300	58000	157.5	143.2	10.90	79	27	1.01	31.6	4.90	87	3.90
50	.300	87000	153.5	142.0	>20.00	83	32	******	31.3	5.00	87	2.70
51	.250	86500	150.5	140.0	15.60	84	27	6.36	30.0	4.90	89	3.00
52	.320	92000	160.5	144.0	2.90	84	16	6.55	30.3	5.30	87	4.40
53	2.100	78700	150.5	142.0	1.20	86	8	2.80	30.6	4.00	89	4.90
54	6.900	89400	156.5	144.0	2.30	85	56	3.22	29.0	5.40	87	4.60
55	.930	84300	152.0	152.0	.72	76	******	******	30.3	7.18	87	*******
56	.420	91100	******	******	*******	******	******	******	******	*******	******	*******
57	.650	91200	163.0	157.0	3.16	79	******	******	30.2	9.96	87	*******
58	2.330	89300	162.0	157.0	1.94	85	******	******	29.8	9.10	87	*******
59	.670	85400	154.0	152.0	1.36	87	******	5.61	29.3	7.70	90	3.91
60	.950	86000	153.0	153.0	1.30	90	******	5.51	31.7	8.00	92	3.93
61	6.300	88700	163.0	162.0	1.60	87	******	5.95	31.0	9.02	94	3.95
62	.230	91500	******	******	*******	******	******	******	******	*******	******	*******
63	.320	91400	******	******	*******	******	******	******	******	*******	******	*******
64	.330	91300	******	******	*******	******	******	******	******	*******	******	*******
65	.470	91200	******	******	*******	******	******	******	******	*******	******	*******
66	2.150	90600	233.0	199.0	2.54	75	55	7.19	32.0	9.12	90	3.81
67	6.350	92000	233.0	202.0	2.40	74	82	7.06	31.8	9.00	92	3.80
68	6.420	90100	253.0	248.0	2.99	74	62	7.84	29.0	9.06	91	3.82
69	6.470	90200	302.0	295.0	3.30	******	******	8.13	30.0	9.06	******	3.64
70	6.400	90000	302.0	297.0	3.38	******	******	8.22	32.0	9.10	******	3.65
71	6.400	90100	305.0	299.0	3.50	******	******	8.56	32.2	9.26	******	3.63
72	6.450	89600	304.0	297.0	3.25	******	******	8.11	31.0	8.76	******	3.81
73	6.450	89900	307.0	300.0	4.46	******	******	9.44	31.2	8.86	******	3.78
74	.650	89900	295.0	289.0	>20.00	75	75	14.35	31.5	8.64	89	3.84
75	.500	88200	295.0	285.0	>20.00	74	75	14.19	30.1	8.00	87	4.65
76	6.300	89800	302.0	291.0	12.78	72	******	9.63	32.0	8.88	85	3.06
77	6.200	91000	301.0	292.0	3.50	72	******	7.38	31.7	9.08	87	3.34
78	.170	14200	150.0	158.0	.60	87	-59	10.50	29.3	.60	110	3.40
79	.170	19800	157.0	159.0	.60	86	-55	10.50	29.5	1.00	110	3.40
80	.210	34000	187.0	195.0	1.20	86	-45	10.40	29.5	1.50	110	3.90
81	.380	48700	155.0	163.0	.70	85	-45	10.30	29.6	2.60	109	3.40
82	4.000	91100	165.0	169.0	.90	89	2	9.00	29.6	9.30	109	3.60
83	.750	82800	149.0	155.0	.60	90	15	9.00	30.0	7.10	111	3.30
84	.170	52000	145.0	153.0	.60	90	27	10.40	28.5	5.20	113	3.30
85	.820	87000	151.0	157.0	.50	91	29	9.40	30.0	8.20	115	3.40
86	3.300	92400	165.0	173.0	.90	87	43	5.90	29.5	9.30	113	3.60
87	4.210	92100	161.0	165.0	.90	92	45	6.70	29.0	9.30	111	3.50
88	6.200	89600	164.0	169.0	.90	92	52	6.70	29.0	9.30	112	3.50
89	.050	******	******	******	*******	******	******	******	******	*******	******	*******
90	6.350	89900	165.0	168.0	.60	96	4	2.20	29.4	9.60	110	3.80
91	3.600	93800	160.0	163.0	.70	91	4	2.40	29.7	9.50	100	3.90
92	5.450	88700	157.0	161.0	.50	94	5	2.30	30.2	10.00	100	3.40
93	.230	******	******	******	*******	******	******	******	******	*******	******	*******
94	.100	******	******	******	*******	******	******	******	******	*******	******	*******
95	.150	******	******	******	*******	******	******	******	******	*******	******	*******
96	.500	87500	152.0	154.0	.90	82	-7	2.10	33.2	2.12	85	4.70
97	6.020	78000	153.0	155.0	.60	72	30	2.20	29.7	2.44	82	5.00
98	.030	******	******	******	*******	******	******	******	******	*******	******	*******
99	.050	******	******	******	*******	******	******	******	******	*******	******	*******
100	3.770	82400	233.0	198.0	1.30	65	26	3.40	29.9	2.60	82	5.20
101	3.100	79500	232.0	199.0	1.30	67	44	3.70	30.0	2.52	85	5.30
102	.900	72900	252.0	249.0	1.80	60	22	3.80	29.5	2.10	82	5.50
103	5.000	77700	253.0	251.0	1.70	63	43	3.90	29.0	2.42	82	5.40
104	6.000	77600	302.0	299.0	2.20	61	51	4.30	29.7	2.56	84	5.40

TABLE 13. (Continued)

TEST NO.	TIME MIN.	SPEED RPM	LOX SEAL U/S PR. CAVITY PSIG	U/S PR. SEAL PSIG	D/S PR. DRAIN PSIG	U/S TEMP CAVITY F	D/S TEMP DRAIN F	LEAKAGE SCFM	HELIUM SEAL U/S PR. PURGE PSIG	D/S PR. TURB SIDE DRAIN PSIG	U/S TEMP PURGE F	LEAKAGE TOTAL SCFM
105	6.000	77300	335.0	300.0	2.00	61	53	4.40	29.0	2.62	85	5.50
106	6.000	77500	335.0	300.0	2.00	63	55	4.47	29.2	2.68	85	5.60
107	.850	71500	303.0	300.0	2.40	70	4	4.70	31.3	2.50	82	6.30
108	6.000	77400	305.0	298.0	2.20	60	45	4.60	33.3	2.88	81	6.50
109	6.000	78700	375.0	299.0	2.40	56	48	4.90	32.0	2.92	78	6.40
110	6.000	77300	310.0	301.0	2.40	56	48	4.90	32.2	2.86	79	6.30
111	6.000	77400	295.0	274.0	2.10	56	49	4.40	34.5	2.94	80	6.60
112	.250	32200	215.0	192.0	6.20	-280	-290	6.50	28.8	6.60	85	3.80
113	.400	71500	249.0	212.0	13.80	******	-280	15.20	30.3	2.18	82	2.93
114	.250	22200	******	******	*******	******	******	******	******	*******	******	*******
115	.250	56700	******	******	*******	******	******	******	******	*******	******	*******
116	.180	70200	******	******	*******	******	******	******	******	*******	******	*******
117	.750	23900	142.0	121.0	.30	-267	-202	5.90	30.7	.48	82	2.80
118	.500	66700	207.0	172.0	5.00	-270	-213	9.40	30.9	1.94	82	2.60
119	.430	29100	65.0	55.0	.80	-255	-195	3.00	29.7	.58	81	2.60
120	.440	64200	95.0	88.0	.90	-255	-187	3.70	30.0	1.88	81	2.00
121	.220	25500	141.0	114.0	2.70	-270	-187	6.50	29.0	.60	78	3.00
122	.050	24500	******	******	*******	******	******	******	******	*******	******	*******
123	.370	64500	92.0	85.0	1.40	-255	-180	4.70	30.9	1.90	78	2.60
124	1.450	64700	98.0	90.0	.20	-207	-151	3.40	29.4	2.00	78	2.40
125	.220	57400	75.0	44.0	.60	-257	-133	4.00	29.7	1.60	75	3.30
126	.78.	28500	143.0	120.0	1.70	-267	-140	5.00	30.4	.60	75	3.00
127	.250	59200	******	******	*******	******	******	******	******	*******	******	*******
128	1.720	67500	194.0	94.0	2.20	-280	-131	6.30	30.4	2.00	72	3.20
129	3.030	43300	73.0	62.0	.80	-267	-133	3.20	24.8	1.00	68	3.80
130	1.120	66500	117.0	132.0	1.50	-272	-140	4.30	35.7	2.10	69	3.90
131	.720	66400	112.0	101.0	1.20	-265	-127	4.30	33.3	2.30	69	3.70
132	1.720	65800	121.0	110.0	.10	-197	-97	1.40	30.0	2.20	70	3.40
133	2.080	41200	69.0	61.0	.60	-257	-112	2.30	30.7	1.00	70	3.80
134	.250	67400	******	******	*******	******	******	******	******	*******	******	*******
135	.530	67200	169.0	115.0	2.30	-267	-133	5.20	29.6	2.30	70	3.90
136	.280	67700	110.0	102.0	1.50	-267	-122	4.80	29.3	2.30	70	4.10
137	.330	66500	104.0	93.0	1.40	-255	-125	4.60	30.8	2.30	70	4.40
138	3.020	65500	120.0	108.0	1.30	-272	-120	4.10	30.2	2.20	65	4.90
139	.670	67600	120.0	135.0	5.10	-275	-167	8.80	31.7	2.30	65	5.40
140	.180	68100	******	******	*******	******	******	******	******	*******	******	*******
141	1.830	66900	126.0	114.0	1.40	-272	-135	4.40	30.0	2.50	65	5.20
142	.720	667.0	120.0	112.0	1.40	-265	-130	4.30	29.5	2.50	65	5.40
143	1.500	65500	118.0	107.0	1.50	-263	-120	4.60	29.2	2.50	66	5.50
144	1.430	31400	129.0	107.0	1.60	-260	-122	4.60	31.0	.90	67	6.00
145	2.470	29800	127.0	104.0	1.30	-270	-115	3.70	30.3	.90	63	5.90
146	1.070	31000	106.0	96.0	1.20	-222	-145	3.70	30.7	.90	65	6.20
147	.830	31800	108.0	97.0	1.40	-215	-140	3.60	30.0	1.00	65	6.20
148	5.030	596.0	156.0	144.0	.50	-170	-101	1.60	30.0	1.70	65	6.00
149	5.430	58200	134.0	122.0	.50	-180	-72	1.80	30.4	1.40	67	6.40
150	.370	77100	183.0	168.0	4.50	******	-152	7.80	30.4	3.70	65	6.90
151	.100	83100	******	******	*******	******	******	******	******	*******	******	*******
152	.130	81100	******	******	*******	******	******	******	******	*******	******	*******
153	1.600	82500	171.0	156.0	.60	-275	-132	1.80	30.6	4.00	67	6.70
154	1.520	80400	170.0	157.0	.50	-167	-75	1.50	29.8	4.10	68	6.50
155	2.400	83000	170.0	160.0	.30	-122	-50	1.60	29.8	4.90	70	6.50
156	.130	84400	******	******	*******	******	******	******	******	*******	******	*******
157	4.150	83000	157.0	172.0	.40	-190	-40	1.70	30.2	4.70	68	6.70
158	.120	84000	******	******	*******	******	******	******	******	*******	******	*******
159	5.730	76000	158.0	144.0	.20	-57	-17	1.40	30.3	3.60	65	6.80
160	.070	88700	******	******	*******	******	******	******	******	*******	******	*******
161	.070	88600	******	******	*******	******	******	******	******	*******	******	*******
162	.080	85000	******	******	*******	******	******	******	******	*******	******	*******
163	1.050	[illegible]	230.0	214.0	1.20	-237	-60	3.50	31.7	4.40	64	7.80
164	.720	29600	164.0	138.0	1.10	-272	-82	3.60	29.0	1.20	64	7.50
165	.470	31000	170.0	143.0	2.60	-276	-101	5.00	29.3	1.30	64	7.70
166	.220	28900	******	******	*******	******	******	******	******	*******	******	*******
167	1.600	84100	220.0	236.0	4.50	-277	-155	7.90	29.7	4.70	64	7.50
168	.230	84100	254.0	235.0	5.10	-275	-140	8.10	31.2	4.90	64	8.40
169	.280	84300	255.0	235.0	4.60	-275	-141	7.70	31.0	4.90	64	8.30
170	.450	84000	254.0	235.0	4.20	-275	-138	7.20	30.5	4.90	64	8.30
171	.900	83800	251.0	233.0	3.60	-275	-135	6.60	30.0	4.60	65	8.10
172	2.350	855.0	368.0	277.0	3.50	-275	-147	6.40	30.4	5.10	66	8.40
173	2.570	83600	292.0	272.0	4.00	-273	-138	7.00	30.6	4.80	66	8.45
174	.830	83700	289.0	267.0	4.40	-272	-142	7.40	30.6	4.80	66	8.40

TABLE 13. (Continued)

TEST NO.	TIME MIN.	SPEED RPM	LOX SEAL U/S PR. CAVITY PSIG	LOX SEAL U/S PR. SEAL PSIG	LOX SEAL D/S PR. DRAIN PSIG	LOX SEAL U/S TEMP CAVITY F	LOX SEAL D/S TEMP DRAIN F	LOX SEAL LEAKAGE SCFM	HELIUM SEAL U/S PR. PURGE PSIG	HELIUM SEAL D/S PR. TURB SIDE DRAIN PSIG	HELIUM SEAL U/S TEMP PURGE F	HELIUM SEAL LEAKAGE TOTAL SCFM
175	1.850	83600	295.0	279.0	4.30	-272	-135	7.30	29.0	4.80	66	8.10
176	.370	83750	290.0	271.0	4.50	-272	-140	7.60	29.0	4.80	66	8.30
177	.580	83500	285.0	266.0	4.50	-272	-140	7.50	29.9	4.80	66	8.40
178	1.070	84100	307.0	286.0	4.30	-272	-137	7.20	30.5	4.90	66	6.40
179	1.180	83600	285.0	263.0	5.30	-277	-177	8.85	31.0	4.70	63	6.30
180	1.530	62000	413.0	368.0	4.80	-275	-150	8.20	30.0	2.80	63	6.20
181	1.480	74500	460.0	401.0	4.30	-275	-162	7.80	30.0	3.30	64	6.20
182	.470	84400	325.0	303.0	5.90	-275	-162	9.30	30.3	4.90	64	6.20
183	1.180	84500	301.0	280.0	4.20	-272	-155	7.70	29.6	4.90	64	6.10
184	.450	84500	303.0	282.0	4.30	-272	-147	7.70	31.0	5.00	64	6.40
185	.800	84400	306.0	265.0	4.30	-272	-147	7.90	30.3	4.90	64	6.20
186	2.820	84100	300.0	285.0	4.30	-272	-140	7.60	31.0	4.80	65	6.30
187	.150	19300	169.5	154.5	6.70	-265	-293	18.10	29.6	.84	62	4.00
188	.100	21600	******	******	*******	******	******	******	******	*******	******	*******
189	.100	23500	******	******	*******	******	******	******	******	*******	******	*******
190	.090	24500	******	******	*******	******	******	******	******	*******	******	*******
191	.188	38500	236.0	177.5	6.90	-270	-300	19.80	32.0	1.80	89	4.20
192	.200	41900	261.5	194.5	7.60	-269	-298	22.30	32.0	2.20	87	4.20
193	.275	48000	310.0	230.0	9.40	-279	-293	26.30	33.0	2.60	87	3.00
194	.300	51800	330.0	249.5	9.00	-265	-293	26.30	33.4	2.90	87	2.60
195	.250	53000	333.0	250.5	7.00	-273	-291	23.40	33.3	3.00	87	2.80
196	.060	76500	******	******	*******	******	******	******	******	*******	******	*******
197	.200	61700	******	******	*******	******	******	******	******	*******	******	*******
198	.250	51400	300.0	235.5	9.20	-272	-290	26.60	31.6	3.00	88	4.80
199	.875	75400	331.5	290.0	3.30	-279	-244	13.00	35.3	4.20	87	1.38
200	1.850	75700	355.0	300.0	2.70	-285	-236	12.10	36.0	4.80	86	5.00
201	.900	77700	330.0	295.0	2.60	-282	-226	12.00	33.7	4.90	90	5.20
202	2.900	78200	326.0	290.0	2.80	-282	-170	12.40	30.0	5.60	90	7.00
203	.159	13100	236.0	173.8	6.40	-265	-300	23.30	30.7	1.80	80	12.21
204	.153	24300	250.5	178.0	8.30	-280	-300	22.10	30.4	4.30	80	12.59
205	.174	30400	260.5	182.0	6.40	-282	-309	28.60	31.0	6.90	81	12.20
206	.699	76800	370.0	182.8	5.60	-295	-245	25.60	30.1	>20.00	81	12.20
207	1.350	75750	379.0	164.8	4.60	-292	-217	20.10	30.9	>20.00	81	11.89
208	.210	82600	381.5	185.8	17.00	-292	-297	59.10	30.3	2.10	85	14.19
209	.225	82000	381.5	194.0	18.10	-292	-299	62.80	31.4	2.10	86	13.93
210	.300	79500	381.5	184.0	18.30	-290	-289	63.60	31.7	1.90	87	13.53
211	3.120	74400	375.0	184.0	6.20	-298	-200	19.20	30.0	1.80	87	13.93
212	1.134	77500	375.0	184.5	6.50	-289	-212	22.30	29.6	1.90	89	13.99
213	.249	41200	310.0	193.2	15.30	-295	-300	54.10	30.2	1.40	89	12.35
214	.150	39100	304.0	192.0	14.80	-295	-300	53.10	29.8	1.40	89	12.42
215	.210	68600	387.0	197.2	20.30	-295	-297	67.40	30.1	2.10	90	14.33
216	.285	74600	388.5	197.2	20.00	-295	-297	68.30	31.0	1.70	91	14.87
217	.339	79400	389.0	206.0	14.90	-295	-295	76.60	32.0	1.90	90	15.06
218	1.149	75900	389.0	205.2	5.70	-295	-230	27.10	32.8	1.90	90	15.18
219	.312	63400	381.5	204.4	14.40	-295	-300	73.90	31.5	1.60	91	14.17
220	.252	61000	385.0	204.8	15.00	-295	-300	79.50	31.6	1.50	90	13.93
221	.255	79700	422.0	207.2	7.00	-269	-300	30.10	31.0	1.30	90	15.31
222	.228	90000	147.5	207.2	3.70	-247	-310	21.30	30.0	1.80	87	9.71
223	.183	80600	395.0	207.6	7.80	-245	-310	42.70	30.0	1.10	87	15.73
224	.233	74400	400.0	207.6	5.60	-257	-295	33.40	29.8	.90	86	15.33
225	.212	92200	******	207.6	2.20	-281	-285	9.80	20.3	1.40	85	5.43
226	3.067	75300	363.5	208.0	3.60	-280	-205	19.80	30.3	1.30	86	15.49
227	3.158	76000	364.0	209.0	3.60	-277	-192	20.37	30.3	1.30	86	15.00
228	******	******	******	******	*******	******	******	******	******	*******	******	*******
229	.220	86400	******	******	*******	******	******	******	******	*******	******	*******
230	.280	46700	390.0	263.0	9.00	-270	-290	32.19	31.5	4.80	103	14.61
231	3.190	76900	393.5	325.0	7.50	-280	-197	24.10	31.9	5.80	100	14.66
232	.220	77600	******	******	*******	******	******	******	******	*******	******	*******
233	.210	77300	******	******	*******	******	******	******	******	*******	******	*******
234	.210	83600	******	245.5	14.50	******	-297	39.44	31.1	1.60	102	14.42
235	.230	83000	******	214.0	9.00	-300	-280	22.36	30.6	5.40	103	14.50
236	3.000	74600	375.5	309.0	11.40	-290	-200	26.37	31.1	1.70	102	14.54
237	3.150	76200	377.5	312.0	11.40	-280	-190	27.37	31.0	6.00	100	14.67
238	3.080	74500	373.5	281.5	14.20	-280	-220	38.72	31.4	5.90	102	14.62
239	3.100	77500	372.0	292.5	14.00	-280	-210	33.00	30.6	6.00	100	14.76
240	.220	94400	******	******	*******	******	******	******	******	*******	******	*******
241	3.153	76100	370.0	283.5	15.10	-290	-235	39.79	31.4	2.10	104	15.00
242	3.150	77700	367.0	275.0	15.30	-285	-233	39.57	31.4	2.00	103	14.68
243	3.150	77700	365.0	283.0	15.10	-295	-234	39.86	31.4	2.20	102	15.04
244	3.580	77000	365.0	295.0	13.90	-285	-227	36.65	31.3	2.20	102	15.05

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OF POOR QUALITY

TABLE 13. (Continued)

TEST NO.	TIME MIN.	SPEED RPM	LOX SEAL U/S PR. CAVITY PSIG	U/S PR. SEAL PSIG	D/S PR. DRAIN PSIG	U/S TEMP CAVITY F	D/S TEMP DRAIN F	LEAKAGE SCFM	HELIUM SEAL U/S PR. PURGE PSIG	D/S PR. TURB SIDE DRAIN PSIG	U/S TEMP PURGE F	LEAKAGE TOTAL SCFM
245	3.65	77630	366.0	292.5	13.50	-285	-223	37.15	31.3	2.20	102	15.08
246	.350	79650	******	282.0	13.20	-290	-240	36.38	31.8	2.10	102	15.08
247	3.100	77850	370.0	296.5	12.30	-280	-212	33.37	31.0	2.10	102	15.12
248	3.100	78200	368.5	298.5	12.00	-285	-217	32.74	31.2	2.10	99	15.19
249	3.150	77300	368.0	296.0	11.69	-288	-217	32.23	31.0	2.10	97	15.24
250	3.150	77100	367.5	295.5	11.30	-290	-217	31.71	31.0	2.00	97	15.24
251	3.100	75600	367.5	287.5	12.00	-285	-225	36.61	31.0	2.00	97	15.20
252	3.150	76500	360.0	271.0	13.40	-285	-233	38.69	31.0	2.20	100	15.02
253	3.150	76500	363.5	284.0	11.80	-295	-217	32.19	30.6	2.00	97	15.17
254	3.100	75800	359.0	272.5	12.50	-280	-235	39.06	31.2	2.00	96	15.13
255	.450	80500	******	******	*******	******	******	******	******	*******	******	*******
256	.200	82000	******	******	*******	******	******	******	******	*******	******	*******
257	3.050	75000	357.5	267.0	11.30	-290	-235	37.45	31.4	1.90	90	15.29
258	.180	81000	******	******	*******	******	******	******	******	*******	******	*******
259	.180	90600	******	******	*******	******	******	******	******	*******	******	*******
260	.300	91100	******	******	*******	******	******	******	******	*******	******	*******
261	3.090	77300	385.0	276.0	15.00	-281	-255	45.14	32.4	2.20	87	14.72
262	3.090	77800	390.5	281.5	14.30	-277	-257	44.52	32.2	2.20	88	14.67
263	3.090	77900	384.0	265.5	12.00	-290	-246	36.24	31.3	2.20	86	15.02
264	3.060	76500	384.0	281.0	12.60	-286	-259	39.44	29.7	2.10	86	15.00
265	3.120	77900	395.5	250.0	14.19	-285	-260	44.52	32.0	2.20	87	15.01
266	3.060	76200	381.5	282.0	12.40	-282	-251	40.29	31.3	2.10	88	14.82
267	3.060	76800	387.5	280.0	12.30	-281	-249	39.81	31.6	2.10	90	14.98
268	3.090	76800	394.0	276.5	13.90	-280	-262	45.16	32.5	2.20	90	15.01
269	3.060	76300	385.0	275.5	13.72	-277	-259	44.83	32.6	2.10	89	14.46
270	3.050	73300	389.0	223.5	9.00	-285	-236	35.00	32.5	2.20	90	16.58
271	3.100	76800	390.0	305.0	8.30	-283	-223	33.70	32.5	2.20	90	16.59
272	3.090	77600	394.0	305.5	7.90	-283	-235	33.76	32.7	2.20	91	16.48
273	3.080	75700	382.0	291.5	9.60	-280	-255	39.71	33.3	2.20	91	16.43
274	3.050	76700	397.5	295.0	8.93	-296	-252	38.13	33.2	2.30	89	16.47
275	3.080	75800	382.5	288.5	10.30	-285	-276	43.00	33.8	2.30	88	16.46
276	3.050	75800	382.5	288.5	10.50	-286	-277	44.11	33.8	2.30	89	16.93
277	3.080	76100	385.0	287.0	12.23	-285	-287	48.44	34.5	2.30	90	16.59
278	3.100	77100	384.0	299.5	8.10	-285	-250	37.61	33.7	2.20	90	16.93
279	3.080	77900	381.5	299.5	8.30	-283	-248	38.93	33.3	2.30	90	16.52
280	3.050	76000	380.0	275.5	13.90	-282	-287	55.18	34.5	2.20	90	16.16
281	3.050	76600	384.0	285.5	9.60	-282	-270	44.51	33.4	2.20	90	16.32
282	3.080	76200	378.5	294.5	8.30	-286	-251	39.71	32.4	2.20	87	16.41
283	3.050	77000	380.0	295.5	7.70	-285	-250	37.47	32.7	2.20	88	16.40
284	3.080	76500	375.5	283.5	10.40	-285	-280	45.57	33.5	2.30	89	16.35
285	3.050	77200	381.5	285.5	9.40	-280	-243	38.91	32.9	2.20	90	15.21
286	3.080	77700	392.5	299.0	7.80	-284	-234	35.59	32.6	2.30	91	15.21
287	3.080	76800	380.5	293.0	7.70	-283	-234	35.15	32.6	2.30	91	15.23
288	3.050	78300	385.0	302.5	7.50	-282	-234	34.71	33.0	2.30	91	15.25
289	3.050	75900	383.5	294.0	8.10	-280	-240	37.27	33.2	2.20	91	15.28
290	3.050	75600	380.0	285.0	10.70	-286	-280	44.44	33.9	2.40	88	15.20
291	3.050	75800	377.0	280.5	11.60	-285	-292	48.06	34.2	2.40	88	15.19
292	3.050	78500	381.5	291.0	10.10	-285	-261	43.77	33.7	2.40	88	15.29
293	3.350	76900	376.5	284.0	10.30	-285	-270	44.87	33.9	2.40	90	15.26
294	3.100	78100	375.0	290.0	9.40	-283	-253	42.56	33.7	2.40	90	15.35
295	3.100	78100	373.5	295.5	7.90	-283	-240	47.91	33.6	2.30	90	15.40
296	3.050	75500	380.0	284.0	11.40	-280	-285	47.31	34.8	2.30	91	15.22
297	3.050	75900	373.5	280.5	11.30	-282	-267	47.31	34.5	2.40	91	15.31
298	3.080	77600	379.5	292.5	8.60	-296	-255	41.97	33.8	2.30	87	15.50
299	1.380	76300	376.0	287.5	9.40	-287	-255	43.03	33.7	2.30	87	15.45
300	2.900	77300	370.0	290.5	7.20	-287	-240	36.51	33.5	2.20	87	15.54
301	3.100	77000	371.5	289.0	7.30	-286	-243	34.51	33.5	2.20	88	15.52
302	3.080	77300	379.0	299.5	7.80	-286	-244	38.70	32.0	2.30	86	14.91
303	3.050	76100	375.0	281.0	10.90	-284	-290	48.77	33.3	2.40	87	14.66
304	3.050	76600	378.0	288.0	9.40	-283	-266	44.63	32.3	2.40	87	14.77
305	3.050	76900	375.0	291.5	8.93	-282	-255	43.45	32.2	2.30	87	14.79
306	3.000	76800	367.0	276.0	7.50	-282	-244	39.96	32.0	2.30	97	14.82
307	.150	35800	******	******	*******	******	******	******	******	*******	******	*******
308	3.080	77500	374.5	299.0	8.00	-285	-244	39.12	35.5	2.20	85	16.24
309	3.050	77100	370.0	300.5	9.30	-284	-239	37.51	37.1	2.20	86	17.33
310	3.05	76800	372.0	289.0	8.80	-283	-275	46.31	30.8	2.30	86	14.60
311	3.130	77600	375.0	270.0	6.60	-282	-245	39.95	31.8	2.30	86	14.70
312	3.050	77800	378.0	264.0	5.90	-280	-243	38.28	31.4	2.40	87	14.69
313	3.050	76900	374.0	286.5	11.80	-280	-250	50.40	32.0	2.60	87	14.58
314	3.060	77000	370.0	277.5	13.40	-286	-296	55.84	33.2	2.60	83	14.49

TABLE 13. (Continued)

TEST NO.	TIME MIN.	SPEED RPM	LOX SEAL U/S PR. CAVITY PSIG	U/S PR. SEAL PSIG	D/S PR. DRAIN PSIG	U/S TEMP CAVITY F	D/S TEMP DRAIN F	LEAKAGE SCFM	HELIUM SEAL U/S PR. PURGE PSIG	D/S PR. TURB SIDE DRAIN PSIG	U/S TEMP PURGE F	LEAKAGE TOTAL SCFM
315	3.120	77300	364.5	278.0	14.10	-286	-293	54.03	33.5	2.70	83	14.45
316	3.050	77600	365.0	283.5	13.10	-285	-292	54.65	33.2	2.70	83	14.44
317	3.080	76200	369.0	285.5	12.30	-283	-289	53.42	33.0	2.80	84	14.45
318	3.090	77600	369.5	292.0	8.70	-283	-268	43.97	31.8	2.60	84	14.69
319	.300	74700	362.5	381.0	1.69	-277	-300	22.04	30.1	1.10	86	14.86
320	.200	55800	372.5	370.0	2.69	-276	-302	32.50	30.2	.60	86	14.89
321	.380	79800	375.0	358.5	7.43	-277	-257	32.93	30.7	2.50	86	15.07
322	.280	66700	372.0	372.5	2.29	-278	-277	21.20	30.8	.70	86	15.10
323	1.130	78300	374.0	313.5	4.50	-282	-271	30.06	32.5	2.40	83	15.16
324	3.070	77000	365.0	281.5	13.20	-282	-286	52.34	35.3	2.60	81	15.41
325	3.080	77900	365.0	291.0	1[illegible].10	-282	-279	44.71	34.6	2.50	80	15.51
326	3.050	77600	372.0	299.5	11.23	-285	-292	47.73	34.8	2.50	77	15.59
327	3.090	77100	370.0	267.0	12.10	-283	-296	50.88	34.9	2.50	77	15.48
328	1.070	76700	373.0	286.5	11.40	-284	-292	49.37	34.9	2.40	77	15.48
329	.100	76800	412.0	377.5	11.30	-278	-296	49.02	32.9	2.30	78	15.73
330	.100	103300	263.0	331.0	12.43	-283	-298	53.43	32.9	*******	78	15.76
331	.150	82900	39[illegible].0	319.0	20.40	-173	-286	78.88	39.6	4.20	74	13.82
332	.263	******	******	******	*******	******	******	******	******	*******	******	*******
333	******	>100000	427.0	397.5	2.74	-255	-87	******	31.6	.76	91	*******
334	.130	>100000	388.0	371.0	1.54	-257	-17	******	33.9	.56	88	*******
335	.090	>100000	397.5	428.0	1.92	-272	-51	******	31.8	.36	86	*******
336	.090	>100000	410.5	420.5	1.99	-285	-61	******	34.3	.38	86	*******
337	.120	>100000	432.5	413.0	1.80	-255	-58	******	27.6	.32	87	*******
338	.090	>100000	409.0	427.5	2.64	-268	-89	******	27.2	.22	87	*******
339	.090	92000	446.5	426.0	2.78	-268	-76	******	28.2	.18	87	*******
340	.140	56300	416.0	344.5	2.86	-277	-131	******	30.4	.16	83	*******
341	.100	92000	414.0	437.5	3.16	-271	-100	******	31.9	.20	87	*******
342	.160	54800	384.5	344.0	3.20	-268	-122	******	33.0	.18	86	*******
343	3.180	74800	381.5	342.0	5.50	-283	-300	31.30	29.9	.24	82	9.21
344	.100	92800	439.0	449.5	2.36	-256	-99	12.85	29.0	.30	90	8.77
345	2.680	77500	391.0	348.5	5.24	-282	-296	30.72	30.2	.28	90	9.16
346	.080	97500	423.0	402.5	2.62	-261	-86	15.95	28.3	.28	90	8.83
347	.090	90300	419.0	434.5	3.32	-266	-131	20.69	29.8	.28	91	9.23
348	.280	65700	422.5	348.5	4.49	-280	-178	23.65	31.6	.32	91	9.50
349	.100	88300	429.0	445.5	3.10	-244	-127	17.17	33.0	.28	87	10.35
350	3.080	76600	386.5	343.5	5.56	-287	-300	31.89	32.5	.34	86	10.45
351	.120	>100000	420.5	425.0	1.60	-263	-63	4.39	29.4	.30	88	9.70
352	.120	>100000	424.0	425.0	2.56	-261	-35	10.38	27.6	.22	86	9.02
353	.120	>100000	419.0	452.0	2.72	-256	-74	14.69	30.4	.18	87	9.99
354	.270	77700	424.5	358.0	5.36	-277	-155	27.47	32.4	.16	87	10.44
355	.450	78900	383.5	349.0	5.29	-283	-296	29.18	30.5	.24	87	10.10
356	3.270	74800	391.0	350.5	4.94	-282	-296	29.59	31.0	.22	87	10.39
357	3.000	75400	397.0	350.5	5.00	-287	-304	29.90	35.7	.22	83	10.88
358	3.090	75200	397.5	364.5	4.89	-287	-308	29.25	31.7	.18	83	11.24
359	3.130	75000	397.5	364.5	4.79	-285	-302	28.73	31.7	.22	84	11.25
360	3.320	76300	392.5	360.0	5.30	-282	-296	33.02	31.0	.24	87	11.24
361	3.130	74800	391.0	359.0	4.95	-286	-300	30.01	30.6	.22	83	11.36
362	3.150	75900	390.0	358.0	4.54	-287	-304	28.27	31.0	.14	84	11.29
363	3.180	75300	391.0	359.5	4.44	-286	-302	28.64	30.8	.18	84	11.31
364	3.100	75500	390.0	357.0	4.74	-285	-3[illegible]	29.26	30.7	.22	85	11.33
365	2.880	75700	389.0	356.5	4.46	-285	-299	27.86	30.7	.22	86	11.36
366	3.150	75500	392.5	356.5	4.56	-283	-299	28.17	31.1	.22	85	11.38
367	3.150	76000	391.0	355.0	4.60	-282	-297	28.25	31.0	.20	86	11.39
368	3.150	75500	386.5	355.0	4.63	-283	-296	28.63	30.2	.20	86	11.42
369	3.150	75700	389.0	356.0	4.68	-286	-304	28.52	30.3	.18	82	11.49
370	3.150	75700	394.0	360.0	4.94	-286	-300	29.37	30.5	.16	84	11.50
371	3.150	75800	391.0	360.0	4.95	-285	-300	27.06	30.2	.24	84	11.50
372	3.150	75900	391.0	359.5	4.78	-283	-299	28.95	30.2	.22	84	11.52
373	3.150	75300	390.5	360.0	4.65	-282	-297	28.87	30.2	.22	85	11.53
374	3.150	75800	391.0	359.5	4.56	-283	-296	28.13	30.2	.22	85	11.54
375	3.150	75900	391.5	360.0	4.58	-287	-304	28.92	30.0	.16	81	11.67
376	3.150	76000	392.0	360.0	4.30	-287	-304	29.93	30.0	-.02	82	11.51
377	3.130	76200	392.5	358.5	4.64	-286	-300	28.45	30.2	.06	82	11.65
378	.120	100000	426.0	373.0	3.68	-129	-97	16.23	31.2	.38	75	12.03
379	.130	81300	407.0	415.5	3.08	-235	-99	15.27	31.2	.34	75	12.01
380	3.190	73700	395.0	361.0	5.20	-283	-299	28.06	30.9	.38	75	12.05
381	3.090	75800	384.0	351.0	5.14	-280	-297	29.77	30.7	.40	76	12.03
382	.330	60600	387.5	450.5	2.20	-266	-179	14.19	30.7	.26	77	12.06
383	.150	79800	415.0	442.0	2.76	-265	-152	15.84	31.0	.38	77	12.05
384	3.130	75000	382.5	350.0	5.10	-277	-296	28.69	30.0	.38	78	12.07

TABLE 13. (Continued)

TEST NO.	TIME MIN.	SPEED RPM	LOX SEAL U/S PR. CAVITY PSIG	U/S PR. SEAL PSIG	D/S PR. DRAIN PSIG	U/S TEMP CAVITY F	D/S TEMP DRAIN F	LEAKAGE SCFM	HELIUM SEAL U/S PR. PURGE PSIG	D/S PR. TURB SIDE DRAIN PSIG	U/S TEMP PURGE F	LEAKAGE TOTAL SCFM
385	3.150	75100	385.0	354.0	4.92	-283	-302	27.31	30.4	.38	76	12.13
386	3.200	75400	393.5	360.5	5.40	-283	-300	29.63	33.3	.42	76	13.06
387	.230	57700	407.0	445.0	2.30	-270	-170	14.98	35.6	.32	78	13.57
388	.170	81500	403.0	436.0	3.12	-270	-162	17.45	31.6	.42	78	13.95
389	3.150	75400	386.5	357.5	4.78	-282	-299	27.26	32.7	.46	78	12.88
390	3.130	75400	389.0	363.0	5.06	-282	-299	28.60	32.7	.46	79	12.89
391	3.150	75700	389.0	360.5	5.42	-280	-296	30.19	32.5	.46	81	12.86
392	3.150	75800	397.5	369.0	5.20	-280	-296	29.33	32.5	.46	81	12.90
393	.650	76200	340.0	311.5	5.19	-280	-187	27.09	31.5	.52	83	12.14
394	3.200	74600	366.5	359.0	5.74	-280	-296	30.43	33.7	.52	85	13.21
395	3.150	74400	390.5	361.0	5.56	-280	-295	29.91	31.7	.54	86	12.62
396	3.150	76500	381.0	351.0	5.10	-282	-299	28.40	31.4	.59	84	12.63
397	.500	75000	381.0	351.5	5.72	-273	-222	16.13	31.4	.54	83	12.60
398	.800	76600	383.5	341.5	5.20	-286	-299	28.80	31.7	.54	83	12.61
399	3.150	74800	365.0	355.0	5.29	-285	-300	29.01	31.2	.54	85	12.71
400	3.200	75000	383.5	354.0	5.64	-285	-299	31.23	31.2	.32	85	12.73
401	3.200	76200	369.0	358.0	5.44	-283	-299	30.64	31.2	.52	85	12.73
402	3.150	76700	384.5	359.0	5.48	-281	-297	30.24	31.2	.52	85	12.73
403	.530	76100	391.0	362.0	5.40	-280	-296	23.48	31.3	.52	86	12.68
404	.150	96800	403.0	370.5	2.94	-224	-103	13.23	31.5	.52	88	12.62
405	3.130	75600	381.0	353.5	5.54	-285	-300	30.27	31.2	.56	84	12.78
406	3.230	74200	385.0	355.0	4.94	-286	-302	27.86	31.1	.56	84	12.82
407	3.200	73700	395.0	361.0	5.50	-285	-300	30.58	31.0	.54	85	12.83
408	3.150	73900	383.0	355.0	5.18	-283	-300	29.44	31.6	.64	87	12.86
409	3.070	74500	390.5	362.5	5.72	-285	-300	31.25	31.2	.62	86	12.91
410	3.150	77000	390.5	360.0	5.36	-284	-300	29.39	31.1	.64	86	12.94
411	3.200	76100	386.5	357.5	5.34	-283	-299	29.48	30.7	.62	86	12.96
412	3.150	76400	385.0	355.5	5.56	-281	-299	30.59	31.2	.56	86	12.96
413	.100	92700	******	******	*******	******	******	******	******	*******	******	*******
414	.260	96800	******	******	*******	******	******	******	******	*******	******	*******
415	.080	99800	******	******	*******	******	******	******	******	*******	******	*******
416	.090	99700	******	******	*******	******	******	******	******	*******	******	*******
417	.100	97300	******	******	*******	******	******	******	******	*******	******	*******
418	.090	97200	******	******	*******	******	******	******	******	*******	******	*******
419	.080	98700	******	******	*******	******	******	******	******	*******	******	*******
420	.090	98200	******	******	*******	******	******	******	******	*******	******	*******
421	.370	70000	341.0	335.0	1.26	-292	-242	9.92	26.8	.24	98	12.29
422	.100	98300	******	******	*******	******	******	******	******	*******	******	*******
423	.080	77100	******	******	*******	******	******	******	******	*******	******	*******
424	.080	75100	******	******	*******	******	******	******	******	*******	******	*******
425	.330	75100	368.5	362.5	1.14	-293	-223	8.76	26.4	.22	92	11.68
426	.130	95000	******	******	*******	******	******	******	******	*******	******	*******
427	.100	94200	******	******	*******	******	******	******	******	*******	******	*******
428	.080	85500	******	******	*******	******	******	******	******	*******	******	*******
429	.080	92700	******	******	*******	******	******	******	******	*******	******	*******
430	.250	42600	******	******	*******	******	******	******	******	*******	******	*******
431	.100	89100	******	******	*******	******	******	******	******	*******	******	*******
432	.100	92700	******	******	*******	******	******	******	******	*******	******	*******
433	.040	27000	******	******	*******	******	******	******	******	*******	******	*******
434	.650	77000	375.0	368.5	2.94	-285	-292	18.41	28.3	.20	91	11.76
435	.100	91700	******	******	*******	******	******	******	******	*******	******	*******
436	.100	95000	******	******	*******	******	******	******	******	*******	******	*******
437	.130	95200	******	******	*******	******	******	******	******	*******	******	*******
438	1.550	76400	376.5	371.0	2.90	-287	-293	20.49	28.3	.14	90	12.12
439	.100	94600	******	******	*******	******	******	******	******	*******	******	*******
440	.100	95200	******	******	*******	******	******	******	******	*******	******	*******
441	.300	98200	******	******	*******	******	******	******	******	*******	******	*******
442	.100	95700	******	******	*******	******	******	******	******	*******	******	*******
443	.300	97200	******	******	*******	******	******	******	******	*******	******	*******
444	.100	98200	******	******	*******	******	******	******	******	*******	******	*******
445	.100	96200	******	******	*******	******	******	******	******	*******	******	*******
446	.100	89800	******	******	*******	******	******	******	******	*******	******	*******
447	1.550	77600	303.5	375.5	2.90	-292	-290	19.15	28.1	.06	87	11.65
448	.100	95800	******	******	*******	******	******	******	******	*******	******	*******
449	.100	97800	******	******	*******	******	******	******	******	*******	******	*******
450	3.200	69000	365.0	377.0	2.74	-289	-296	19.13	28.1	.06	87	11.63
451	.100	96400	******	******	*******	******	******	******	******	*******	******	*******
452	.080	54000	******	******	*******	******	******	******	******	*******	******	*******
453	.050	99100	******	******	*******	******	******	******	******	*******	******	*******
454	.050	98200	******	******	*******	******	******	******	******	*******	******	*******

TABLE 13. (Continued)

TEST NO.	TIME MIN.	SPEED RPM	LOX SEAL U/S PR. CAVITY PSIG	U/S PR. SEAL PSIG	D/S PR. DRAIN PSIG	U/S TEMP CAVITY F	D/S TEMP DRAIN F	LEAKAGE SCFM	HELIUM SEAL U/S PR. PURGE PSIG	D/S PR. TURB SIDE DRAIN PSIG	U/S TEMP PURGE F	LEAKAGE TOTAL SCFM
455	.050	10200	******	******	*******	******	******	******	******	*******	******	*******
456	.050	3060	******	******	*******	******	******	******	******	*******	******	*******
457	.050	84900	******	******	*******	******	******	******	******	*******	******	*******
458	1.580	67200	360.0	346.0	2.66	-293	-304	19.45	31.3	.38	93	7.57
459	.080	88700	******	******	*******	******	******	******	******	*******	******	*******
460	1.550	75500	361.0	346.5	2.40	-296	-304	17.99	31.3	.38	92	7.58
461	3.520	73700	361.0	371.0	2.22	-294	-303	18.75	32.0	.38	92	7.58
462	4.920	71800	386.0	372.5	2.30	-292	-302	18.74	31.9	.38	95	7.55
463	.080	83200	******	******	*******	******	******	******	******	*******	******	*******
464	.670	78000	360.5	347.5	2.34	-292	-299	******	31.0	.38	95	7.56
465	.050	95600	******	******	*******	******	******	******	******	*******	******	*******
466	.050	99700	******	******	*******	******	******	******	******	*******	******	*******
467	.050	98600	******	******	*******	******	******	******	******	*******	******	*******
468	.050	97000	******	******	*******	******	******	******	******	*******	******	*******
469	.050	89200	******	******	*******	******	******	******	******	*******	******	*******
470	.050	92700	******	******	*******	******	******	******	******	*******	******	*******
471	.050	82900	******	******	*******	******	******	******	******	*******	******	*******
472	.050	71600	******	******	*******	******	******	******	******	*******	******	*******
473	.050	74800	******	******	*******	******	******	******	******	*******	******	*******
474	.100	74000	******	******	*******	******	******	******	******	*******	******	*******
475	.030	50400	******	******	*******	******	******	******	******	*******	******	*******
476	.030	65900	******	******	*******	******	******	******	******	*******	******	*******
477	.080	5500	******	******	*******	******	******	******	******	*******	******	*******
478	.080	10200	******	******	*******	******	******	******	******	*******	******	*******
479	******	******	******	******	*******	******	******	******	******	*******	******	*******
480	.080+100000		******	******	*******	******	******	******	******	*******	******	*******
481	.050	97500	******	******	*******	******	******	******	******	*******	******	*******
482	3.330	66800	395.0	371.5	2.56	-289	-294	19.69	26.5	.42	96	7.50
483	.070	99200	******	******	*******	******	******	******	******	*******	******	*******
484	.070	[illegible]	******	******	*******	******	******	******	******	*******	******	*******
485	3.330	71600	382.5	370.0	2.46	-287	-294	18.68	28.5	.40	96	7.49
486	5.000	75900	388.0	375.0	2.22	-293	-298	19.43	29.5	.38	94	7.49
487	6.050	74200	385.5	373.5	2.16	-293	-300	17.38	28.8	.38	93	7.03
488	6.000	76800	389.0	375.0	2.09	-289	-299	17.38	29.0	.38	94	6.97
489	6.000	74400	385.0	371.5	2.80	-293	-300	17.32	31.0	.36	92	7.35
490	.050	83100	******	******	*******	******	******	******	******	*******	******	*******
491	6.000	75800	391.5	377.5	2.14	-290	-299	17.22	32.8	.36	92	7.61
492	.070	83000	******	******	*******	******	******	******	******	*******	******	*******
493	6.000	76800	387.5	372.5	2.38	-292	-297	17.98	32.5	.36	93	7.61
494	.100	84600	******	******	*******	******	******	******	******	*******	******	*******
495	6.000	76500	390.0	375.0	2.17	-289	-294	17.21	32.1	.36	94	7.63
496	6.000	76700	390.0	377.0	2.08	-286	-294	17.20	32.0	.36	93	7.62
497	.100	81700	******	******	*******	******	******	******	******	*******	******	*******
498	6.000	74700	390.0	376.5	2.06	-293	-300	17.25	31.8	.34	90	7.64
499	.100	83600	******	******	*******	******	******	******	******	*******	******	*******
500	6.000	76500	395.0	380.0	2.20	-290	-299	18.01	32.0	.32	90	7.64
501	6.000	77700	388.5	375.0	2.30	-290	-299	17.96	32.0	.32	91	7.70
502	.100	82100	******	******	*******	******	******	******	******	*******	******	*******
503	6.000	78400	394.0	378.5	2.20	-289	-296	17.94	32.1	.34	91	7.70
504	.100	82000	******	******	*******	******	******	******	******	*******	******	*******
505	6.000	77200	400.0	385.0	2.15	-286	-294	17.18	32.0	.24	90	7.70
506	.150	82800	******	******	*******	******	******	******	******	*******	******	*******
507	10.000	75500	390.0	375.0	2.22	-293	-300	17.24	32.0	[illegible]	86	7.69
508	.030	81100	******	******	*******	******	******	******	******	*******	******	*******
509	10.000	75200	393.0	378.5	2.30	-292	-300	17.24	33.6	.20	87	7.68
510	.150	80000	******	******	*******	******	******	******	******	*******	******	*******
511	10.000	75000	391.0	375.5	2.40	-287	-297	17.98	33.4	.18	87	7.68
512	.150	63200	******	******	*******	******	******	******	******	*******	******	*******
513	10.000	76800	395.0	380.0	2.36	-294	-300	18.03	33.6	.18	83	7.72
514	.500	83200	******	******	*******	******	******	******	******	*******	******	*******
515	.130	76300	******	******	*******	******	******	******	******	*******	******	*******
516	.130	77600	******	******	*******	******	******	******	******	*******	******	*******
517	8.000	76200	398.5	371.5	2.50	-290	-299	19.10	31.7	.14	95	7.32
518	******	******	******	******	*******	******	******	******	******	*******	******	*******
519	.270	76200	******	******	*******	******	******	******	******	*******	******	*******
520	.200	71200	******	******	*******	******	******	******	******	*******	******	*******
521	.230	85600	******	******	*******	******	******	******	******	*******	******	*******
522	1.900	76400	365.0	360.0	3.00	-293	-304	20.97	25.8	.10	100	9.57
523	.450	71500	******	******	*******	******	******	******	******	*******	******	*******
524	.080	47500	******	******	*******	******	******	******	******	*******	******	*******

TABLE 13. (Continued)

TEST NO.	TIME MIN.	SPEED RPM	LOX SEAL U/S PR. CAVITY PSIG	U/S PR. SEAL PSIG	D/S PR. DRAIN PSIG	U/S TEMP CAVITY F	D/S TEMP DRAIN F	LEAKAGE SCFM	HELIUM SEAL U/S PR. PURGE PSIG	D/S PR. TURB SIDE DRAIN PSIG	U/S TEMP PURGE F	LEAKAGE TOTAL SCFM
525	3.250	79900	364.5	360.5	2.90	-297	-300	19.57	28.3	.10	101	9.70
526	3.187	77000	389.0	382.0	2.92	-285	-300	20.27	29.0	.06	101	9.70
527	3.300	77000	359.5	379.5	3.07	-290	-303	20.33	28.7	.06	99	9.57
528	3.150	74000	385.0	377.5	2.99	-289	-302	20.96	28.8	.04	100	9.59
529	.050	56900	******	******	******	******	******	******	******	******	******	******
530	3.200	75200	362.5	375.0	2.78	-287	-299	19.61	28.4	.04	100	9.57
531	.150	38700	******	******	******	******	******	******	******	******	******	******
532	.600	61500	******	******	******	******	******	******	******	******	******	******
533	.100	86000	******	******	******	******	******	******	******	******	******	******
534	.100	87900	******	******	******	******	******	******	******	******	******	******
535	3.200	77000	384.0	377.5	4.69	-287	-293	29.32	28.3	.12	100	9.64
536	.100	87500	******	******	******	******	******	******	******	******	******	******
537	.120	97800	******	******	******	******	******	******	******	******	******	******
538	3.150	75000	382.0	370.0	4.26	-296	-297	26.39	28.8	.12	103	9.60
539	3.250	78200	383.0	370.5	4.26	-292	-296	27.03	28.8	.10	100	9.64
540	3.150	77300	384.5	371.0	3.96	-294	-300	25.38	29.6	.12	99	9.66
541	.120	92700	******	******	******	******	******	******	******	******	******	******
542	3.150	76300	388.5	375.0	4.76	-293	-299	28.59	28.6	.10	99	9.63
543	3.150	77600	392.0	379.5	4.30	-290	-299	25.95	29.6	.08	100	9.66
544	.200	29500	******	******	******	******	******	******	******	******	******	******
545	3.200	77000	395.0	381.5	4.34	-286	-293	27.06	28.6	.08	99	9.63
546	3.200	76000	396.0	383.0	4.19	-286	-293	25.95	28.3	.06	100	9.66
547	1.370	76500	391.5	375.0	5.12	-293	-295	29.25	28.8	.02	97	9.37
548	.100	91000	******	******	******	******	******	******	******	******	******	******
549	3.150	76300	399.0	383.5	4.48	-292	-297	27.13	28.8	.04	99	9.35
550	3.150	77200	402.0	387.5	4.17	-289	-298	27.10	28.4	.02	100	9.39
551	3.150	77500	400.5	385.0	5.04	-287	-296	29.27	28.7	.04	98	9.39
552	.130	87100	******	******	******	******	******	******	******	******	******	******
553	3.250	76900	397.5	382.5	4.60	-285	-293	27.62	28.6	.02	99	9.37
554	3.130	77500	392.0	376.5	4.42	-285	-294	27.10	28.8	.02	99	9.36
555	.300	86000	******	******	******	******	******	******	******	******	******	******
556	2.650	77000	395.0	379.0	4.18	-285	-294	26.50	28.8	.02	100	9.36
557	6.130	76900	386.0	365.0	5.80	-293	-297	31.75	31.0	.02	93	10.01
558	.120	86600	******	******	******	******	******	******	******	******	******	******
559	.130	85000	******	******	******	******	******	******	******	******	******	******
560	.020	1000	******	******	******	******	******	******	******	******	******	******
561	.350	44900	******	******	******	******	******	******	******	******	******	******
562	.100	95300	******	******	******	******	******	******	******	******	******	******
563	.100	59400	******	******	******	******	******	******	******	******	******	******
564	.430	48500	******	******	******	******	******	******	******	******	******	******
565	.130	77100	******	******	******	******	******	******	******	******	******	******
566	.180	7800	******	******	******	******	******	******	******	******	******	******
567	.080	25200	******	******	******	******	******	******	******	******	******	******
568	2.300	71600	385.0	378.5	7.50	-277	-293	36.67	29.2	.01	90	13.08
569	.130	88500	******	******	******	******	******	******	******	******	******	******
570	.130	88300	******	******	******	******	******	******	******	******	******	******
571	3.120	76000	387.0	385.5	5.74	-285	-296	31.17	29.8	.62	96	14.13
572	1.650	73500	389.5	361.0	5.90	-285	-293	32.91	30.0	.84	96	13.84
573	******	******	******	******	******	******	******	******	******	******	******	******
574	.100	86000	******	******	******	******	******	******	******	******	******	******
575	1.800	72000	392.5	344.0	5.50	-294	-290	28.29	33.0	.92	96	14.80
576	.130	91400	******	******	******	******	******	******	******	******	******	******
577	.180	64900	******	******	******	******	******	******	******	******	******	******
578	2.580	75600	392.5	386.0	5.80	-289	-299	28.94	33.1	.76	92	14.96
579	.150	85700	******	******	******	******	******	******	******	******	******	******
580	1.500	77600	389.0	385.5	4.92	-287	-296	30.78	32.7	.84	96	14.96
581	.100	86000	******	******	******	******	******	******	******	******	******	******
582	.100	87000	******	******	******	******	******	******	******	******	******	******
583	1.350	74300	392.0	385.0	5.34	-285	-292	32.02	29.9	.66	95	13.52
584	3.300	76500	388.0	383.5	5.56	-268	-292	30.27	29.7	.90	95	13.52
585	.220	66000	******	******	******	******	******	******	******	******	******	******
586	.100	96400	******	******	******	******	******	******	******	******	******	******
587	1.300	74100	393.0	385.0	5.46	-288	-296	29.23	29.3	.84	91	13.59
588	.950	74600	392.5	365.5	6.00	-289	-299	30.22	29.7	.66	91	13.59
589	3.180	71900	393.0	387.5	5.46	-289	-299	30.27	29.2	.66	92	13.63
590	3.100	75000	396.5	350.5	5.16	-286	-297	27.76	29.1	.84	92	13.68
591	2.720	78500	386.5	391.5	4.79	-287	-296	25.13	29.0	.66	90	13.71
592	1.450	77000	390.0	383.0	6.18	-287	-296	32.21	30.0	.86	90	15.09
593	3.200	80200	391.0	384.0	5.37	-296	-296	29.34	30.6	.04	90	15.46
594	.220	92200	******	******	******	******	******	******	******	******	******	******

TABLE 13. (Continued)

TEST NO.	TIME MIN.	SPEED RPM	LOX SEAL U/S PR. CAVITY PSIG	U/S PR. SEAL PSIG	D/S PR. DRAIN PSIG	U/S TEMP CAVITY F	D/S TEMP DRAIN F	LEAKAGE SCFM	HELIUM SEAL U/S PR. PURGE PSIG	D/S PR. TURB SIDE DRAIN PSIG	U/S TEMP PURGE F	LEAKAGE TOTAL SCFM
595	3.100	75900	392.5	386.5	6.50	-285	-296	30.76	30.5	.60	91	15.49
596	2.300	71300	391.5	385.0	5.40	-285	-295	29.29	30.5	.82	91	15.56
597	2.535	76730	394.0	384.0	4.74	-282	-285	30.55	5.9	.70	90	5.08
598	6.100	77800	398.0	386.0	5.16	-286	-299	29.68	29.8	.70	87	14.45
599	.130	86800	******	******	*******	******	******	******	******	*******	******	*******
600	1.280	83800	392.0	384.0	5.00	-286	-296	29.13	29.7	.78	88	14.42
601	.130	87500	******	******	*******	******	******	******	******	*******	******	*******
602	4.980	79000	396.0	385.0	4.94	-285	-294	27.51	29.2	.72	90	14.43
603	3.200	76300	397.0	386.0	5.42	-283	-293	29.17	29.8	.76	90	14.43
604	6.100	74700	395.0	384.5	5.32	-281	-293	29.18	29.2	.66	89	14.47
605	.100	88700	******	******	*******	******	******	******	******	*******	******	*******
606	6.100	77800	395.0	384.5	5.76	-286	-299	30.78	30.0	.70	87	14.52
607	2.700	72800	394.0	383.0	5.39	-286	-297	29.23	29.2	.70	87	14.49
608	1.700	70300	395.5	385.0	5.46	-286	-296	30.13	29.3	.76	87	14.55
609	.130	93800	******	******	*******	******	******	******	******	*******	******	*******
610	2.630	70600	395.5	384.0	5.00	-285	-293	28.28	29.9	.64	87	14.55
611	.060	69800	******	******	*******	******	******	******	******	*******	******	*******
612	2.300	75300	395.5	382.0	5.74	-281	-292	29.95	30.0	.62	86	14.99
613	4.755	77700	399.0	384.0	5.88	-283	-289	31.03	30.2	.66	83	15.07
614	3.500	77100	399.5	385.0	5.32	-289	-297	29.19	30.2	.68	81	15.10
615	2.150	77700	399.5	384.0	5.60	-287	-296	30.60	30.6	.72	81	15.10
616	.150	91600	******	******	*******	******	******	******	******	*******	******	*******
617	.150	97000	******	******	*******	******	******	******	******	*******	******	*******
618	2.580	75500	396.5	381.5	5.98	-285	-293	30.52	30.7	.70	82	15.07
619	2.550	77100	396.0	382.0	6.34	-284	-293	32.43	30.7	.64	83	15.11
620	7.650	71200	396.5	381.5	5.96	-281	-293	29.12	30.1	.62	83	15.20
621	.100	95800	******	******	*******	******	******	******	******	*******	******	*******
622	3.430	72900	398.5	382.5	6.24	-277	-297	31.73	30.0	.74	80	16.27
623	.167	91000	******	******	*******	******	******	******	******	*******	******	*******
624	2.550	74900	399.5	379.0	5.62	-283	-293	30.87	30.2	.68	81	15.44
625	.150	66500	******	******	*******	******	******	******	******	*******	******	*******
626	10.100	72400	396.5	375.5	4.55	-287	-296	25.94	30.7	.60	76	15.56
627	6.500	72300	399.0	379.0	5.74	-285	-293	30.76	30.6	.62	75	15.57
628	7.630	70500	397.0	379.5	5.97	-283	-297	28.77	30.7	.62	76	15.51
629	7.930	73000	400.0	379.0	6.20	-293	-294	32.98	30.7	.90	72	15.47
630	.130	92000	******	******	*******	******	******	******	******	*******	******	*******
631	6.100	76300	397.5	377.5	6.14	-287	-287	30.89	30.2	.96	74	14.98
632	6.081	70300	395.5	377.5	6.62	-286	-286	34.26	30.7	1.02	72	15.06
633	.050	******	******	******	*******	******	******	******	******	*******	******	*******
634	3.100	74400	371.0	371.0	5.54	-286	-299	29.44	35.0	1.16	115	23.12
635	.100	76100	******	******	*******	******	******	******	******	*******	******	*******
636	.100	80600	******	******	*******	******	******	******	******	*******	******	*******
637	2.350	70500	349.5	347.5	5.42	-293	-299	29.03	30.0	1.44	112	21.59
638	.100	83000	******	******	*******	******	******	******	******	*******	******	*******
639	3.150	72100	373.5	370.0	5.69	-296	-303	29.53	31.3	1.22	110	22.22
640	3.183	73700	370.5	367.5	5.56	-292	-302	29.48	31.5	1.22	111	22.58
641	.100	81900	******	******	*******	******	******	******	******	*******	******	*******
642	3.330	71800	372.5	368.5	5.74	-289	-302	28.51	35.3	1.36	113	22.65
643	3.400	73500	381.5	377.5	5.68	-293	-303	29.67	31.0	1.28	109	21.62
644	3.200	73500	378.5	375.5	5.12	-292	-302	27.12	30.5	1.02	111	21.74
645	3.200	76600	376.0	372.5	5.14	-287	-300	27.30	30.7	1.14	111	20.97
646	.100	79700	******	******	*******	******	******	******	******	*******	******	*******
647	3.150	70230	383.0	379.0	4.95	-285	-300	29.33	31.8	1.10	110	20.90
648	.080	80500	******	******	*******	******	******	******	******	*******	******	*******
649	.100	79800	******	******	*******	******	******	******	******	*******	******	*******
650	3.150	75300	321.5	379.5	4.76	-293	-305	26.90	31.8	.94	107	21.02
651	3.132	75600	382.5	380.0	4.56	-293	-305	26.38	30.8	.92	107	21.07
652	3.100	74300	382.5	380.0	4.54	-290	-303	25.78	32.0	.84	107	21.11
653	3.100	75200	383.5	379.0	4.59	-299	-303	26.35	31.1	.94	108	21.11
654	.100	79800	******	******	*******	******	******	******	******	*******	******	*******
655	3.100	76300	381.5	377.5	5.28	-287	-300	27.84	31.2	.96	108	21.14
656	3.200	74300	383.5	379.0	4.79	-286	-300	26.87	32.2	.92	109	21.14
657	3.080	75300	385.5	382.5	5.20	-285	-300	27.55	31.0	.94	108	20.54
658	3.080	74600	385.5	380.0	5.00	-293	-304	27.62	31.1	.90	105	20.59
659	3.100	74700	385.5	379.0	5.00	-293	-307	27.12	31.1	.90	105	20.61
660	3.170	75200	385.0	379.0	5.60	-293	-303	26.22	31.3	.94	107	20.66
661	.100	57500	******	******	*******	******	******	******	******	*******	******	*******
662	3.080	74900	384.5	378.5	5.24	-293	-303	27.60	31.3	.94	107	20.69
663	3.080	75600	385.0	378.5	4.84	-293	-303	27.06	31.3	.90	106	20.73
664	3.080	75800	383.5	377.0	4.89	-293	-302	27.24	31.3	.90	107	20.71

TABLE 13. (Continued)

TEST NO.	TIME MIN.	SPEED RPM	LOX SEAL U/S PR. CAVITY PSIG	U/S PR. SEAL PSIG	D/S PR. DRAIN PSIG	U/S TEMP CAVITY F	D/S TEMP DRAIN F	LEAKAGE SCFM	HELIUM SEAL U/S PR. PURGE PSIG	D/S PR. TURB SIDE DRAIN PSIG	U/S TEMP PURGE F	LEAKAGE TOTAL SCFM
665	3.130	74900	383.5	376.5	4.90	-293	-300	27.36	31.3	.90	107	20.71
666	******	******	******	******	*******	******	******	******	******	*******	******	*******
667	.150	******	******	******	*******	******	******	******	******	*******	******	*******
668	.150	******	******	******	*******	******	******	******	******	*******	******	*******
669	.080	22600	******	******	*******	******	******	******	******	*******	******	*******
670	.130	82000	******	******	*******	******	******	******	******	*******	******	*******
671	.600	76500	346.5	340.0	3.59	-284	-299	21.11	30.1	.32	97	4.52
672	******	******	******	******	*******	******	******	******	******	*******	******	*******
673	3.150	76500	389.0	379.0	3.26	-286	-303	20.41	29.7	.42	95	4.32
674	3.150	76800	388.0	377.5	3.16	-285	-300	20.40	26.1	.49	95	4.98
675	.600	79000	386.5	377.5	2.73	-293	-302	17.43	29.9	.44	95	5.80
676	3.150	76920	396.0	389.0	3.28	-293	-303	19.87	30.3	.42	96	6.34
677	3.100	77000	396.0	386.0	3.19	-293	-300	16.31	31.3	.42	97	6.67
678	3.150	76900	398.0	385.5	3.34	-293	-298	19.15	29.9	.44	97	6.80
679	.070	19200	******	******	*******	******	******	******	******	*******	******	*******
680	8.880	77000	396.5	382.5	3.93	-284	-299	23.52	29.8	.50	86	5.57
681	10.100	75800	393.5	376.0	4.30	-287	-302	23.21	32.9	.56	82	6.34
682	10.100	77500	394.0	376.5	4.24	-285	-299	23.21	29.9	.56	82	6.37
683	10.200	77000	394.5	376.5	4.36	-287	-303	23.14	30.0	.56	79	6.80
684	10.100	77300	392.0	374.0	4.38	-287	-303	23.03	29.5	.58	80	7.20
685	10.100	77300	390.0	372.0	4.28	-285	-300	22.64	29.8	.58	81	7.23
686	10.100	77130	394.0	375.0	4.16	-287	-303	22.42	30.0	.58	78	7.31
687	3.100	77300	396.0	377.5	4.16	-289	-303	22.65	30.5	.58	78	7.35
688	3.100	76500	396.5	377.5	3.94	-285	-302	20.19	30.5	.46	78	7.39
689	3.100	75800	395.0	375.0	4.20	-284	-302	20.82	30.5	.46	78	7.42
690	3.100	75500	393.5	373.5	4.16	-283	-300	20.54	30.4	.46	78	7.50
691	3.100	74500	394.5	375.5	4.18	-285	-299	20.39	30.4	.48	78	7.53
692	3.150	78000	395.0	375.0	4.16	-280	-298	19.69	30.4	.48	78	7.50
693	3.100	76100	394.5	375.0	4.18	-287	-303	19.60	30.5	.50	75	7.59
694	3.100	76300	393.5	374.0	4.16	-290	-305	17.12	30.4	.50	75	7.67
695	3.100	76000	391.5	372.5	4.18	-290	-303	18.82	30.4	.54	75	7.67
696	3.100	76700	391.5	372.0	4.20	-289	-303	18.50	30.3	.54	75	7.72
697	3.150	77500	396.5	375.5	4.19	-286	-302	18.54	30.4	.56	75	7.69
698	3.100	76300	398.5	377.5	4.20	-285	-302	18.63	30.4	.54	75	7.72
699	.150	14000	******	******	*******	******	******	******	******	*******	******	*******
700	.050	13200	******	******	*******	******	******	******	******	*******	******	*******
701	3.150	78300	389.0	379.5	3.76	-283	[illegible]	27.54	28.5	.62	93	9.05
702	3.100	74700	388.5	379.5	3.70	-287	-306	27.30	29.8	.58	90	8.95
703	3.150	76600	387.0	379.5	3.74	-287	-307	27.04	30.4	.62	91	9.22
704	3.100	75000	389.0	380.0	3.74	-287	-306	27.22	30.5	.62	91	9.38
705	3.100	77200	388.0	380.5	3.76	-259	-302	27.01	32.9	.62	95	10.01
706	3.100	74900	390.0	381.0	3.76	-259	-302	27.02	32.8	.64	96	10.19
707	3.100	77200	398.5	380.0	3.66	-259	-302	26.43	29.6	.64	96	9.08
708	3.100	77300	389.0	382.0	3.76	-259	-307	27.23	29.3	.66	96	9.06
709	3.100	77000	388.5	381.0	3.78	-259	-307	27.29	28.9	.66	92	9.12
710	3.100	77300	389.0	382.0	3.82	-259	-307	27.39	28.9	.66	92	9.17
711	3.100	77700	389.0	383.0	3.76	-259	-307	26.93	20.7	.68	93	9.22
712	3.100	76700	386.5	381.0	3.78	-259	-306	27.37	28.5	.70	94	9.25
713	3.050	77500	388.5	382.0	3.80	-259	-302	27.12	28.4	.70	94	9.25
714	.100	88800	******	******	*******	******	******	******	******	*******	******	*******
715	.050	[illegible]	******	******	*******	******	******	******	******	*******	******	*******
716	.100	87100	******	******	*******	******	******	******	******	*******	******	*******
717	.050	68500	******	******	*******	******	******	******	******	*******	******	*******
718	.350	65000	******	******	*******	******	******	******	******	*******	******	*******
719	3.100	77000	394.0	385.5	3.16	-292	-308	24.25	29.8	.70	92	9.99
720	3.200	74000	395.0	365.5	3.46	-293	-307	25.62	30.4	.68	92	10.29
721	3.200	76800	394.5	387.0	3.30	-290	-307	24.94	30.4	.66	94	10.61
722	.200	73900	******	******	*******	******	******	******	******	*******	******	*******
723	3.100	76300	396.5	383.0	3.34	-287	-305	24.36	30.5	.66	95	10.91
724	3.100	75000	394.0	386.5	3.22	-285	-303	23.95	32.5	.68	95	11.25
725	3.100	79000	392.5	385.0	3.20	-285	-303	24.54	28.9	.66	95	10.32
726	3.100	78200	394.0	385.0	3.22	-285	-303	24.37	30.5	.68	96	10.97
727	3.100	78300	394.5	388.0	3.26	-285	-302	24.53	30.4	.66	97	11.17
728	3.100	78000	395.0	388.5	3.40	-290	-305	24.75	28.8	.64	93	10.80
729	3.100	78230	394.5	385.5	3.42	-292	-308	25.05	29.8	.66	93	11.00
730	3.100	78000	394.0	385.5	3.34	-290	-309	24.49	30.5	.68	93	11.25
731	3.100	77100	393.0	384.0	3.30	-289	-307	24.31	30.5	.68	94	11.39
732	3.050	72000	395.0	386.5	3.36	-287	-307	24.49	31.0	.66	94	11.55
733	3.100	78800	394.0	382.5	3.44	-286	-304	24.60	31.0	.76	95	11.77
734	3.100	76700	394.5	384.0	3.47	-286	-303	24.37	31.0	.76	95	12.01

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TABLE 13. (Concluded)

TEST NO.	TIME MIN.	SPEED RPM	LOX SEAL U/S PR. CAVITY PSIG	U/S PR. SEAL PSIG	D/S PR. DRAIN PSIG	U/S TEMP CAVITY F	D/S TEMP DRAIN F	LEAKAGE SCFM	HELIUM SEAL U/S PR. PURGE PSIG	D/S PR. TURB SIDE DRAIN PSIG	U/S TEMP PURGE F	LEAKAGE TOTAL SCFM
735	3.100	76000	395.0	384.5	3.42	-295	-303	23.74	31.3	.74	95	12.12
736	1.650	75000	395.0	385.0	3.20	-285	-302	21.83	30.2	.68	95	11.03
737	3.250	76300	395.0	386.0	3.42	-292	-309	22.74	29.8	.70	92	11.35
738	3.100	75100	394.0	382.5	3.40	-290	-308	22.39	29.5	.68	92	11.46
739	3.050	76700	394.0	384.0	3.42	-290	-309	22.47	29.9	.68	93	11.64
740	3.100	77200	394.5	384.0	3.50	-286	-307	22.92	30.9	.66	93	11.74
741	3.100	76000	395.0	385.0	3.56	-286	-307	22.54	31.0	.66	93	11.76
742	3.250	76000	394.0	383.0	3.54	-295	-304	22.27	30.3	.70	93	11.89
743	3.100	75700	395.0	382.5	3.59	-285	-303	22.65	30.5	.70	94	11.83
744	2.200	76800	395.0	382.5	3.46	-285	-302	22.35	30.5	.70	94	11.83
745	.100	1300	******	******	*******	******	******	******	******	*******	******	*******
746	.600	77300	392.5	382.5	3.50	-293	-310	21.02	30.9	.70	91	11.96
747	3.100	67500	398.0	386.5	3.60	-292	-310	20.98	30.4	.64	90	11.80
748	3.200	76500	395.0	384.0	3.72	-290	-308	21.55	30.9	.74	90	11.89
749	1.700	62000	396.5	385.5	3.56	-289	-307	20.29	30.5	.56	90	11.80

TABLE 14. DATA SUMMARY
(SI UNITS)

TEST NO.	TIME SEC.	SPEED RPS	LOX SEAL U/S PR. CAVITY KN/SQ M	LOX SEAL U/S PR. SEAL MN/SQ M	LOX SEAL D/S PR. DRAIN MN/SQ M	LOX SEAL U/S TEMP CAVITY K	LOX SEAL D/S TEMP DRAIN K	LOX SEAL LEAKAGE SCMS	HELIUM SEAL U/S PR. PURGE KN/SQ M	HELIUM SEAL D/S PR. TURB SIDE DRAIN KN/S	HELIUM SEAL U/S TEMP PURGE K	HELIUM SEAL LEAKAGE TOTAL SCMS
35	6	*****	465	441	34	275	279	.00312	291	0	296	.00245
36	17	567	465	450	29	276	264	.00012	210	10	294	.00217
37	2	540	472	436	27	271	265	.00009	210	10	294	.00222
38	3	537	465	433	29	266	252	.00011	210	10	294	.00222
39	4	533	469	430	29	262	262	.00011	209	9	294	.00222
40	384	422	459	427	48	236	255	.00024	207	6	294	.00227
41	5	617	1048	987	98	291	256	.00033	217	10	293	.00189
42	5	627	1045	937	105	290	256	.00037	217	11	293	.00184
43	15	800	1045	985	112	290	255	.00045	221	15	293	.00175
44	10	1187	1045	985	>138	289	256	*******	214	26	293	.00137
45	9	1198	1051	937	>138	289	256	*******	214	23	293	.00127
46	6	250	1007	971	26	301	269	.00008	214	3	305	.00227
47	7	450	1034	987	30	301	271	.00011	208	7	305	.00217
48	13	601	1034	987	30	301	273	.00014	205	10	305	.00193
49	18	1467	1086	987	75	299	270	.00748	218	34	304	.00184
50	15	1453	1059	955	>138	301	273	*******	216	34	304	.00127
51	15	1442	1038	959	108	302	273	.00377	207	34	305	.00142
52	18	1533	1103	993	20	307	264	.00310	209	37	304	.00208
53	126	1312	1038	979	8	303	260	.00132	211	28	305	.00231
54	414	1490	1079	993	16	303	286	.00152	193	37	304	.00217
55	56	1405	1048	1048	5	299	*****	*******	209	50	304	*******
56	25	1518	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
57	39	1520	1124	1082	22	299	*****	*******	208	69	309	*******
58	122	1483	1103	1082	13	[illegible]	*****	*******	205	63	304	*******
59	40	1423	1062	1048	9	304	*****	.00265	202	53	305	.00185
60	57	1433	1055	1055	9	300	*****	.00260	219	55	306	.00185
61	378	1478	1124	1103	11	304	*****	.00281	214	62	308	.00186
62	14	1525	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
63	19	1523	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
64	20	1522	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
65	28	1523	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
66	129	1510	1400	1372	18	297	291	.00339	221	63	305	.00180
67	378	1500	1420	1379	17	296	301	.00333	219	62	306	.00179
68	384	1502	1744	1710	21	296	301	.00370	200	62	305	.00161
69	384	1500	2068	2034	23	*****	*****	.00384	207	62	*****	.00172
70	384	1503	2132	2048	23	*****	*****	.00389	207	63	*****	.00172
71	384	1502	2103	2062	24	*****	*****	.00395	208	64	*****	.00171
72	384	1493	2096	2049	22	*****	*****	.00383	214	60	*****	.00180
73	384	1498	2117	2068	31	*****	*****	.00446	215	61	*****	.00178
74	39	1496	2034	1986	>138	297	297	.00679	217	60	305	.00181
75	30	1470	2034	1966	>138	296	297	.00669	208	55	309	.00219
76	378	1497	2068	2026	88	295	*****	.00454	221	51	303	.00144
77	372	1517	2075	2013	59	294	*****	.00348	219	63	304	.00158
78	10	237	1034	1089	4	304	223	.00500	252	4	316	.00160
79	10	330	1034	1096	4	303	225	.00496	203	7	316	.00160
80	13	567	1289	1344	8	303	230	.00491	203	10	316	.00184
81	23	812	1069	1124	5	303	230	.00486	204	18	316	.00160
82	240	1515	1138	1158	6	305	256	.00425	204	64	316	.00170
83	45	1380	1027	1069	4	305	264	.00425	207	49	317	.00156
84	10	867	1000	1055	4	305	270	.00491	197	36	318	.00156
85	48	1450	1041	1082	4	306	271	.00444	207	57	319	.00160
86	198	1507	1138	1172	6	304	278	.00326	203	69	318	.00170
87	252	1502	1110	1145	6	306	290	.00316	200	64	317	.00165
88	372	1497	1131	1165	6	306	294	.00316	200	69	318	.00165
89	3	*****	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
90	361	1498	1138	1158	4	309	258	.00104	203	66	311	.00179
91	96	1513	1103	1103	5	306	255	.00113	205	66	311	.00184
92	327	1478	1082	1110	3	309	258	.00109	208	69	311	.00160
93	2	*****	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
94	6	*****	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
95	9	*****	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
96	30	1342	1048	1062	6	301	251	.00099	209	15	303	.00080
97	361	1300	1055	1076	4	295	272	.00104	205	17	301	.00236
98	2	*****	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
99	3	*****	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
100	226	1340	1400	1365	9	293	269	.00160	206	18	301	.00245
101	180	1317	1393	1372	9	293	280	.00142	207	17	303	.00250
102	59	1215	1724	1717	12	289	268	.00179	203	14	301	.00260
103	360	1295	1744	1731	12	289	280	.00179	200	17	301	.00255
104	360	1293	2062	2055	16	289	284	.00203	205	18	302	.00255

TABLE 14. (Continued)

TEST NO.	TIME SEC.	SPEED RPS	LOX SEAL U/S PR. CAVITY KNT/SQ M	U/S PR. SEAL MKNT/SQ M	D/S PR. DRAIN MKNT/SQ M	U/S TEMP CAVITY K	D/S TEMP DRAIN K	LEAKAGE SCMS	HELIUM SEAL U/S PR. PURGE KNT/SQ M	D/S PR. TURB SIDE DRAIN KNT/SQ M	U/S TEMP PURGE K	LEAKAGE TOTAL SCMS
105	360	1288	2103	2068	14	289	285	.00259	200	18	303	.00260
106	360	1292	2103	2066	14	289	286	.00208	201	18	303	.00264
107	51	1192	2089	2058	17	294	258	.00222	216	17	301	.00297
108	361	1293	2103	2055	15	289	282	.00217	230	20	300	.00307
109	363	1312	2103	2062	17	286	282	.00231	221	20	299	.00302
110	363	1283	2137	2075	17	286	282	.00231	222	20	299	.00297
111	361	1290	2034	1889	14	286	283	.00208	238	20	300	.00311
112	15	537	1462	1324	43	100	94	.00307	199	46	303	.00179
113	24	1192	1717	1593	95	*****	100	.00765	209	15	301	.00137
114	15	372	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
115	15	945	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
116	11	1170	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
117	45	383	979	834	2	107	143	.00278	212	3	301	.00132
118	30	1145	1427	1186	34	105	137	.00444	213	13	301	.00123
119	26	485	448	379	6	114	147	.00142	205	4	300	.00123
120	26	1070	655	607	6	114	151	.00175	207	13	300	.00094
121	13	425	972	796	19	105	151	.00307	200	4	299	.00142
122	3	478	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
123	22	1075	634	586	10	114	155	.00222	213	13	299	.00123
124	87	1078	676	621	1	140	171	.00160	203	14	299	.00113
125	13	957	517	303	4	113	181	.00189	205	11	297	.00156
126	47	475	986	827	12	107	178	.00236	210	4	297	.00142
127	15	987	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
128	103	1125	1338	648	15	100	171	.00297	210	14	295	.00151
129	182	722	503	427	6	107	191	.00151	171	7	293	.00179
130	67	1108	807	910	10	104	178	.00203	246	14	294	.00184
131	43	1107	772	696	8	108	185	.00203	230	16	294	.00175
132	103	1097	834	758	1	146	201	.00066	207	15	294	.00160
133	125	683	476	421	4	113	193	.00109	212	7	294	.00179
134	15	1127	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
135	32	1120	1165	920	14	107	191	.00245	204	16	294	.00184
136	17	1128	758	703	10	107	186	.00227	202	16	294	.00193
137	29	1108	717	641	10	114	186	.00217	212	16	294	.00208
138	131	1092	827	745	9	104	189	.00193	208	15	291	.00231
139	40	1127	827	731	35	103	163	.00415	219	16	291	.00255
140	11	1135	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
141	110	1115	869	786	13	104	180	.00205	207	17	291	.00245
142	43	1112	827	772	10	108	185	.00203	203	17	291	.00255
143	90	1092	814	738	10	111	189	.00217	201	17	292	.00260
144	86	523	889	738	11	111	188	.00217	214	6	293	.00283
145	148	497	876	717	7	105	191	.00142	209	6	290	.00278
146	64	517	731	662	8	132	175	.00175	212	6	291	.00293
147	53	530	745	669	10	136	178	.00170	207	7	291	.00293
148	302	993	1076	993	3	161	199	.00076	207	12	291	.00283
149	326	970	924	641	3	155	215	.00085	210	10	293	.00302
150	22	1265	1262	1158	31	*****	171	.00368	210	26	291	.00326
151	6	1385	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
152	9	1352	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
153	96	1342	1179	1076	4	125	199	.00085	211	28	293	.00316
154	91	1340	1172	1062	4	162	214	.00071	205	28	293	.00307
155	144	1383	1172	1103	2	188	228	.00076	205	30	294	.00307
156	9	1407	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
157	249	1303	1289	1136	3	157	233	[illegible]	208	32	293	.00316
158	7	1470	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
159	344	1267	1089	993	1	224	246	.00066	209	25	291	.00321
160	4	1478	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
161	4	1477	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
162	5	1417	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
163	63	1367	1586	1475	8	124	222	.00165	219	30	291	.00368
164	43	493	1131	951	8	174	210	.00170	200	8	291	.00354
165	29	517	1172	986	18	102	199	.00236	202	9	291	.00363
166	13	482	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
167	96	1472	1517	1527	31	101	169	.00368	198	32	291	.00354
168	14	1402	1751	1620	35	103	178	.00392	215	34	291	.00396
169	17	1405	1758	1627	32	103	177	.00363	214	34	291	.00392
170	27	1400	1751	1620	29	103	179	.00340	210	34	291	.00392
171	54	1397	1731	1636	25	103	180	.00311	207	33	291	.00382
172	141	1425	2537	1910	24	103	174	.00302	210	35	292	.00396
173	154	1397	2013	1975	29	104	179	.00333	210	33	292	.00396
174	50	1395	1993	1855	30	104	176	.00349	211	33	292	.00396

TABLE 14. (Continued)

TEST NO.	TIME SEC.	SPEED RPS	LOX SEAL U/S PR. CAVITY KN/SQ M	LOX SEAL U/S PR. SEAL KN/SQ M	LOX SEAL D/S PR. DRAIN KN/SQ M	LOX SEAL U/S TEMP CAVITY K	LOX SEAL D/S TEMP DRAIN K	LOX SEAL LEAKAGE SCMS	HELIUM SEAL U/S PR. PURGE KN/SQ M	HELIUM SEAL D/S PR. TURB SIDE KN/SQ M	HELIUM SEAL U/S TEMP PURGE K	HELIUM SEAL LEAKAGE TOTAL SCMS
175	111	1393	2034	1889	29	104	183	.00330	200	33	292	.00382
176	22	1396	1999	1868	31	104	178	.00359	200	33	292	.00392
177	35	1392	1965	1834	31	109	178	.00354	206	33	292	.00396
178	64	1402	2117	1972	30	104	179	.00340	210	34	292	.00396
179	71	1393	1965	1813	37	101	157	.00415	219	32	290	.00297
180	92	1333	2848	2537	33	103	172	.00387	207	19	290	.00293
181	87	1242	3172	2765	30	103	165	.00368	207	23	291	.00293
182	28	1407	2241	2089	41	103	165	.00439	209	34	291	.00293
183	71	1408	2075	1931	29	104	169	.00363	204	34	291	.00288
184	24	1408	2089	1944	30	104	174	.00363	214	34	291	.00302
185	48	1407	2110	1955	30	104	174	.00373	209	34	291	.00293
186	169	1402	2068	1965	30	104	178	.00359	214	33	291	.00297
187	9	322	1169	1055	46	104	93	.00854	204	6	306	.00189
188	6	360	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
189	6	293	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
190	5	400	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
191	11	642	1627	1224	48	105	89	.00934	221	12	305	.00198
192	12	696	1803	1341	52	106	90	.01052	221	15	304	.00198
193	16	800	2137	1586	65	100	93	.01241	228	18	304	.00142
194	18	663	2275	1717	62	102	93	.01241	230	20	304	.00123
195	15	883	2296	1776	48	104	94	.01104	230	21	304	.00132
196	4	1275	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
197	12	1362	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
198	15	857	2206	1624	63	104	94	.01255	219	21	304	.00227
199	53	1257	2286	1999	21	100	123	.00614	243	29	304	.00065
200	163	1262	2448	2068	19	97	141	.00571	248	33	303	.00236
201	54	1295	2275	2234	18	99	130	.00566	232	34	305	.00245
202	174	1303	2248	1999	19	99	161	.00585	207	39	305	.00330
203	10	218	1627	1233	44	108	89	.01103	212	12	300	.00576
204	9	405	1727	1227	57	100	89	.01043	210	33	300	.00594
205	10	507	1796	1255	44	99	84	.01359	214	48	300	.00576
206	42	1280	2551	1260	39	91	119	.01209	242	>138	300	.00576
207	81	1262	2613	1136	32	93	135	.00949	213	>138	300	.00561
208	13	1277	2630	1288	117	93	90	.02784	209	14	303	.00670
209	13	1367	2630	1269	125	93	89	.02964	216	14	303	.00657
210	18	1325	2530	1269	125	94	95	.03011	219	13	304	.00639
211	187	1240	2586	1269	43	90	144	.00906	207	12	304	.00657
212	69	1292	2556	1271	45	95	138	.01038	204	13	305	.00660
213	15	687	2137	1332	103	91	89	.02553	207	10	305	.00583
214	9	652	2095	1324	102	91	89	.02506	205	10	305	.00586
215	13	1143	2669	1360	138	91	90	.02181	208	14	305	.00676
216	17	1243	2679	1360	138	91	90	.03223	214	12	306	.00702
217	20	1323	2682	1420	103	91	91	.03710	221	13	305	.00711
218	69	1250	2682	1415	39	91	178	.00949	226	13	305	.00716
219	19	1057	2630	1439	99	91	89	.03488	217	11	306	.00669
220	15	1017	2654	1412	103	91	89	.03752	218	10	305	.00657
221	15	1328	2913	1429	48	106	89	.01421	214	9	309	.00723
222	14	1500	1017	1429	26	118	83	.01005	207	12	304	.00458
223	11	1343	2723	1431	54	119	83	.02015	207	8	304	.00742
224	14	1243	2758	1431	39	113	91	.01576	205	6	303	.00723
225	13	1503	*******	1431	15	99	97	.00463	140	10	303	.00256
226	184	1255	2576	1434	25	100	141	.02934	209	9	303	.00731
227	189	1267	2510	1434	25	151	149	.02961	209	9	303	.00708
228	*****	*****	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
229	13	1440	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
230	17	778	2689	1793	62	106	54	.01519	217	73	313	.00696
231	191	1282	2644	2241	52	150	146	.01137	220	40	311	.00692
232	13	1293	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
233	13	1288	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
234	13	1397	*******	2389	170	*****	90	.01061	214	11	312	.00681
235	14	1363	*******	1475	62	133	100	.01055	225	37	313	.00684
236	185	1243	2589	2130	79	96	144	.01245	214	12	312	.00686
237	189	1270	2603	2151	79	107	150	.01292	214	41	311	.00692
238	185	1242	2575	1941	98	100	133	.01827	216	41	312	.00690
239	186	1292	2565	2017	97	100	139	.01567	211	41	311	.00697
240	13	1407	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
241	189	1268	2551	1955	104	94	125	.01845	216	14	313	.00708
242	189	1295	2533	1896	105	97	126	.01967	216	15	313	.00693
243	189	1295	2517	1951	104	97	125	.01881	216	15	312	.00710
244	195	1283	2517	1965	96	97	129	.01730	216	15	312	.00710

TABLE 14. (Continued)

TEST NO.	TIME SEC.	SPEED RPS	LOX SEAL U/S PR. CAVITY KN/SQ M	U/S PR. SEAL KN/SQ M	D/S PR. DRAIN KN/SQ M	U/S TEMP CAVITY K	D/S TEMP DRAIN K	LEAKAGE SCMS	HELIUM SEAL U/S PR. PURGE KN/SQ M	D/S PR. TURB SIDE DRAIN KN/S	U/S TEMP PURGE K	LEAKAGE TOTAL SCMS
245	219	1293	2523	2033	93	97	131	.01753	216	15	312	.00712
246	21	1327	*******	1944	91	100	122	.01703	219	14	312	.00712
247	186	1297	2551	2044	85	111	138	.01561	214	14	312	.00714
248	186	1303	2541	2058	83	97	135	.01545	215	14	310	.00717
249	186	1288	2537	2041	80	95	135	.01521	214	14	309	.00719
250	189	1285	2534	2037	78	94	135	.01497	214	14	309	.00719
251	186	1260	2534	1982	83	97	130	.01728	214	14	309	.00717
252	189	1275	2482	1868	92	97	126	.01826	214	15	311	.00709
253	189	1275	2506	1958	81	97	135	.01519	212	14	309	.00716
254	185	1263	2475	1865	86	100	125	.01843	215	14	309	.00714
255	27	1342	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
256	12	1367	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
257	183	1250	2465	1858	78	94	125	.01767	216	13	305	.00722
258	11	1350	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
259	11	1343	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
260	16	1352	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
261	185	1288	2654	1903	103	99	114	.02130	223	15	304	.00695
262	185	1297	2692	1941	99	101	113	.02101	222	15	304	.00692
263	185	1298	2648	1975	83	94	119	.01865	216	15	303	.00709
264	184	1275	2648	1937	87	96	116	.01861	205	14	303	.00708
265	187	1298	2658	1931	97	97	111	.02101	221	15	304	.00708
266	184	1270	2630	1944	85	99	116	.01901	216	14	304	.00699
267	184	1280	2672	1948	85	99	117	.01879	218	14	305	.00707
268	185	1280	2648	1906	96	100	110	.02131	224	15	305	.00708
269	184	1272	2654	1900	94	101	111	.02114	225	14	305	.00682
270	183	1305	2682	2093	62	97	124	.01652	224	15	305	.00782
271	186	1280	2689	2103	55	98	131	.01590	224	15	305	.00783
272	185	1293	2646	2106	54	98	125	.01593	225	15	306	.00778
273	185	1262	2674	2010	66	100	114	.01974	230	15	306	.00775
274	183	1276	2672	2034	61	90	115	.01920	229	16	305	.00777
275	185	1263	2637	1999	71	97	102	.02029	233	16	304	.00777
276	183	1263	2637	1989	72	96	101	.02082	233	16	305	.00775
277	185	1266	2654	1979	84	97	96	.02286	238	16	305	.00783
278	185	1285	2648	2058	56	97	116	.01775	232	15	305	.00799
279	185	1298	2630	2065	57	98	116	.01937	230	16	305	.00780
280	183	1267	2634	1900	95	99	96	.02604	238	15	305	.00763
281	183	1277	2548	1958	68	99	105	.02101	230	15	305	.00770
282	185	1280	2610	2031	57	96	116	.01827	223	15	304	.00774
283	183	1283	2620	2037	53	97	116	.01768	225	15	304	.00774
284	185	1275	2589	1955	72	97	100	.02151	231	16	305	.00772
285	183	1283	2630	1975	65	96	120	.01936	227	15	305	.00718
286	185	1295	2637	2062	54	98	125	.01680	225	16	306	.00718
287	185	1280	2620	2020	53	98	125	.01659	226	16	306	.00719
288	183	1300	2654	2086	52	99	125	.01638	228	16	306	.00720
289	183	1265	2623	2027	56	100	122	.01759	229	15	306	.00721
290	183	1260	2620	1965	74	96	120	.02097	234	17	304	.00717
291	183	1263	2599	1934	80	97	93	.02268	236	17	304	.00717
292	183	1300	2630	2036	70	97	110	.02066	232	17	304	.00722
293	201	1282	2596	1962	71	97	105	.02118	234	17	305	.00720
294	186	1302	2596	1999	65	98	115	.02009	232	17	305	.00724
295	186	1302	2575	2037	59	98	122	.02261	232	16	305	.00727
296	183	1253	2620	1959	79	100	97	.02233	240	16	306	.00718
297	183	1265	2575	1934	78	99	107	.02233	238	17	306	.00723
298	185	1293	2610	2017	59	96	114	.01957	233	16	304	.00732
299	83	1272	2592	1982	65	96	114	.02031	232	16	304	.00729
300	174	1288	2551	[illegible]	50	96	122	.01723	231	15	304	.00733
301	186	1283	2555	1993	50	96	120	.01723	231	15	304	.00732
302	195	1288	2613	2065	54	96	120	.01926	221	16	303	.00724
303	183	1268	2586	1937	75	98	94	.02302	230	17	304	.00692
304	183	1280	2626	1986	65	98	108	.02106	223	17	304	.00697
305	183	1282	2586	2010	61	99	114	.02251	222	16	304	.00698
306	185	1280	2530	1972	52	90	112	.01886	221	16	304	.00699
307	9	597	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
308	185	1292	2562	2062	55	97	122	.01846	245	15	303	.00766
309	183	1285	2572	2072	64	98	123	.01770	256	15	303	.00818
310	183	1280	2565	1993	61	98	103	.02196	226	16	303	.00689
311	186	1293	2586	2068	46	99	119	.01885	219	16	303	.00694
312	183	1297	2626	2096	41	100	122	.01807	216	17	304	.00693
313	183	1282	2579	1975	81	100	116	.02279	227	19	334	.00683
314	185	1283	2591	1913	95	96	91	.02435	229	19	331	.00689

TABLE 14. (Continued)

TEST NO.	TIME SEC.	SPEED RPS	LOX SEAL U/S PR. CAVITY KN/SQ M	U/S PR. SEAL KN/SQ M	D/S PR. DRAIN KN/SQ M	U/S TEMP CAVITY K	D/S TEMP DRAIN K	LEAKAGE SCMS	HELIUM SEAL U/S PR. PURGE KN/SQ M	T/S PR. TURB SIDE DRAIN KN/SQ M	U/S TEMP PURGE K	LEAKAGE TOTAL SCMS
315	197	1288	2513	1917	97	96	93	.02550	231	19	301	.00682
316	183	1293	2517	1955	90	97	93	.02579	229	19	301	.00681
317	185	1303	2544	1958	85	98	95	.02521	228	19	302	.00682
318	185	1293	2548	2013	60	98	106	.02075	219	18	302	.00693
319	18	1245	2499	2620	11	101	89	.00946	208	8	303	.00701
320	12	933	2555	2551	18	102	89	.01062	208	4	303	.00703
321	23	1330	2586	2472	51	101	113	.01554	212	17	303	.00711
322	17	1112	2551	2569	15	101	131	.01001	212	5	303	.00713
323	66	1305	2579	2152	31	99	125	.01419	224	17	301	.00715
324	184	1283	2517	1941	91	100	96	.02470	243	18	300	.00727
325	185	1298	2517	2006	73	103	105	.02113	239	17	300	.00732
326	183	1293	2551	1996	77	97	93	.02253	240	17	298	.00733
327	185	1295	2551	1979	83	97	91	.02401	241	17	298	.00731
328	64	1278	2551	1975	79	98	93	.02332	241	17	298	.00731
329	6	1180	2841	2603	78	101	91	.02313	227	16	299	.00742
330	6	172	1813	2232	85	100	93	.02003	227	*******	299	.00749
331	9	1392	2689	2199	141	198	96	.03723	273	29	296	.00652
332	5	*****	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
333	*****	>1667	2696	2741	19	114	211	*******	218	5	306	*******
334	8	>1667	2675	2558	11	113	246	*******	234	4	304	*******
335	5	>1667	2741	2951	13	104	227	*******	219	2	303	*******
336	5	>1667	2830	2599	14	108	221	*******	236	3	303	*******
337	6	>1667	2775	2827	12	114	223	*******	190	2	304	*******
338	5	>1667	2820	2948	18	108	226	*******	188	2	304	*******
339	5	1533	2833	2937	19	106	212	*******	194	1	304	*******
340	8	938	2868	2375	20	101	183	*******	210	1	301	*******
341	6	1533	2854	3030	22	105	200	*******	220	1	304	*******
342	10	913	2651	2372	22	106	168	*******	228	1	303	*******
343	191	1247	2630	2358	38	98	89	.01477	206	2	301	.00435
344	6	1547	3027	2099	16	113	200	.00606	200	2	305	.00414
345	161	1292	2696	2433	36	99	91	.01450	208	2	305	.00432
346	5	1625	2916	2775	18	110	208	.00753	195	2	305	.00417
347	5	1505	2889	2996	23	108	199	.00976	205	2	306	.00436
348	17	1095	2913	2433	33	100	156	.01116	218	2	306	.00448
349	6	1472	2958	3079	21	120	185	.00810	228	2	304	.00488
350	185	1277	2665	2358	38	96	89	.01505	224	2	303	.00493
351	7	>1667	2899	2933	11	109	223	.00207	203	2	304	.00458
352	7	>1667	2923	2935	18	110	236	.00490	193	2	303	.00426
353	7	>1667	2889	3116	19	113	214	.00693	210	1	304	.00471
354	12	1295	2927	2441	35	101	169	.01296	223	1	304	.00493
355	27	1315	2644	2406	36	98	91	.01377	210	2	304	.00477
356	196	1247	2696	2417	34	97	91	.01392	214	2	304	.00490
357	183	1257	2737	2417	34	95	86	.01411	246	2	301	.00513
358	185	1253	2741	2513	33	95	89	.01360	219	1	301	.00530
359	186	1253	2741	2513	33	97	88	.01356	219	2	302	.00531
360	199	1272	2706	2482	34	99	91	.01417	214	2	304	.00530
361	188	1247	2696	2475	34	96	89	.01416	212	2	301	.00536
362	189	1265	2689	2453	31	96	86	.01334	214	1	302	.00533
363	191	1255	2696	2472	31	96	88	.01352	212	1	302	.00534
364	186	1258	2689	2461	33	97	89	.01381	212	2	303	.00535
365	173	1262	2682	2458	33	97	89	.01315	212	2	303	.00536
366	189	1256	2706	2458	31	98	89	.01329	219	2	303	.00537
367	189	1267	2696	2455	32	99	90	.01333	214	1	303	.00538
368	189	1263	2679	2455	32	100	91	.01351	208	1	303	.00539
369	189	1262	2682	2455	32	96	95	.01346	209	1	301	.00542
370	189	1262	2717	2482	34	96	89	.01386	210	1	302	.00543
371	189	1263	2696	2482	34	97	89	.01277	208	2	302	.00543
372	189	1265	2696	2479	33	98	93	.01366	228	2	302	.00544
373	189	1255	2692	2482	32	99	90	.01359	208	2	303	.00543
374	189	1263	2696	2479	31	100	91	.01328	208	2	303	.00545
375	189	1265	2699	2482	32	96	86	.01365	207	1	300	.00551
376	189	1267	2723	2482	33	96	86	.01413	207	0	301	.00543
377	188	1270	2706	2472	32	96	89	.01343	208	3	301	.00550
378	9	1667	2937	2572	25	184	235	.00766	215	3	297	.00568
379	8	1355	2506	2872	21	125	200	.00721	215	2	297	.00567
380	191	1228	2723	2489	26	98	89	.01324	213	3	297	.00569
381	185	1263	2648	2420	35	100	9[illegible]	.01405	212	3	298	.00568
382	20	1010	2672	2136	15	108	156	.00673	212	2	298	.00569
383	6	1330	2361	2047	19	1.8	171	.00748	214	3	298	.00569
384	183	1250	2637	2413	35	101	91	.01354	207	3	299	.00570

TABLE 14. (Continued)

TEST NO.	TIME SEC.	SPEED RPS	LOX SEAL U/S PR. CAVITY KN/SQ M	U/S PR. SEAL KN/SQ M	D/S PR. DRAIN KN/SQ M	U/S TEMP CAVITY K	D/S TEMP DRAIN K	LEAKAGE SCMS	HELIUM SEAL U/S PR. PURGE KN/SQ M	D/S PR. TURB SIDE DRAIN KN/SQ M	U/S TEMP PURGE K	LEAKAGE TOTAL SCMS
385	189	1252	2654	2441	34	98	88	.01289	210	3	298	.00572
386	192	1257	2713	2426	37	98	89	.01298	230	3	298	.00616
387	14	962	2836	3058	16	105	156	.00702	245	2	299	.00540
388	10	1358	2779	3026	22	105	165	.00824	218	3	299	.00658
389	189	1257	2665	2465	33	99	89	.01287	225	3	299	.00608
390	188	1257	2682	2482	35	99	89	.01350	225	3	299	.00608
391	189	1262	2682	2486	37	100	91	.01425	224	3	300	.00607
392	189	1263	2741	2544	36	100	91	.01384	224	3	300	.00609
393	39	1270	2344	2148	36	100	151	.01279	217	4	301	.00573
394	192	1243	2665	2475	40	100	91	.01436	232	4	303	.00623
395	189	1240	2692	2490	38	100	91	.01412	219	4	303	.00596
396	189	1275	2627	2420	35	99	89	.01340	216	4	302	.00596
397	30	1250	2627	2424	39	104	132	.00761	216	4	301	.00595
398	48	1277	2644	2355	36	96	89	.01359	219	4	301	.00595
399	187	1247	2654	2455	36	97	89	.01369	215	4	303	.00600
400	192	1250	2644	2441	39	97	89	.01474	215	4	303	.00601
401	192	1270	2682	2468	38	98	89	.01446	215	4	303	.00601
402	189	1278	2651	2441	38	99	90	.01427	215	4	303	.00601
403	32	1268	2696	2496	37	130	91	.01108	216	4	303	.00598
404	9	1613	2779	2555	20	151	198	.00624	217	4	304	.00596
405	188	1260	2627	2437	38	97	89	.01429	215	4	302	.00603
406	194	1237	2654	2455	34	96	88	.01315	214	4	302	.00605
407	192	1226	2689	2489	38	97	89	.01443	214	4	303	.00606
408	189	1232	2641	2448	36	98	89	.01342	218	4	304	.00607
409	184	1242	2692	2486	39	97	89	.01475	215	4	303	.00609
410	189	1283	2692	2482	37	98	89	.01387	214	4	303	.00611
411	192	1268	2665	2465	37	98	89	.01391	212	4	303	.00612
412	189	1273	2654	2451	38	99	89	.01443	215	4	303	.00612
413	6	1545	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
414	5	1647	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
415	5	1663	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
416	5	1662	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
417	6	1622	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
418	5	1620	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
419	5	1645	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
420	5	1637	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
421	22	1167	2351	2310	9	93	121	.00468	185	2	3_4	.00580
422	6	1636	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
423	5	1285	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
424	5	1252	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
425	20	1252	2541	2409	9	98	131	.00413	182	2	306	.00551
426	9	150[illegible]	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
427	6	1570	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
428	5	1425	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
429	5	1545	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
430	15	710	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
431	6	1485	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
432	6	1545	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
433	2	450	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
434	39	1253	2586	2541	20	97	93	.00869	195	1	306	.00555
435	6	1528	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
436	6	1563	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
437	8	1587	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
438	93	1273	2596	2558	22	96	93	.00767	195	1	305	.00572
439	6	1577	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
440	6	1587	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
441	6	1633	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
442	6	1595	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
443	6	1520	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
444	6	1637	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
445	5	1603	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
446	[illegible]	1457	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
447	93	1293	2644	2589	20	93	89	.00924	194	[illegible]	3 4	.00550
448	6	1597	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
449	6	1630	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
450	192	1153	2659	2599	19	95	91	.00983	194	0	3 4	.00549
451	6	16_7	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
452	3	9[illegible]	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
453	3	1652	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
454	3	1637	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******

TABLE 14. (Continued)

TEST NO.	TIME SEC.	SPEED RPS	LOX SEAL U/S PR. CAVITY KN/SQ M	U/S PR. SEAL KN/SQ M	D/S PR. DRAIN KN/SQ M	U/S TEMP CAVITY K	D/S TEMP DRAIN K	LEAKAGE SCMS	HELIUM SEAL U/S PR. PURGE KN/SQ M	D/S PR. TURB SIDE DRAIN KN/SQ M	U/S TEMP PURGE K	LEAKAGE TOTAL SCMS
455	3	1667	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
456	3	50	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
457	3	1415	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
458	95	1117	2482	2386	18	93	86	.00918	216	3	307	.00357
459	5	1478	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
460	93	1258	2489	2399	17	91	86	.00949	216	3	306	.00358
461	211	1228	2489	2558	15	92	87	.00885	221	3	306	.00358
462	265	1197	2661	2568	16	93	88	.00884	220	3	303	.00356
463	5	1367	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
464	43	1300	2436	2396	15	93	89	*******	214	3	308	.00357
465	3	1593	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
466	3	1662	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
467	3	1643	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
468	3	1617	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
469	3	1487	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
470	3	1545	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
471	3	1362	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
472	3	1193	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
473	3	1247	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
474	6	1233	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
475	2	545	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
476	2	1098	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
477	5	92	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
478	5	170	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
479	*****	*****	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
480	5	1567	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
481	3	1625	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
482	220	1113	2654	2551	18	95	92	.00882	197	3	309	.00354
483	4	1653	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
484	4	1353	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
485	220	1193	2637	2551	17	96	92	.00882	197	3	309	.00353
486	300	1265	2675	2592	15	93	90	.00917	203	3	308	.00353
487	363	1237	2658	2575	15	93	89	.00820	199	3	307	.00332
488	360	1260	2682	2586	14	95	89	.00822	200	3	308	.00329
489	360	1240	2654	2561	19	93	89	.00817	214	2	306	.00347
490	3	1385	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
491	360	1263	2599	2603	15	94	89	.00813	226	2	306	.00359
492	4	1363	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
493	360	1290	2672	2568	16	93	90	.00849	224	2	307	.00359
494	6	1410	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
495	360	1275	2689	2586	14	95	92	.00812	221	2	309	.00359
496	360	1278	2689	2599	14	96	92	.00812	221	2	307	.00360
497	6	1362	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
498	360	1246	2689	2596	14	93	88	.00814	219	2	305	.00361
499	6	1343	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
500	360	1275	2723	2620	15	94	89	.00850	221	2	305	.00361
501	360	1295	2679	2586	16	94	90	.00848	221	2	306	.00363
502	6	1363	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
503	360	1307	2717	2610	15	95	91	.00847	221	2	306	.00363
504	6	1367	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
505	360	1287	2758	2654	15	96	92	.00811	221	2	305	.00363
506	9	1380	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
507	600	1258	2689	2586	15	93	89	.00814	221	1	303	.00363
508	2	1352	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
509	610	1253	2710	2610	16	93	89	.00814	232	1	304	.00362
510	9	1333	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
511	620	1250	2696	2589	17	96	90	.00849	230	1	304	.00362
512	9	1387	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
513	600	1280	2723	2620	16	92	86	.00851	232	1	301	.00364
514	70	1387	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
515	9	1272	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
516	6	1297	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
517	487	1270	2679	2561	17	94	89	.00854	219	1	[illegible]	.00345
518	*****	*****	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
519	16	1437	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
520	12	1187	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
521	14	1427	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
522	114	1273	2517	2482	21	97	86	.00990	178	1	311	.07452
523	27	1192	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
524	5	792	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******

TABLE 14. (Continued)

TEST NO.	TIME SEC.	SPEED RPS	LOX SEAL U/S PR. CAVITY KNT/SQ	U/S PR. SEAL MKNT/SQ	D/S PR. DRAIN MKNT/SQ M	U/S TEMP CAVITY K	D/S TEMP DRAIN K	LEAKAGE SCMS	HELIUM SEAL U/S PR. PURGE KNT/SQ	D/S PR. TURB SIDE MDRAIN KNT/S	U/S TEMP PURGE K	LEAKAGE TOTAL SCMS
525	195	1332	2513	2485	20	96	89	.00924	195	1	311	.00458
526	191	1283	2682	2634	20	97	89	.00957	200	0	311	.00458
527	198	1283	2479	2617	21	94	87	.00959	198	0	310	.00452
528	189	1233	2654	2673	20	95	88	.00989	199	0	311	.00453
529	3	948	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
530	192	1253	2637	2592	19	96	89	.00925	196	0	311	.00452
531	9	645	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
532	36	1025	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
533	6	1433	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
534	6	1465	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
535	192	1283	2648	2555	32	96	93	.01322	195	1	311	.00455
536	6	1458	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
537	7	1463	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
538	189	1250	2634	1862	29	96	93	.01245	199	1	313	.00453
539	195	1303	2641	2555	29	93	91	.01276	199	1	311	.00455
540	189	1288	2651	2558	27	92	99	.01198	197	1	310	.00456
541	7	1545	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
542	189	1272	2679	2586	33	93	89	.01354	197	1	310	.00454
543	189	1293	2733	2610	28	94	89	.01225	197	1	311	.00456
544	12	492	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
545	192	1283	2723	2633	30	96	93	.01277	197	1	310	.00454
546	192	1267	2730	2641	29	96	93	.01225	195	0	311	.00456
547	82	1275	2699	2592	35	93	91	.01383	199	0	309	.00442
548	6	1517	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
549	189	1272	2751	2644	31	93	93	.01280	199	0	310	.00441
550	189	1267	2772	2672	28	95	93	.01279	196	0	311	.00443
551	189	1292	2761	2654	35	96	91	.01381	198	0	310	.00443
552	8	1452	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
553	195	1280	2741	2637	32	97	93	.01304	197	0	310	.00442
554	188	1283	2703	2596	33	97	92	.01279	199	0	310	.00442
555	18	1433	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
556	156	1283	2723	2636	29	97	92	.01251	199	0	311	.00442
557	368	1282	2661	2517	40	93	93	.01498	214	0	307	.00472
558	7	1443	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
559	8	917	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
560	2	17	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
561	21	74	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
562	6	1422	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
563	6	99	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
564	26	828	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
565	8	1265	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
566	5	132	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
567	5	423	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
568	138	1193	2654	2610	52	101	93	.01731	201	0	305	.00617
569	8	1475	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
570	8	1472	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
571	187	1267	2668	2658	40	97	91	.01471	205	4	309	.00667
572	99	1225	2686	2489	41	97	93	.01553	207	6	309	.00653
573	*****	*****	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
574	6	1423	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
575	6	1200	2692	2372	38	98	94	.01335	228	6	309	.00698
576	8	1523	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
577	11	1082	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
578	155	1262	2692	2651	40	95	89	.01366	228	5	306	.00706
579	9	1425	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
580	97	1293	2657	2658	34	96	91	.01453	225	6	309	.00726
581	6	1433	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
582	6	1450	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
583	81	1238	2703	2654	37	97	93	.01511	206	6	308	.00637
584	198	1275	2675	2644	38	106	93	.01429	205	6	309	.00638
585	5	1103	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
586	6	1440	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
587	66	1235	2689	2654	38	106	91	.01393	202	6	306	.00641
588	57	1243	2706	2659	41	95	89	.01426	205	6	306	.00641
589	191	1198	2710	2672	38	95	90	.01429	201	6	306	.00643
590	186	1255	2665	2623	36	96	93	.01319	201	6	306	.00646
591	167	1308	2679	2632	33	96	91	.01233	200	6	305	.00647
592	87	1283	2689	2641	43	96	91	.01523	207	6	305	.00712
593	192	1337	2696	2648	37	96	91	.01337	211	6	305	.00730
594	13	1537	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******

TABLE 14. (Continued)

TEST NO.	TIME SEC.	SPEED RPS	LOX SEAL U/S PR. CAVITY KNT/SQ M	U/S PR. SEAL MKNT/SQ M	D/S PR. DRAIN MKNT/SQ M	U/S TEMP CAVITY K	D/S TEMP DRAIN K	LEAKAGE SCMS	HELIUM SEAL U/S PR. PURGE KNT/SQ	D/S PR. TURB SIDE MDRAIN KNT/S	U/S TEMP PURGE K	LEAKAGE TOTAL SCMS.
595	186	1265	2706	2655	41	97	91	.01452	213	6	316	.00731
596	138	1188	2699	2659	37	97	91	.01382	210	6	316	.00739
597	152	1278	2717	2648	33	99	97	.01442	91	5	325	.00240
598	365	1297	2744	2661	36	96	89	.01354	225	5	324	.00682
599	9	1447	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
600	77	1297	2753	2640	34	96	91	.01373	205	5	324	.00681
601	9	1456	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
602	299	1317	2733	2654	34	97	92	.01298	201	5	325	.00681
603	192	1272	2737	2651	37	98	93	.01377	205	5	325	.00681
604	366	1245	2723	2651	37	99	93	.01377	201	5	325	.00683
605	6	1478	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
606	366	1297	2723	2651	40	96	89	.01953	207	5	334	.00685
607	162	1213	2717	2641	37	96	93	.01383	201	5	324	.00684
608	152	1172	2727	2654	38	96	91	.01422	202	5	324	.00687
609	8	1563	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
610	158	1177	2727	2645	34	97	93	.01325	226	4	324	.00687
611	5	1163	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
612	138	1255	2727	2634	40	99	93	.01413	227	4	333	.00707
613	285	1295	2751	2648	41	98	95	.01464	228	5	321	.00711
614	217	1285	2754	2654	37	95	90	.01375	208	5	330	.00713
615	129	1295	2754	2648	39	96	91	.01444	211	5	329	.00713
616	9	1527	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
617	9	1453	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
618	155	1258	2734	2630	41	97	93	.01440	212	5	331	.00711
619	153	1285	273[illegible]	2634	44	98	93	.01531	212	4	321	.00713
620	459	1187	2734	2630	41	99	93	.01374	208	4	331	.00717
621	6	1597	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
622	256	1215	2748	2623	43	101	94	.01497	207	5	310	.00768
623	11	1517	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
624	153	1246	2759	2613	39	98	94	.01457	208	5	3[illegible]5	.00729
625	6	1128	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
626	656	1207	2734	2596	31	96	91	.01224	212	4	298	.00734
627	397	1205	2751	2613	40	97	93	.01452	211	4	297	.00735
628	458	1175	2737	2617	41	98	94	.01358	212	4	298	.00732
629	476	1217	2758	2613	43	99	93	.01556	212	6	295	.00730
630	8	1533	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
631	366	1272	2741	2623	42	95	96	.01458	208	7	296	.00727
632	365	1172	2748	2623	46	96	96	.01617	212	7	295	.00712
633	3	*****	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
634	186	1240	2556	2558	35	96	89	.01389	241	8	319	.01091
635	6	1268	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
636	6	1343	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
637	141	1175	2410	2396	37	93	89	.01370	257	10	318	.01019
638	6	1383	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
639	189	1262	2575	2551	39	91	87	.01394	216	8	316	.01049
640	191	1228	2555	2534	38	93	88	.01391	217	8	317	.01066
641	6	1365	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
642	2[illegible]	1197	2568	2541	43	95	88	.01346	243	9	318	.01069
643	209	1225	2630	2603	39	93	87	.01400	219	9	316	.01020
644	192	1226	2610	2589	35	93	88	.01280	210	7	317	.01026
645	192	1177	2592	2568	35	96	89	.01288	212	8	317	.00990
646	6	1229	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
647	189	1170	2641	2613	34	97	89	.01384	219	8	316	.00996
648	5	1347	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
649	6	1330	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
650	189	1255	2630	2617	33	93	86	.01270	219	6	315	.00992
651	189	1260	2637	2620	32	93	86	.01245	212	6	315	.00999
652	186	1238	2637	2620	31	94	87	.01217	221	6	315	.00996
653	185	1253	2644	2613	32	95	87	.01244	214	6	315	.00996
654	6	1331	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
655	186	1272	2630	2633	36	96	89	.01314	215	7	315	.00998
656	192	1228	2644	2613	33	94	89	.01268	222	6	315	.00998
657	185	1255	2658	2623	36	97	89	.01300	214	6	315	.00969
658	185	1243	2658	2620	34	93	86	.01324	214	6	314	.00972
659	186	1245	2654	2613	34	93	85	.01280	214	6	314	.00973
660	186	1253	2654	2613	39	97	87	.01332	216	6	315	.00975
661	6	758	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
662	185	1248	2651	2610	35	97	87	.01323	216	6	315	.00976
663	175	1262	2654	2610	33	93	87	.01277	216	6	314	.00978
664	185	1263	2649	2599	34	93	89	.01276	216	6	315	.00977

TABLE 14. (Continued)

TEST NO.	TIME SEC.	SPEED RPS	LOX SEAL U/S PR. CAVITY KNT/SQ M	U/S PR. SEAL KNT/SQ M	D/S PR. DRAIN KNT/SQ M	U/S TEMP CAVITY K	D/S TEMP DRAIN K	LEAKAGE SCMS	HELIUM SEAL U/S PR. PURGE KNT/SQ M	D/S PR. TURB SIDE DRAIN KNT/SQ M	U/S TEMP PURGE K	LEAKAGE TOTAL SCMS
665	188	1248	2644	2596	34	93	89	.01277	216	6	315	.00977
666	*****	*****	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
667	6	*****	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
668	9	*****	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
669	5	543	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
670	8	1367	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
671	36	1280	2389	2344	21	98	89	.00996	208	2	309	.00213
672	*****	*****	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
673	189	1275	2682	2613	22	96	87	.00963	205	3	308	.00204
674	189	1280	2679	2633	22	97	88	.00963	180	3	306	.00235
675	36	1317	2665	2603	19	93	88	.00823	206	3	308	.00274
676	189	1282	2730	2682	23	93	89	.00938	209	3	309	.00299
677	186	1283	2730	2661	22	93	89	.00864	216	3	309	.00315
678	189	1282	2744	2655	23	93	90	.00904	206	3	309	.00321
679	4	320	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
680	533	1283	2734	2637	27	98	89	.01110	205	3	303	.00263
681	606	1263	2713	2592	28	96	88	.01095	227	4	301	.00299
682	606	1292	2717	2596	28	97	89	.01095	206	4	301	.00301
683	612	1283	2720	2596	28	96	87	.01092	207	4	299	.00321
684	606	1288	2703	2579	28	96	87	.01087	203	4	300	.00340
685	606	1298	2689	2555	28	97	89	.01068	205	4	300	.00341
686	606	1285	2717	2592	29	96	87	.01058	207	4	299	.00345
687	186	1286	2730	2603	29	95	87	.01069	210	4	299	.00347
688	186	1275	2734	2603	27	97	88	.00953	210	3	299	.00349
689	186	1263	2723	2586	29	98	89	.00983	210	3	299	.00350
690	186	1258	2713	2575	29	98	89	.00969	210	3	299	.00354
691	185	1242	2720	2589	29	100	89	.00962	210	3	299	.00355
692	186	1300	2723	2592	29	100	90	.00929	210	3	299	.00354
693	186	1268	2720	2586	29	96	87	.00925	210	3	297	.00358
694	186	1272	2713	2579	29	94	86	.00902	210	3	297	.00362
695	186	1267	2699	2569	29	94	87	.00888	210	4	297	.00362
696	186	1276	2699	2565	29	95	87	.00873	209	4	297	.00364
697	186	1292	2734	2596	29	96	88	.00883	210	4	297	.00363
698	186	1272	2748	2603	29	97	88	.00879	210	4	297	.00364
699	3	233	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
700	3	230	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
701	189	1305	2692	2617	26	98	89	.01300	197	5	307	.00427
702	186	1245	2679	2617	26	96	85	.01274	205	4	305	.00422
703	186	1277	2668	2610	26	96	85	.01276	210	4	306	.00435
704	186	1250	2682	2620	26	96	85	.01285	210	4	305	.00443
705	186	1287	2675	2623	26	111	88	.01275	227	4	308	.00472
706	186	1248	2689	2627	26	111	88	.01275	226	4	309	.00480
707	186	1287	2679	2620	25	111	86	.01247	204	4	309	.00429
708	186	1288	2682	2620	25	111	89	.01285	202	5	309	.00428
709	186	1283	2679	2627	26	111	85	.01288	199	5	306	.00430
710	186	1288	2682	2620	26	111	85	.01293	199	5	306	.00433
711	186	1295	2692	2620	26	111	85	.01271	198	5	307	.00435
712	186	1300	2679	2627	26	111	85	.01292	197	5	308	.00437
713	183	1292	2679	2620	26	111	87	.01280	196	5	308	.00437
714	6	1480	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
715	3	133	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
716	6	1452	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
717	3	113	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
718	21	1417	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
719	186	1283	2717	2655	22	97	84	.01144	205	5	306	.00471
720	192	1303	2723	2665	24	94	85	.01209	210	5	306	.00486
721	192	1280	2720	2668	23	94	85	.01172	210	5	308	.00501
722	12	1232	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
723	186	1272	2734	2692	23	96	86	.01150	210	5	308	.00515
724	186	1250	2717	2665	22	97	87	.01130	224	5	308	.00531
725	186	1317	2706	2654	22	97	87	.01158	196	5	308	.00487
726	186	1303	2717	2651	22	97	87	.01150	210	5	309	.00510
727	186	1305	2720	2675	22	97	88	.01158	210	5	309	.00527
728	186	1300	2723	2679	23	94	84	.01168	199	4	307	.00510
729	186	1303	2720	2658	23	93	84	.01192	205	5	307	.00519
730	186	1300	2717	2658	23	94	84	.01156	210	5	307	.00531
731	186	1285	2710	2648	23	95	85	.01171	210	5	308	.00538
732	183	1200	2723	2679	23	96	85	.01156	214	5	308	.00545
733	186	1313	2717	2637	24	96	86	.01165	214	5	308	.00555
734	186	1278	2720	2648	24	96	87	.01150	219	5	309	.00567

TABLE 14. (Concluded)

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TEST NO.	TIME SEC.	SPEED RPS	LOX SEAL U/S PR. CAVITY KNT/SQ	U/S PR. SEAL MKNT/SQ	D/S PR. DRAIN MKNT/SQ M	U/S TEMP CAVITY K	D/S TEMP DRAIN K	LEAKAGE SCMS	HELIUM SEAL U/S PR. PURGE KNT/SQ	D/S PR. TURB SIDE DRAIN KNT/S	U/S TEMP PURGE K	LEAKAGE TOTAL SCMS
735	186	1267	2723	2651	24	97	87	.01120	216	5	308	.00572
736	99	1255	2723	2654	22	97	88	.01030	208	5	308	.00521
737	195	1272	2723	2651	24	93	84	.01073	205	5	306	.00536
738	186	1252	2717	2637	23	94	84	.01057	203	5	306	.00541
739	183	1276	2717	2648	24	94	84	.01060	206	5	307	.00549
740	186	1267	2720	2648	24	96	140	.01058	213	5	307	.00554
741	196	1267	2723	2654	25	96	85	.01064	214	5	307	.00555
742	195	1267	2717	2641	24	97	86	.01051	209	5	307	.00559
743	196	1262	2723	2637	24	97	87	.01069	210	5	309	.00558
744	132	1282	2723	2637	24	97	88	.01055	210	5	306	.00558
745	6	217	*******	*******	*******	*****	*****	*******	*******	*******	*****	*******
746	36	1208	2726	2637	24	93	83	.00992	213	5	306	.00564
747	186	1125	2744	2655	25	93	83	.00993	210	4	305	.00567
748	192	1275	2723	2648	26	94	84	.01022	210	5	305	.00561
749	102	1033	2734	2655	25	95	85	.00958	210	4	305	.00557

TESTER SHAFT DEFLECTION TESTS

A total of 34 shaft deflection, tests (Table 15) were performed with two Bently proximity probes mounted 1.57 rad (90 degreew) apart over the helium seal mating ring to measure deflection. The LOX and helium seals were not installed. The objective was to perform two 6-minute duration tests, one with a slow start of 4188 rad/s/minute (440,000 rpm/minute) to 9425 rad/s (90,000 rpm) and one with a fast start of 4188 rad/s/s (40,000 rpm/sec) to 9425 rad/s (90,000 rpm). Tests 032 and 034 met the objective. The other tests were terminated due to facility problems.

The Bently transducer measurements of the tester shaft deflection at the helium seal location indicated that the maximum peak to peak deflection was 0.000038 m (0.0015 in.) at 4188 rad/s (40,000 rpm) and 0.000025 m (0.0010 in.) at 9425 rad/s (90,000 rpm). The results are summarized in Table 16.

TABLE 15. TESTER SHAFT DEFLECTION TEST SUMMARY

Number	Date, 1975	Duration, seconds	Speeds, rad/s rpm	Remarks
001	04-29	15	2408 (23,000)	Low-speed cutoff
002		10	2513 (24,000)	Low-speed cutoff
003	04-30	10	7538 (72,000	Bearing cavity redline automatic cutoff
004		9	942 (9,000)	Low-speed cutoff
005		14	5528 (91,000)	Overspeed cutoff
006		15	2618 (25,000)	Low-speed cutoff
007		15	2827 (27,000)	
008		28	3769 (36,000)	
009		12	2827 (27,000)	
010		36	3874 (37,000)	
011		8	9528 (91,000)	Overspeed cutoff
012		9	5528 (91,000)	Overspeed cutoff
013		32		Turbine pressure decay
014	05-02	8		Overspeed cutoff
015		32		
016		11		
017		10		
018		5		
019		15		
020		12		
021		15		
022		25		
023		20		
024		20		
025		21		
026		25		
027		25		
028		26		
029		70		
030		120		
031		15	--	Instrumentation malfunction
032		360	9425 (90,000)	Overspeed and low LOX cutoff
033		15	3769 (36,000)	Low-speed cutoff
034		362	9425 (90,000)	Normal operator shutdown

TABLE 16. TESTER SHAFT DEFLECTION TEST RESULTS

Speed, rad/s rpm	Acceleration Amplitude, g_p	Bently Displacement (Spot Face = 0.0033 in.)	
		No. 1 m ($in._{p-p}$)	No. 2, m ($in._{p-p}$)
3455 (33,000)	0.6	0.000033 (0.0013)	0.000033 90.0013)
4188 (40,000)	0.8	0.000025 (0.001)	0.000038 (0.0015)
4188 (40,000)	1.0	↓	0.000025
4816 (46,000)	0.5	↓	↓
5130 (49,000)	0.44	↓	↓
5759 (55,000)	0.40	↓	↓
6177 (59,000)	0.36	↓	↓
6806 (65,000)	0.20	↓	↓
9109 (87,000)	0.40	↓	↓
9425 Typical (90,000)	0.36	↓	↓
All responses are synchronous			

Inspection of the tester hardware revealed that the bearings and slave seals were in good condition. There were indications that the bearing preload spring and both bearing outer races had spun during testing, but no significant damage resulted. The spring compression was increased to ensure sufficient bearing preload to prevent outer race spinning.

PRELIMINARY GASEOUS NITROGEN CHECKOUT TESTS

NASA Machined Bellows LOX Seal

Build No. 1 Assembly. The tester was assembled with the machined metal bellows LOX seal and the purged double floating ring helium seal (Tables 7 and 8) for the Schedule I preliminary gaseous nitrogen checkout testing at 2618 rad/s (25,2000 rpm) to 9425 rad/s (90,000 rpm).

The installed length of the bellows LOX seal was adjusted to provide an operating spring load of 21.80 N (4.9 pounds) to be consistent with the theoretical hydrodynamic lift force of approximately 22.24 N (5 pound) with gaseous nitrogen at the minimum test speed of 2618 rad/s (25,000 rpm). The bellows free length was 0.00038 m (0.015 in.) over the print tolerance and the spring rate was 35,024 N/m (200 lb/in.) instead of the original design value of 20,409 N/m (117 lb/in.), which required installing the seal at 0.0047 m (0.184 in.) length. The design nominal operating length is 0.0038 m (0.150 in.). The redesigned bellows mean effective diameter is the same as the original design; therefore, the theoretical pressure loads are nearly balanced. The seal is designed for 0.7 pressure balance ratio.

The helium seal turbine side seal ring ID was 0.0000076 m (0.0003 in.) over print tolerance and the dam width was 0.0015 to 0.0017 m (0.060 to 0.065 in.) instead of the print requirement of 0.0011 to 0.0013 m (0.045 to 0.050 in.).

Tests 035-045. A total of 11 tests for a total time of 7.65 minutes, including test point No. 1 was performed. During the first test series, the LOX pressure in the bearing cavity was higher than the 275,790 N/m^2 (40 psi) GN_2 seal purge pressure; consequently, tests 035 through 040 operated with LOX in the seal cavity at 461,949 N/m^2g (67 psig). GN_2 seal supply pressure was increased to 1,054,898 N/m^2g (153 psig) for the second series and testing was terminated after three starts at the second test point conditions when the GN_2 leakage past the LOX seal increased significantly, resulting in seal drain cavity pressures above the redline of 137,895 N/m^2g (20 psig) and the leakage orifice pressure in excess of 68,948 N/m^2g (10 psig).

Build 1 Disassembly. The posttest 045 seal hardware and inspection data are tabulated in Tables 10 and 11. The helium seal leakage was slightly lower than the assembly values, indicating no wear or deterioration. the LOX seal leakage was 10 to 25 times the build values, indicating deterioration of the sealing surfaces. Photographs of the LOX seal carbon ring and mating ring are shown in Fig. 57 and 58. The LOX seal carbon face was worn 0.00036 to 0.000061 m (0.0014 to 0.0024 in.) and was scored from rubbing contact. The profile traces indicated twisting of either the carbon ring and/or the mate ring. The carbon face was worn more on the inner diameter with a taper of approximately 0.000018 m (0.0007 in.) from the inner edge of the dam to the outer edge of the lift pad. Comparisons of the carbon face surface profiles pretest and posttest are given in Fig. 59 and 60.

Results and Conclusions. The LOX seal carbon wear was apparently caused by the face closing force exceeding the hydrodynamic lift force. The spring load was set to be equal to the theoretical lift force and the pressure load is nearly balanced at the predicted bellows effective diameter. The lift force may be lower due to nonparallel interface film thickness caused by distortion of either the seal ring and/or the mating ring. The bellows effective diameter may be shifting inward due to pressure deflection of the convolution plates, causing a larger pressure closing force.

It was decided to suspend the bellows seal testing and switch to the piston ring seal to evaluate the effect of a smaller closing force by eliminating the bellows effective diameter variable and reducing the spring load. Consideration will be given to measuring the bellows effective diameter at the operating pressure limits.

Rayleigh Step Piston Ring LOX Seal

Build 2 Assembly. The tester was assembled with a new piston ring LOX seal and the same helium seal that was used on build 1 to continue the schedule I gaseous nitrogen checkout testing. It was agreed to reduce the LOX seal spring load to 13.34 N (3.0 pounds) and to perform the gaseous nitrogen tests at 9425 rad/s (90,000 rpm) to demonstrate satisfactory operation at the nominal design point prior to testing at the low speed limits. The theoretical lift force increases to 66.72 N (15 pounds) at 9425 rad/s (90,000 rpm). It was also agreed to inspect the seals after the first 6-minute test to check for LOX seal wear.

Tests 046-054. A total of nine tests for 10.58 minutes, including one 6.9-minute duration test was performed to complete the test objective. The LOX and helium seal performance was satisfactory on all tests. The LOX seal leakage rate of 0.09 m^3/minute (3.22 scfm) indicates that the seal is operating properly with a film thickness of approximately 0.0000076 to 0.00001 m (0.0003 to 0.0004 in.). The measured helium seal leakage compares to the calculated values for a diametral clearance of 0.000038 (0.0015 in.) as follows:

	Total Leakage m^3/minute (scfm)
Measured Static	0.11 (3.8)
Measured Dynamic	0.13 (4.6)
Calculated Isentropic Flow	0.15 (5.4)
Calculated NASA QUASC Program	0.10 (3.6)

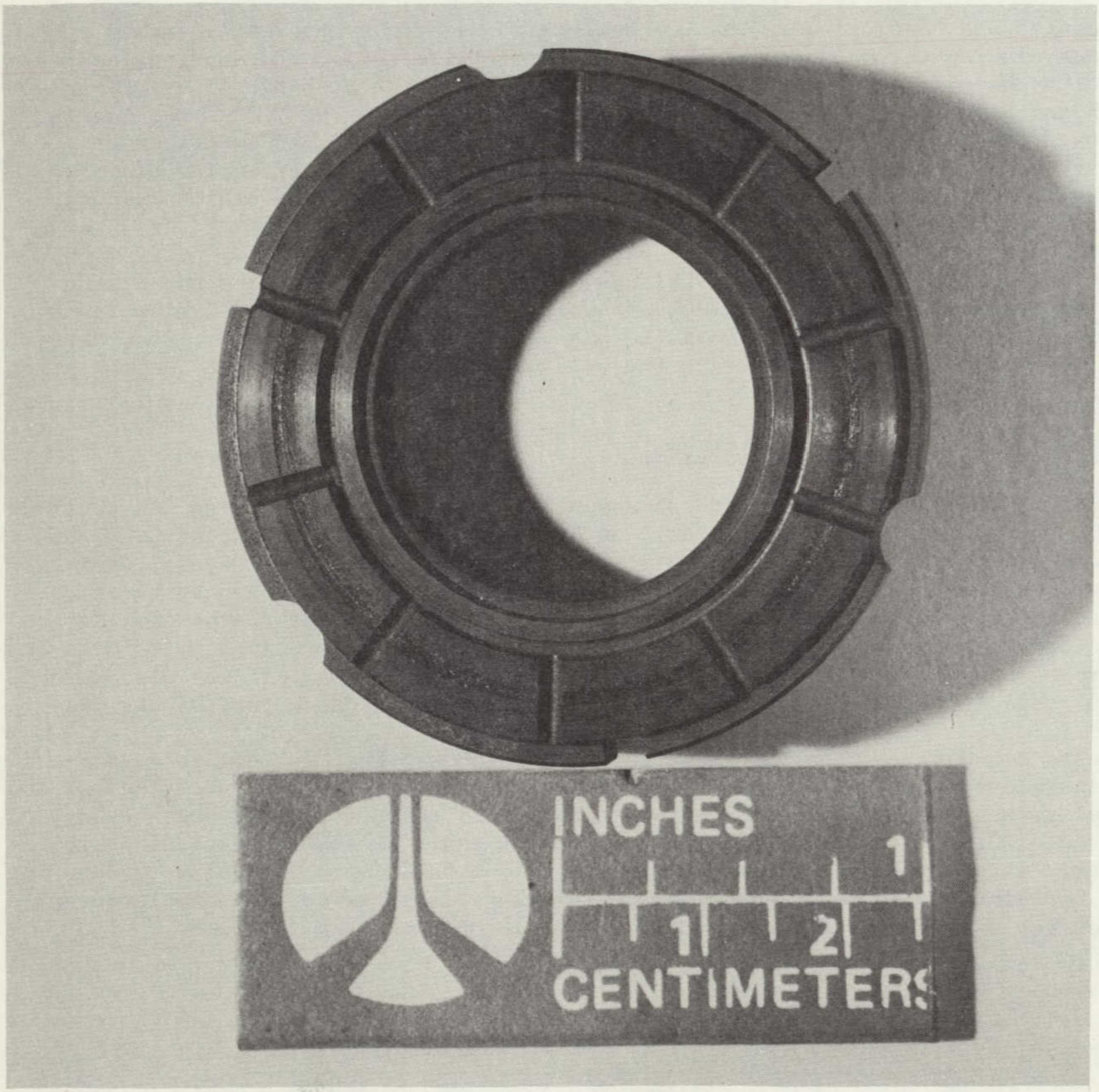

Figure 57. Worn LOX Seal Carbon Ring Posttest 045
(P/N RS009697, S/N 037508, Build 1)

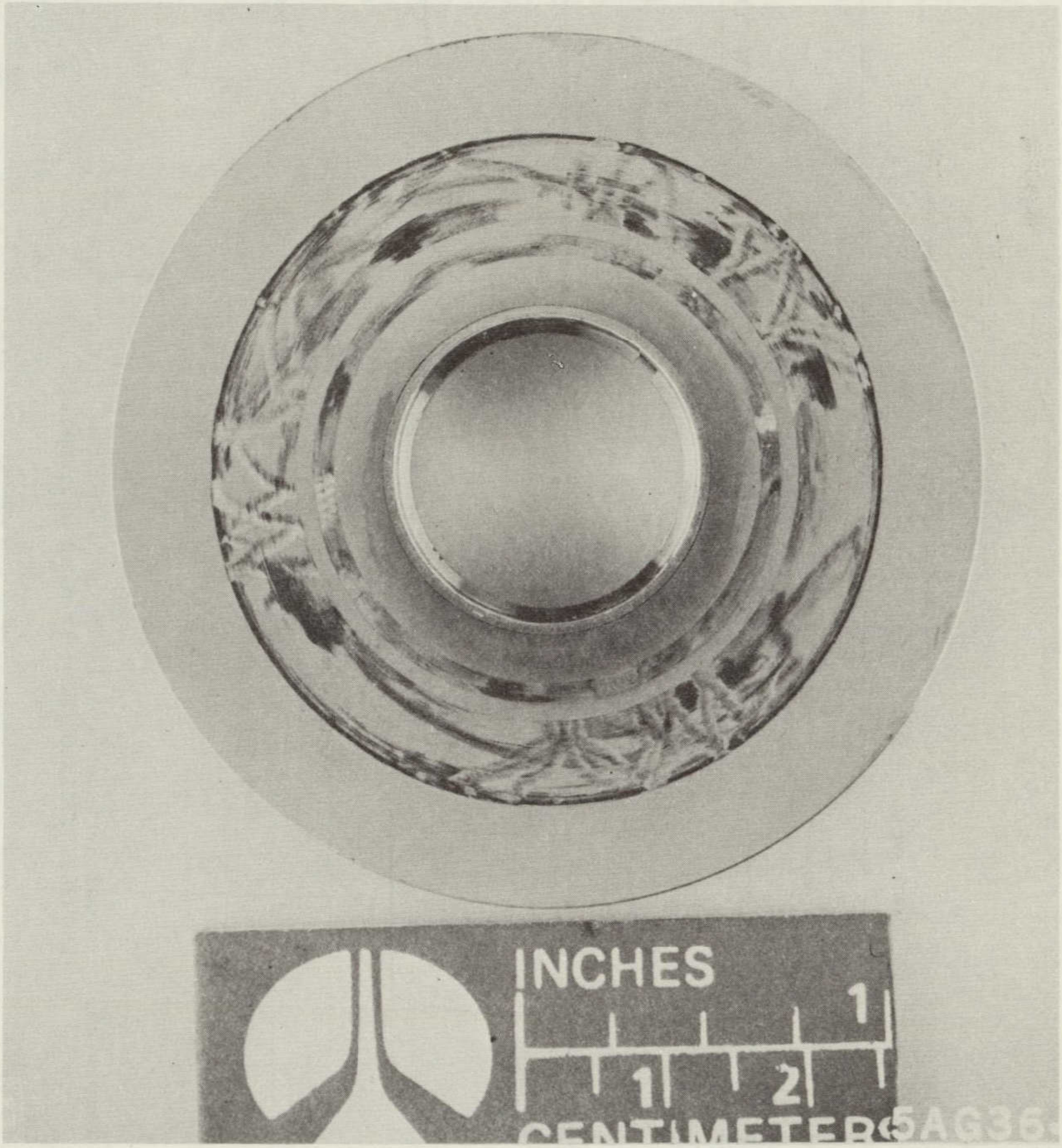

Figure 58. Worn LOX Seal Mate Ring Posttest 045
(P/N RS009698X, S/N 002, Build 1)

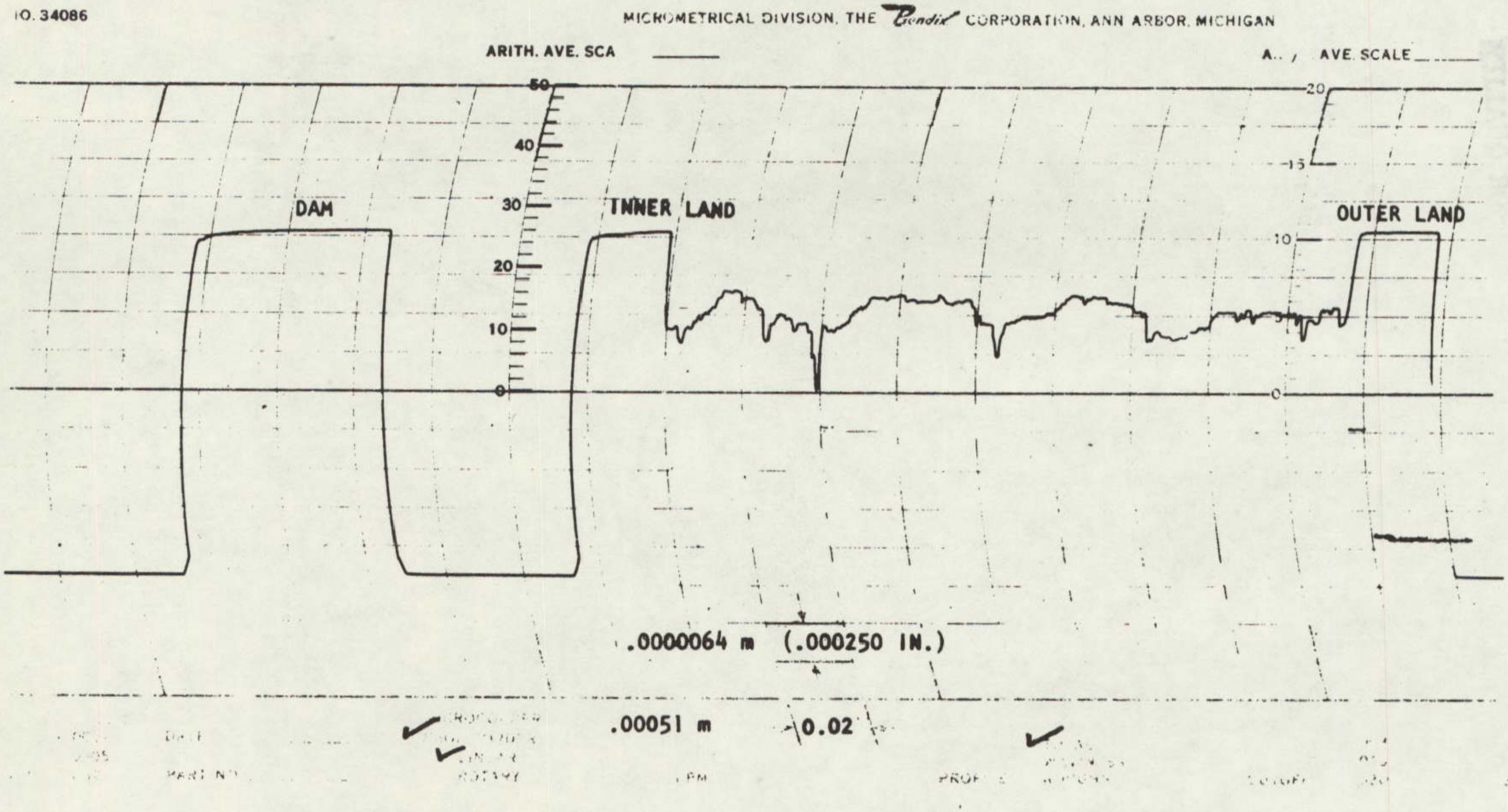

Figure 59. Typical Surface Profile Trace of LOX Seal Carbon Face
(RS009697X, S/N 08 New, Pretest 035, Build 1)

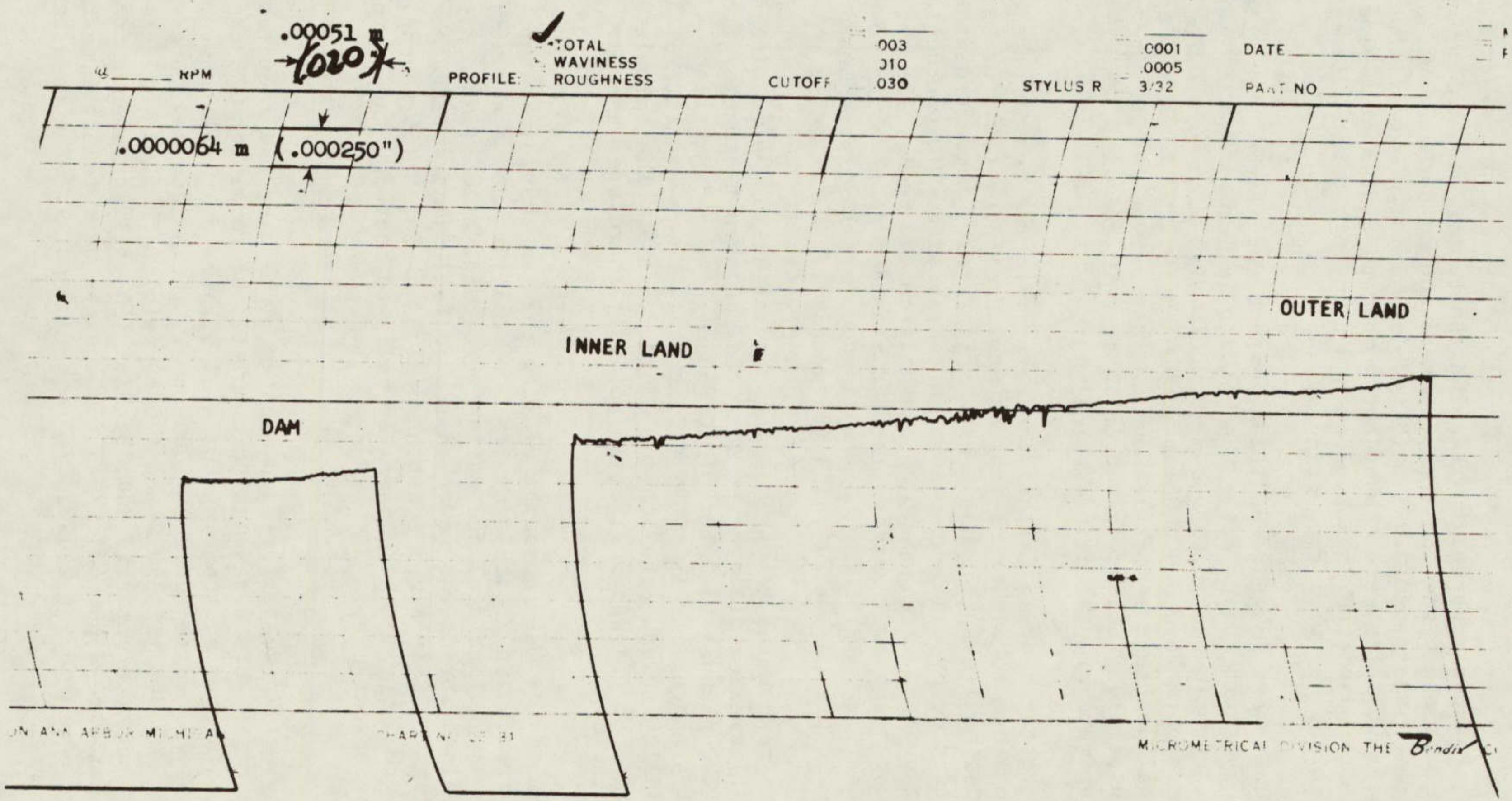

Figure 60. Typical Profile Trace of LOX Seal Carbon Face
(RS009697X, S/N 08, Posttest 045, Build 1)

Build 2 Disassembly. Posttest inspection revealed the tester thrust bearing to be failed. The tester shaft was loose at the seal end in both the radial and axial direction. The shaft had 0.001 m (0.040 in.) axial movement toward the seal end. The bearing balls were flaked and worn with flat spots. The inner race was worn both on the thrust shoulder and down on the race diameter. The bearing preload spring was worn from spinning.

The LOX and helium seals were in good condition, except for slight wear which may have been caused by shaft runout after the bearing failure. The LOX seal face was worn evenly approximately 0.000005 m (0.0002 in.), Fig. 61. The helium seal recess pads were worn 0.000005 to 0.00001 m (0.0002 to 0.0004 in.). The LOX and helium seal posttest static leakage was approximately the same as pretest. The seal inspection data are given in Tables 10 and 11. Photographs of the seal hardware are shown in Fig. 62 and 63.

Investigation of the tester bearing failure indicated that the bearing preload spring had lost preload due to either thermal expansion differentials or wear from spinning. The Belleville spring has a high spring rate; therefore, the preload is greatly affected by a slight change in compression. It was decided to rework the bearing preload arrangement to change from the Belleville spring to a series of 18 compression coil springs located around a plate which loads the bearing outer race (Fig. 64). The coil springs have a low spring rate and will maintain a constant preload of 244,64 N (55 pounds).

It was also decided to rework the tester bearings by installing balls with a 0.000013 m (0.0005 in.) smaller diameter to increase the thrust capacity from approximately 890 N (200 pounds) to 1112 N (250 pounds) for a B_{10} life of 4 hours. The capacity is approximately 556 N (125 pounds) for a B_{10} life of 25 hours. The smaller balls increase the bearing contact angle. The calculated bearing thrust load on test 054 was 503 N (113 pounds); therefore, the thrust capacity should be adequate.

Build 3 Assembly. The tester was reassembled using the same Rayleigh step piston ring LOX seal from build 2 with a new carbon seal ring and a new mating ring (Table 7). The same helium seal and mating were reinstalled (Table 8). The tester bearing preload spring was reworked from a Belleville spring to compression coil springs to maintain a constant preload of 245 N (55 pounds). The bearings were reworked by installing smaller balls to increase the contact angle for a larger thrust capacity.

Tests 055-077. A total of 23 tests for 73.8 minutes, including the required ten 6-minute duration tests were performed to complete the remaining GN_2 checkout tests on the Rayleigh step piston ring LOX seal (Table 6). All tests were performed at 9425 $\pm$105 rad/s (90,000 $\pm$1000 rpm). The helium seal pressure was maintained at 206,843 $\pm$13,790 N/m^2g (30 $\pm$2 psig). The LOX seal gaseous nitrogen pressure was increased in 344,738 N/m^2 (50 psi) increments from 1,034,214 N/m^2g (150 psig) to 2,084,427 N/m^2g (300 psig). A total of 9 tests for 45.65 minutes were performed at 2,068,427 N/m^2g (300 psig). The seal performance was satisfactory.

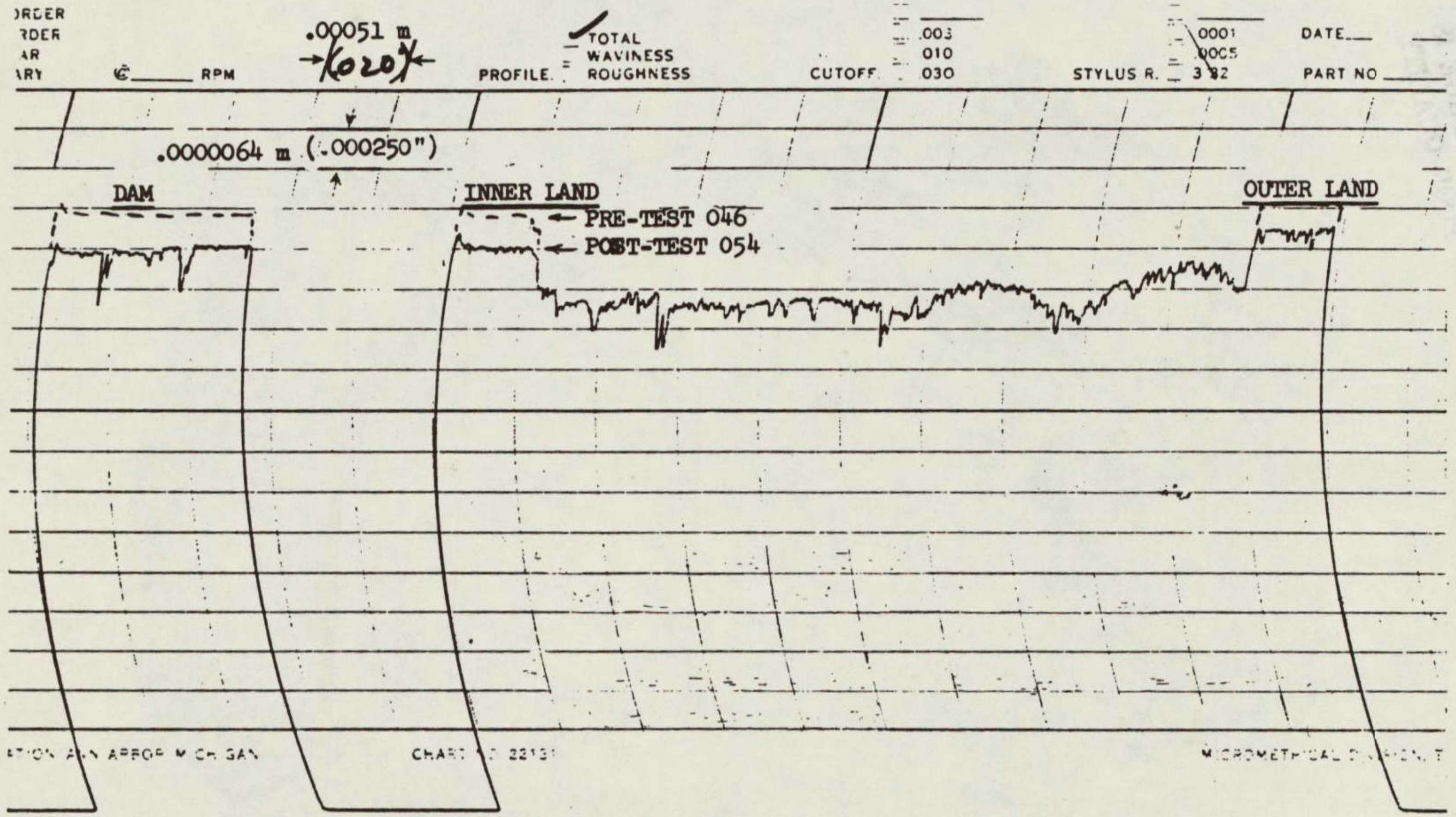

Figure 61. Typical Profile Trace of LOX Seal Carbon Face (P/N RS009697X, S/N 05, Piston Ring Seal Pretest 046 and Posttest 054, Build 2)

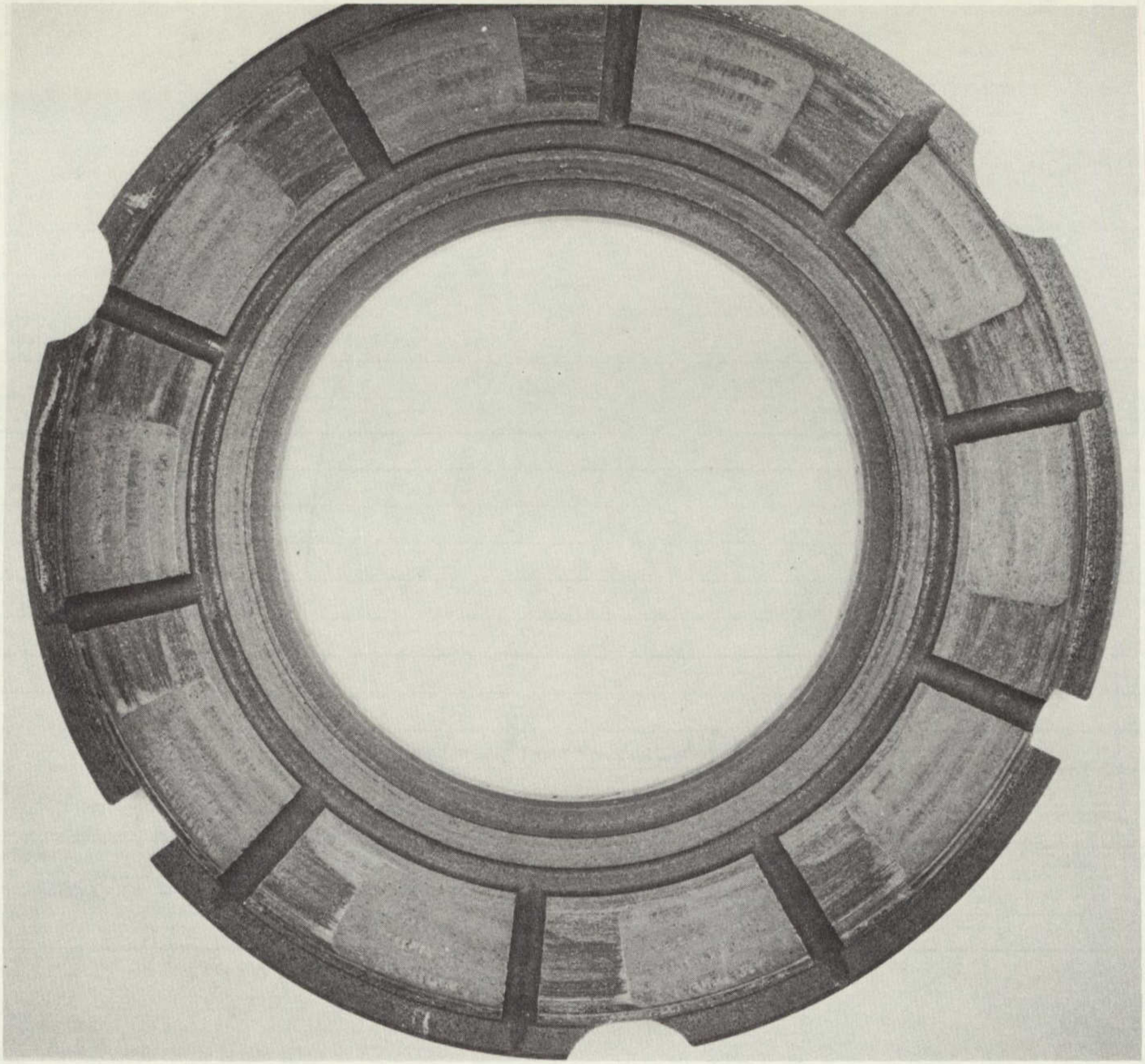

Figure 62. LOX Seal Carbon Ring (P/N RS009697X, S/N 04, Posttest 054, Build 2)

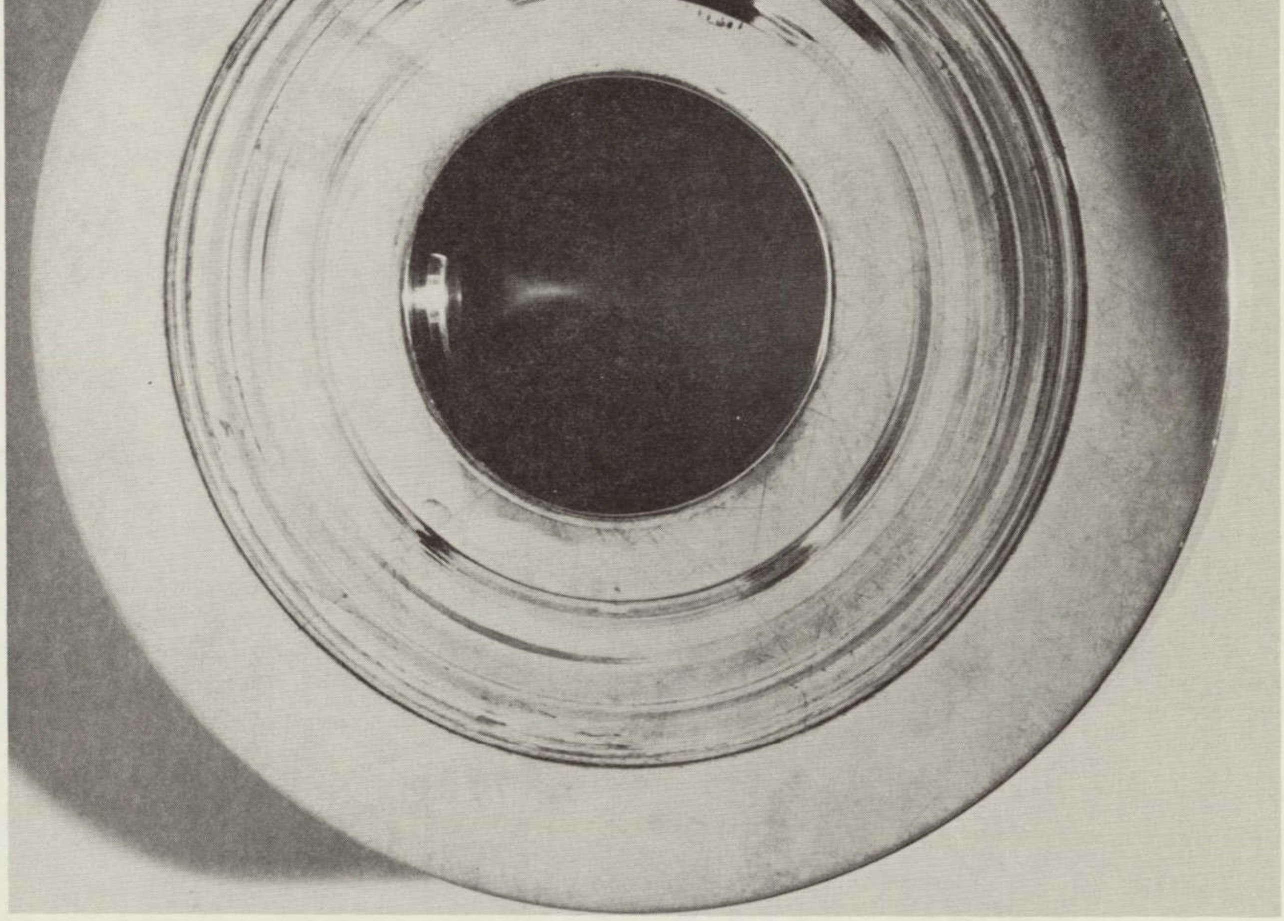

Figure 63. LOX Mating Ring (P/N RS009698X, S/N 01, Posttest 054, Build 2)

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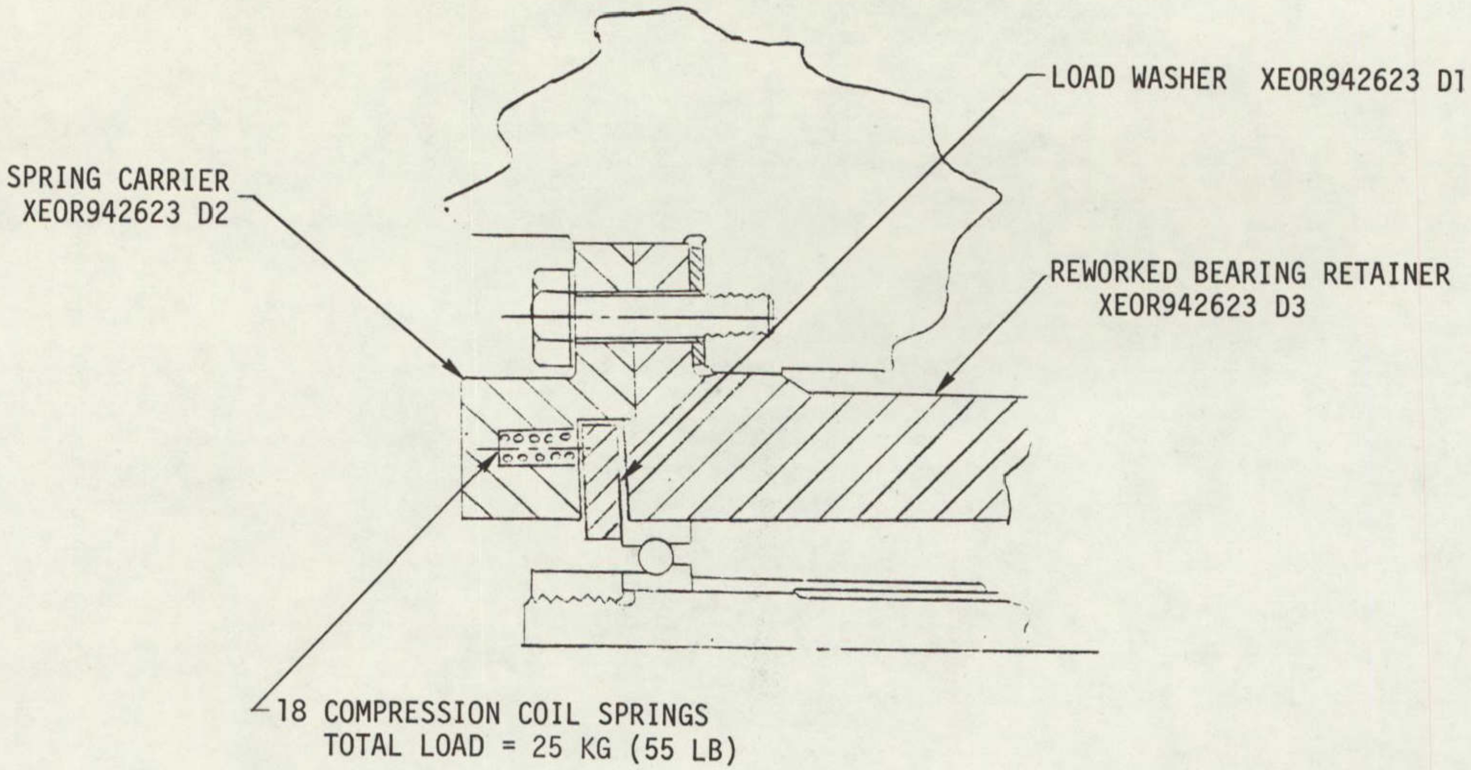

Figure 64. Modified Tester Bearing Preload Spring Arrangement

The helium seal leakage held steady near the predicted value of 0.10 m^3/minute (3.6 scfm) throughout the test series. The leakage varied from 0.09 m^3/minute (3.06 scfm) to 0.13 m^3/minute (4.65 scfm). Most of the tests varied from 0.10 m^3/minute (3.6 scfm) to 0.11 m^3/minute (3.9 scfm). The average leakage was 0.107 m^3/minute (3.77 scfm). The leakage tended to decrease during the test series.

The LOX seal leakage indicated that the seal was operating properly with a consistent film thickness of 0.00001 to 0.000013 m (0.0004 to 0.0005 in.) as the pressure was increased, except for two tests (074 and 075) where the leakage was excessive. A comparison of the theoretical film thickness for the measured leakage is given below:

Seal Pressure, N/m^2g (psig)	Measured Leakage, m^3/minute (scfm)	Theoretical Film Thickness m (in.)
1,034,214 (150)	0.156 (5.5	0.000012 (0.00049)
1,378,951 (200)	0.201 (7.1)	0.000012 (0.00049)
1,723,689 (250)	0.221 (7.8)	0.000011 (0.00044)
2.068,427 (300)	0.241 (8.5)	0.000011 (0.00042)

The excessive LOX seal leakage on tests 074 and 075 was probably caused by either foreign particles or carbon debris between the carbon sealing face and mating ring. The seal appeared to correct itself on the last two tests with the leakage returning to normal.

Build 3 Disassembly. Posttest inspection indicated that the tester bearings were in good condition. The bearings turned smooth and were properly loaded by the coil spring preload arrangement. The bearing end of the tester was not disassembled.

The Rayleigh step LOX seal carbon face was worn evenly across the dam and recess pads 0.00001 m (0.0004 in.), Fig. 65. The recess pads were worn down to a depth of approximately 0.0000025 m (0.0001 in.). The mating ring had a uniform contact pattern with one worn spot. The surface was worn approximately 0.0000076 m (0.0003 in.) in the dam and recess land areas (Fig. 66). The static GN_2 leakage increased by a factor of approximately 10 from pretest to posttest (Table 9). The seal was in good condition otherwise, except that the chrome plating on the pilot ring RS009648X was partially flaked off at the pilot. The chrome apparently failed due to a poor bond. Photographs of the LOX seal hardware are shown in Fig. 67 and 68.

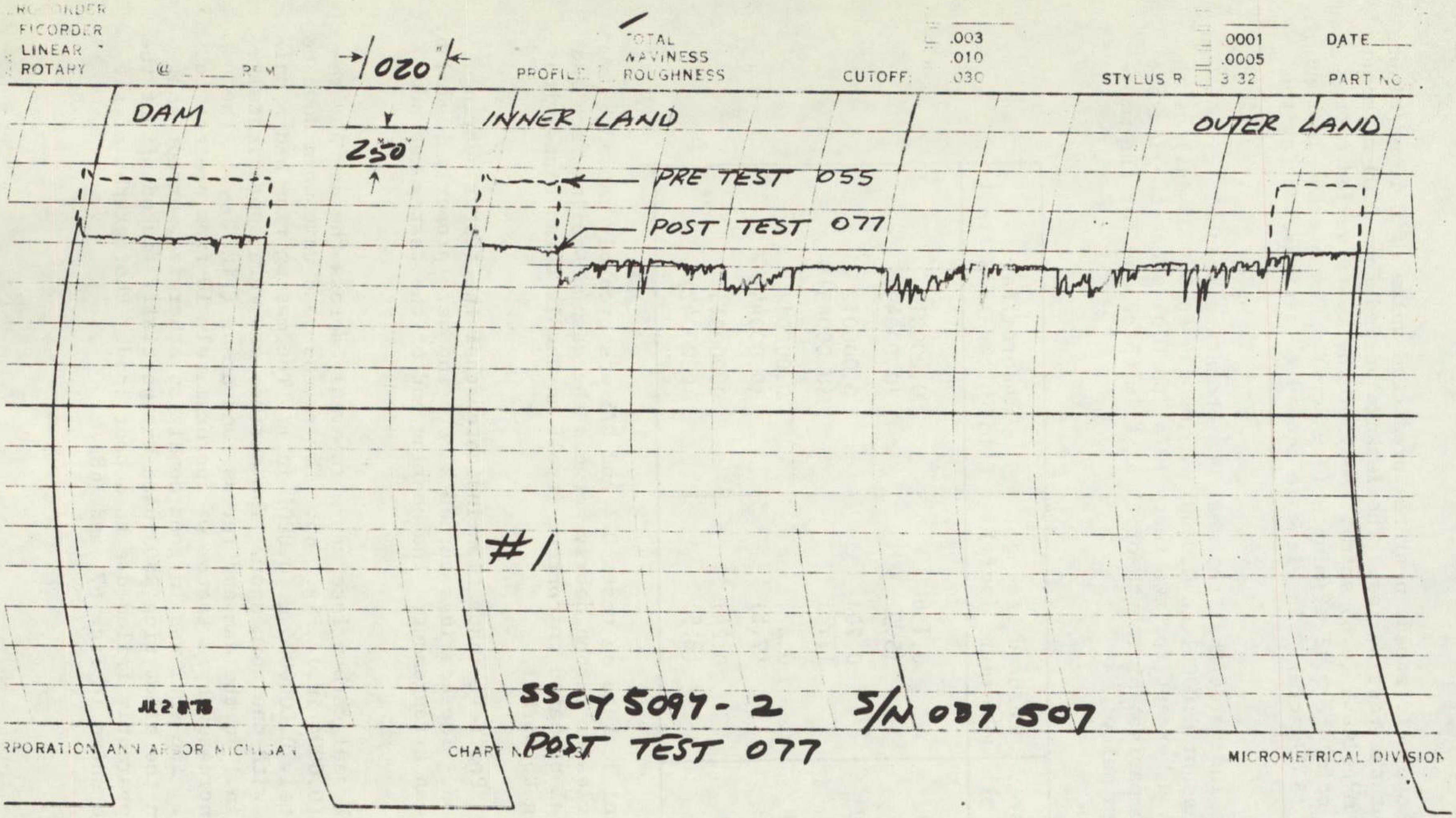

Figure 65. Typical Profile Trace of LOX Seal Carbon Face (P/N RS009697X, S/N 07, Piston Ring Seal Pretest 055 and Posttest 077)

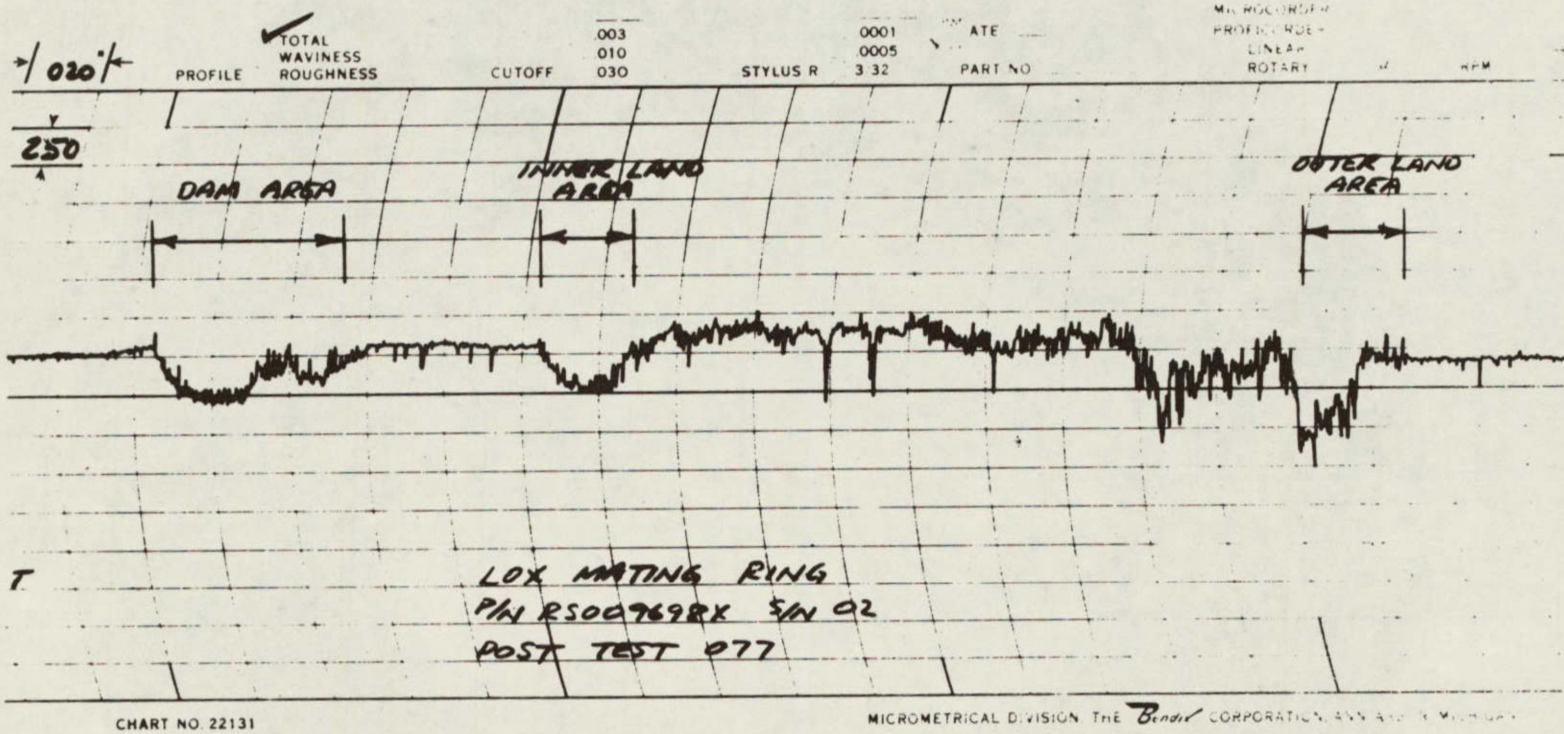

Figure 66. Profile Trace of LOX Mating Ring Surface At Worn Spot (P/N RS009698X, S/N 02, Posttest 077)

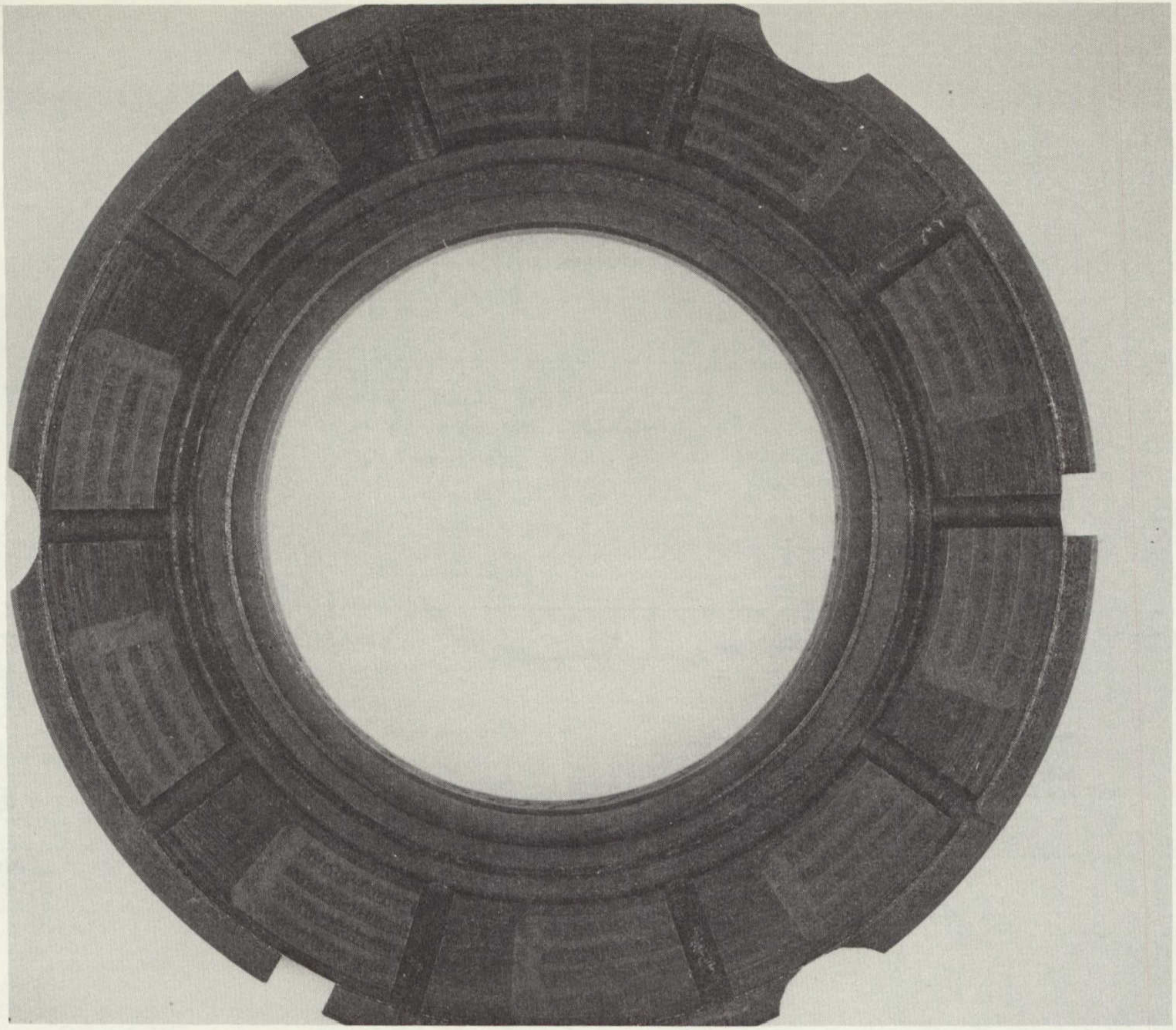

Figure 67. LOX Seal Carbon Ring (P/N RS009697X, S/N 07, Posttest 077)

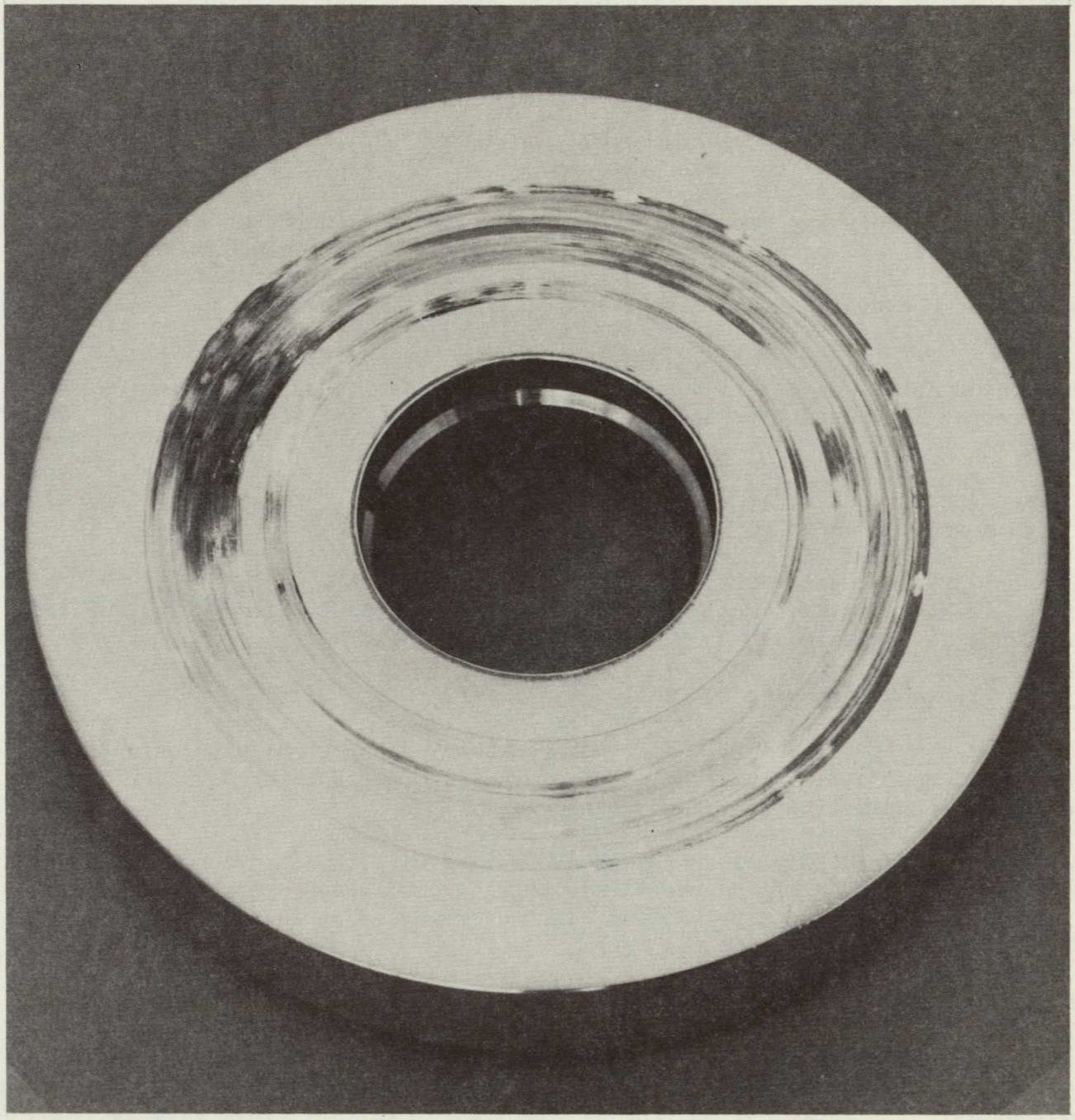

Figure 68. LOX Mating Ring (P/N RS009698X, S/N 02, Posttest 077)

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The helium seal was in good condition. There was no measurable wear on either the sealing dam or the recess pads (Table 11). The mating ring was in good condition with only a slight trace of contact. The posttest static leakage was less than the pretest leakage.

Results and Conclusions. Two new carbons and mating rings with the same housing and piston ring were used for 32 starts for 1 hour 24 minutes of GN_2 checkout testing at 9425 rad/s (90,000 rpm) from 1,034,214 N/m^2 to 2,068,427 N/m^2 (150 to 300 psi) LOX seal pressure.

The first assembly was tested for 9 starts and 10.58 minutes at 1,034,214 N/m^2 (150 psi) LOX seal pressure. LOX seal carbon eas worn evenly 0.000005 m (0.0002 in.). The mating ring had one worn spot. The tester bearing had failed but the LOX seal was not visibly damaged. LOX seal leakage was 0.09 m^3/minute (3.22 scfm).

The second build was tested for 23 starts totalling 1 hour, 13.8 minutes, at 9425 rad/s (90,000 rpm) from 1,034,214 to 3,068,427 N/m^2 (150 to 300 psi) GN_2 pressure.

LOX seal carbon was worn evenly 0.000013 m (0.0005 in.); the mating ring had one worn spot. The pilot ring had flaked chrome at the pilot.

LOX seal GN_2 leakage plotted versus sealed pressure is shown in Fig. 69. Predicted leakage for GN_2 at 2,068,427 N/m^2 (300 psi) and 9425 rad/s (90,000 rpm) could not be determined.

Spiral Groove Piston Ring LOX Seal

Build 4 Assembly. The seal tester was reassembled using the alternate spiral groove LOX seal and mating ring manufactured by Crane Packing Co. The same helium seal and mating ring were reinstalled.

Inspection of the LOX seal spiral groove mating ring revealed the ends of the grooves to be closed off on one side with a narrow land due to the cleanup diameter not being concentric. The ring was reworked at Rocketdyne by grinding the lands off and relapping the face.

The initial installation of the LOX seal had excessive static leakage due to the piston ring being 0.00038 m (0.015 in.) loose on the housing. The piston ring was expanded outward against the seal ring instead of being tight at the secondary sealing diameter of the housing. The problem was corrected by making a circumferential wave spring from 0.000076 m (0.003 in.) brass shim stock and inserting the spring around the outside diameter of the piston ring to load it radially inward.

Tests 078-088. The test objective was to perform one 6-minute-duration test on the spiral groove LOX seal with gaseous nitrogen at 1,034,214 N/m^2g (150 psig) and 9425 rad/s (90,000 rpm) and then inspect the seals.

A total of 11 tests for 20.35 minutes, including the required one 6-minute-duration test was performed to complete the objective (Table 13). The initial tests were terminated due to tester speed control problems. The speed varied

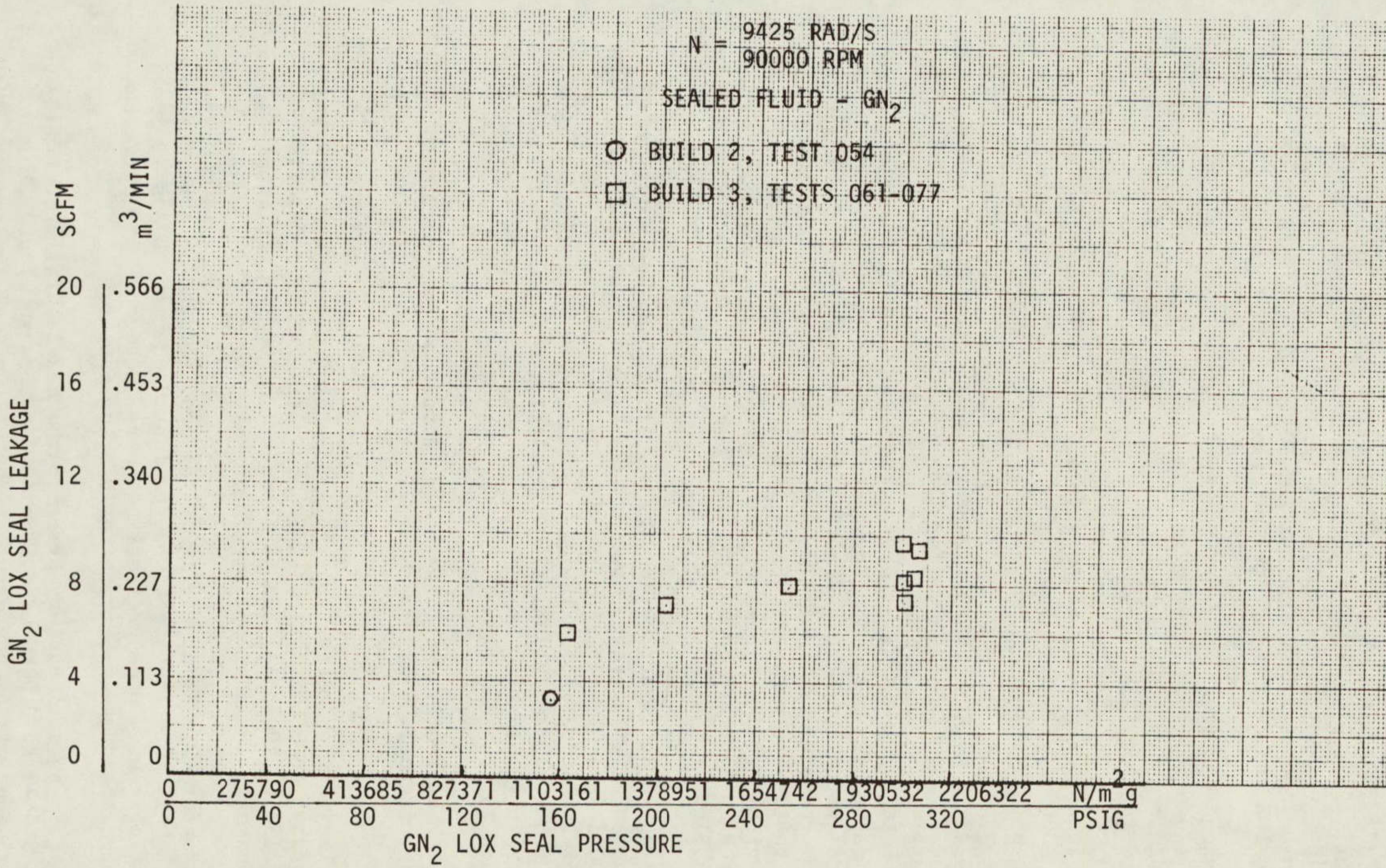


Figure 69. NASA Rayleigh Step Piston Ring LOX Seal GN_2 Checkout Tests Leakage

from 1487 rad/s (14,200 rapm) to 9538 rad/s (91,100 rpm). The last three tests were performed at 9425 rad/s (90,000 rpm). The LOX seal gaseous nitrogen pressure was maintained between 1,054, 898 N/m^2g (153 psig) and 1,344,478 N/m^2g (195 psig). The helium seal pressure was 196,501 to 208,222 N/m^2m (28.5 to 30.2 psig). the LOX and helium seal performance was satisfactory.

The LOX seal leakage was steady during the tests and gradually decreased from 0.300 m^3/minute (10.6 scfm) to 0.190 m^3/minute (6.7 scfm) at the completion of testing. The LOX seal drain pressure varied from 3447 to 8273 N/m^2g (0.5 to 1.2 psig), indicating low leakage rates.

The helium seal leakage continued to hold steady near the predicted valve of 0.102 m^3/minute (3.6 scfm). The leakage varied from 0.093 m^3/minute (3.3 scfm) to 0.100 m^3/minute (3.9 scfm).

Build 4 Disassembly. Posttest inspection revealed the tester and seals to be in good condition.

The spiral groove LOX seal was in as new condition with no significant rubbing contact and no measurable wear. The carbon face was polished slightly. The mating ring spiral groove surface had very slight traces of light contact when viewed under a microscope. The spiral groove depth was 0.00001 m (0.0004 in.) pretest and posttest. The posttest static leakage was less than pretest (Table 9). Typical profile traces of the carbon seal face and the spiral groove mating ring surface are shown in Fig. 70 and 71. The mating ring surface is shown in Fig. 72.

The helium seal was in satisfactory condition. The carbon and mating ring appearance was the same as pretest; however, the carbon recess pads were worn 0.0000025 m (0.0001 in.). The carbon inside diameter was worn 0.000005 to 0.00001 m (0.0002 to 0.0004 in.). The static leakage at 206,825 N/m^2g (30 psig) decreased from 0.128 m^3/minute (7800 scim) pretest to 0.089 m^3/minute (5400 scim) posttest (Table 11). The helium seal hardware conditions is shown in Fig. 73 through 75.

Build 5 Assembly. The tester was reassembled using the same spiral groove LOX seal and floating ring helium seal as build 4 with no rework (Tables 7 and 8).

Tests 089-092. The test objective was to perform eleven 6-minute-duration tests on the spiral groove LOX seal with gaseous nitrogen at 1,034,214 to 2,068,427 N/m^2g (150 to 300 psig) and 9425 rad/s (90,000 rpm) to complete the schedule I gaseous nitrogen checkout testing.

A total of 4 tests for 13.45 minutes, including one 6-minute-duration test was performed (Table 13). The last test was terminated when the LOX seal drain pressure and bearing cavity pressure redlines were exceeded. Investigation revealed the seals were damaged by a tester bearing failure.

The seal performance was satisfactory prior to the bearing failure. The LOX seal leakage was 0.0623 to 0.0680 m^3/minute (2.2 to 2.4 scfm) at 1,103,162 N/m^2 (160 psig) gaseous nitrogen pressure. The helium seal leakage was 0.096 to 0.110 m^3/minute (3.4 to 3.9 scfm) at 206,843 N/m^2g (30 psig) helium pressure.

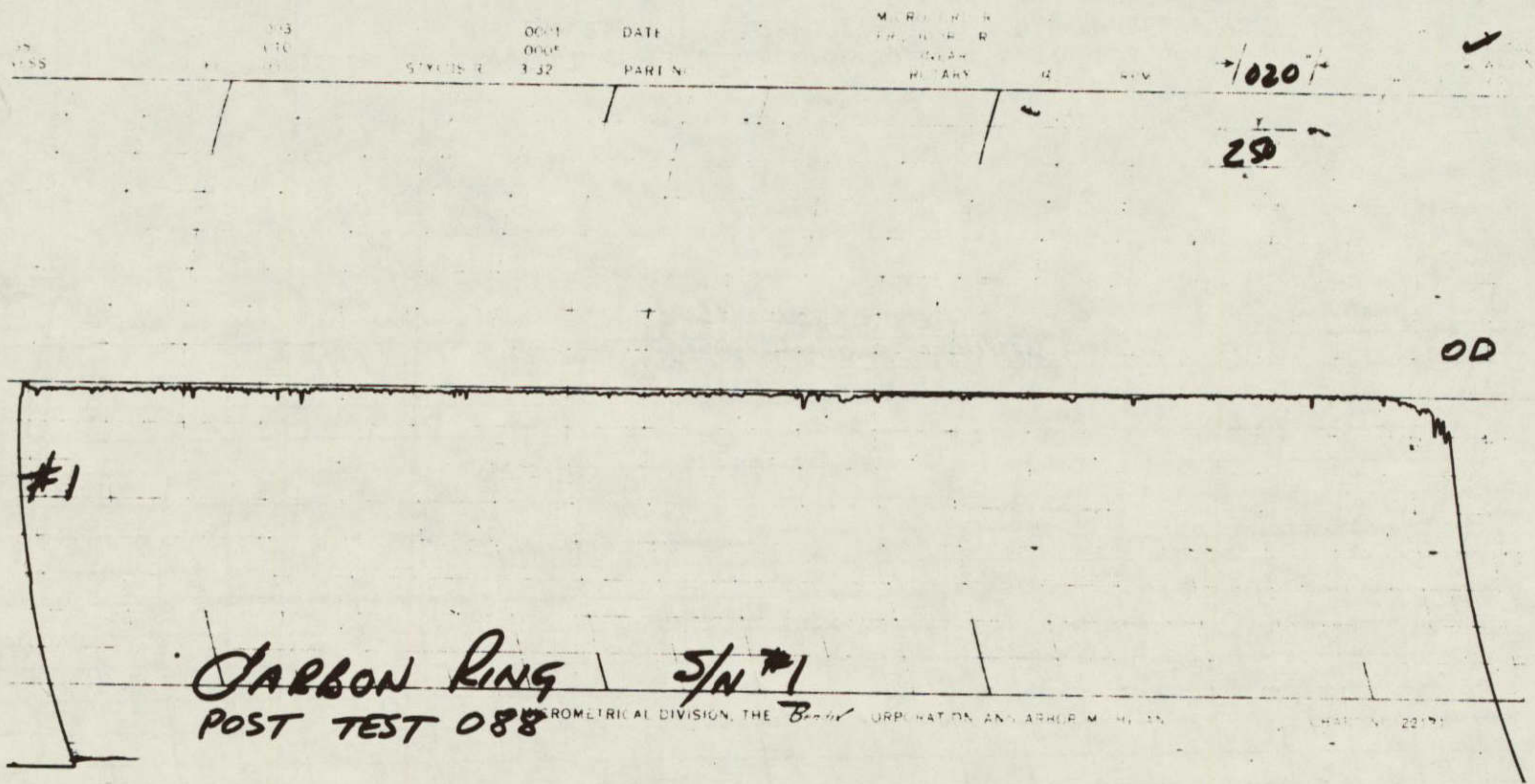


Figure 70. Typical Profile Trace of Spiral Groove LOX Seal
Carbon Face (P/N A28-0812-11, S/N 01, Posttest 088)

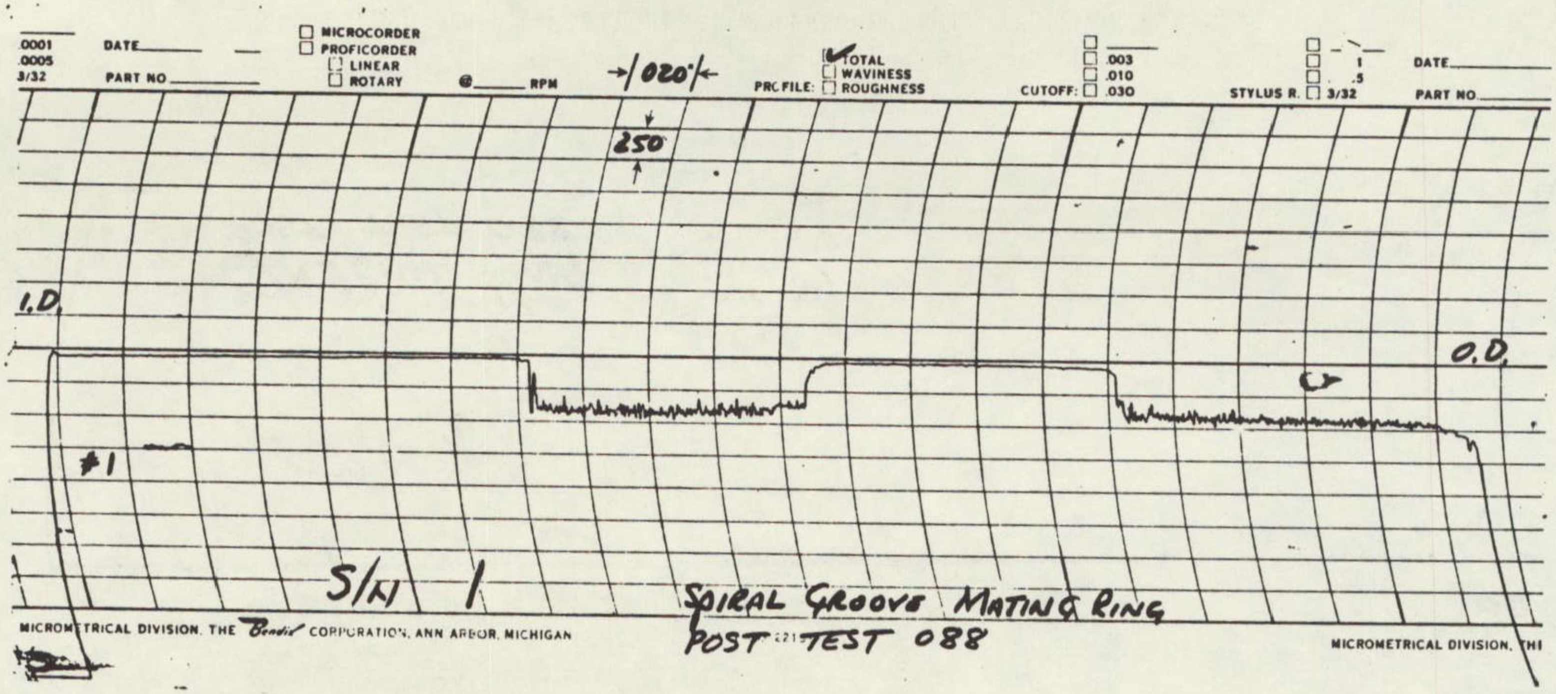


Figure 71. Typical Profile Trace of Spiral Groove LOX Seal Mating Ring (P/N C28-0812-10, S/N 01, Posttest 088)

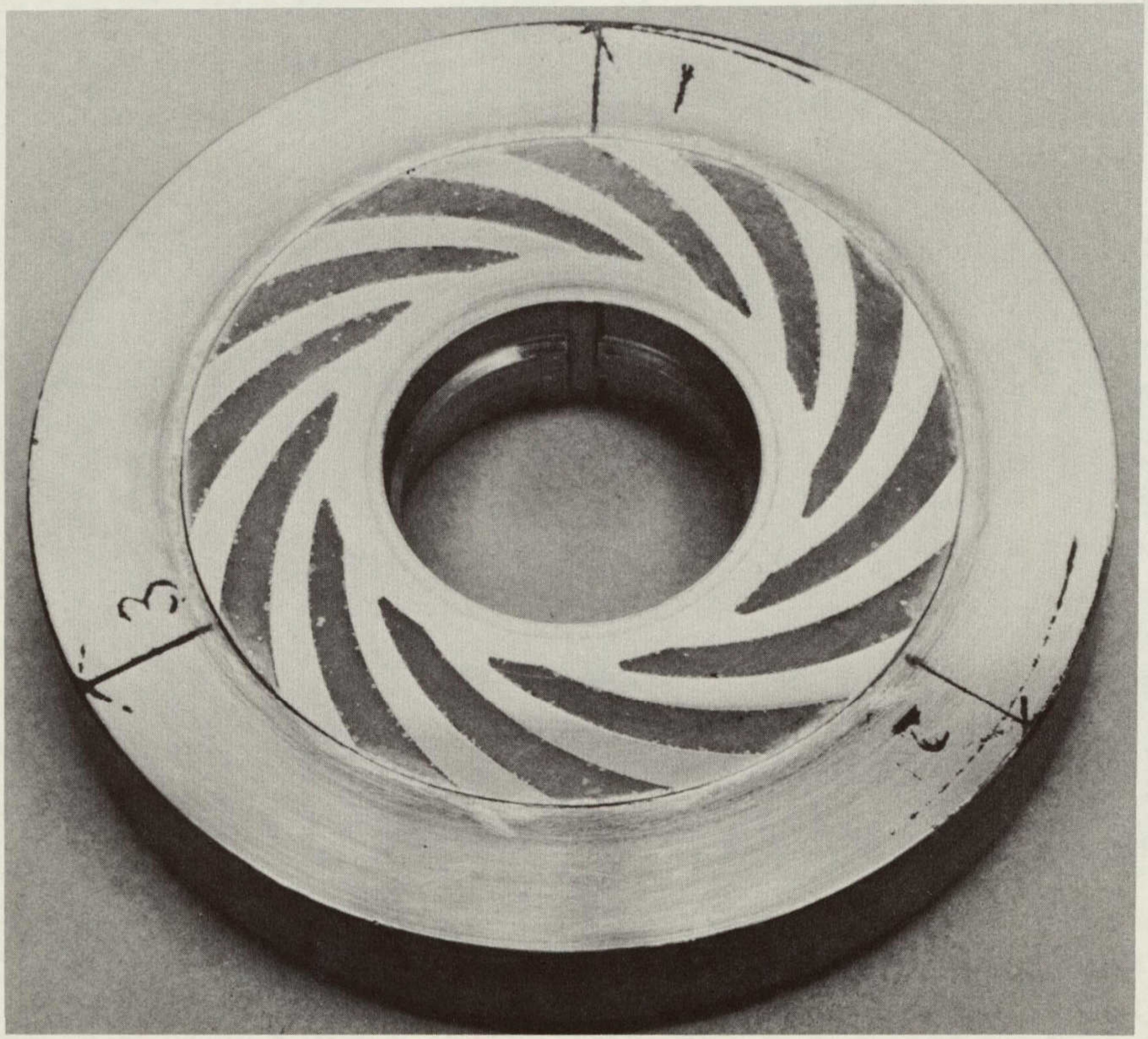


Figure 72. Spiral Groove LOX Seal Mating Ring
(P/N C28-0812-10, S/N 01, Posttest 088)

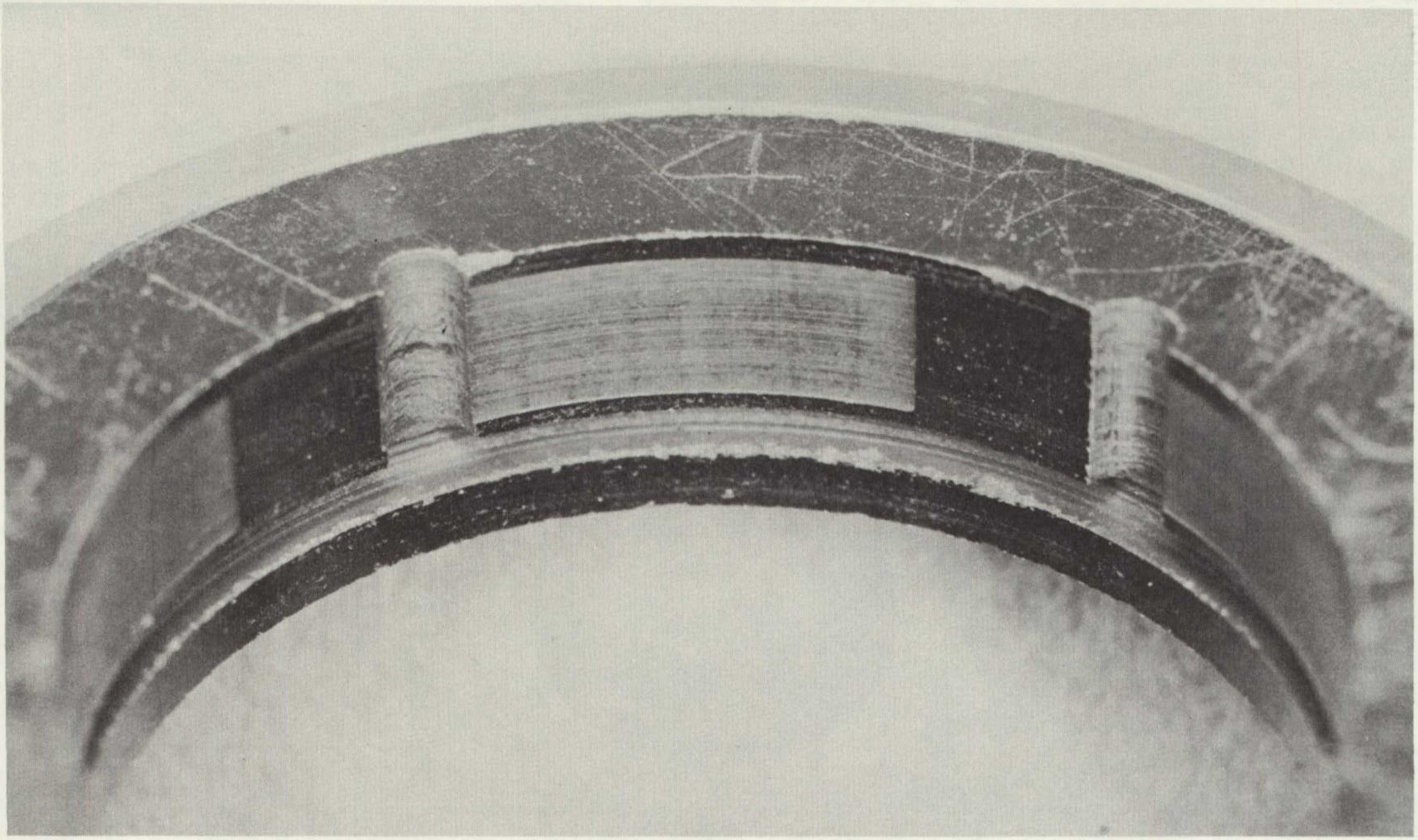


Figure 73. Helium Seal LOX Side Ring (P/N RS009693X, S/N 01, Posttest 088)

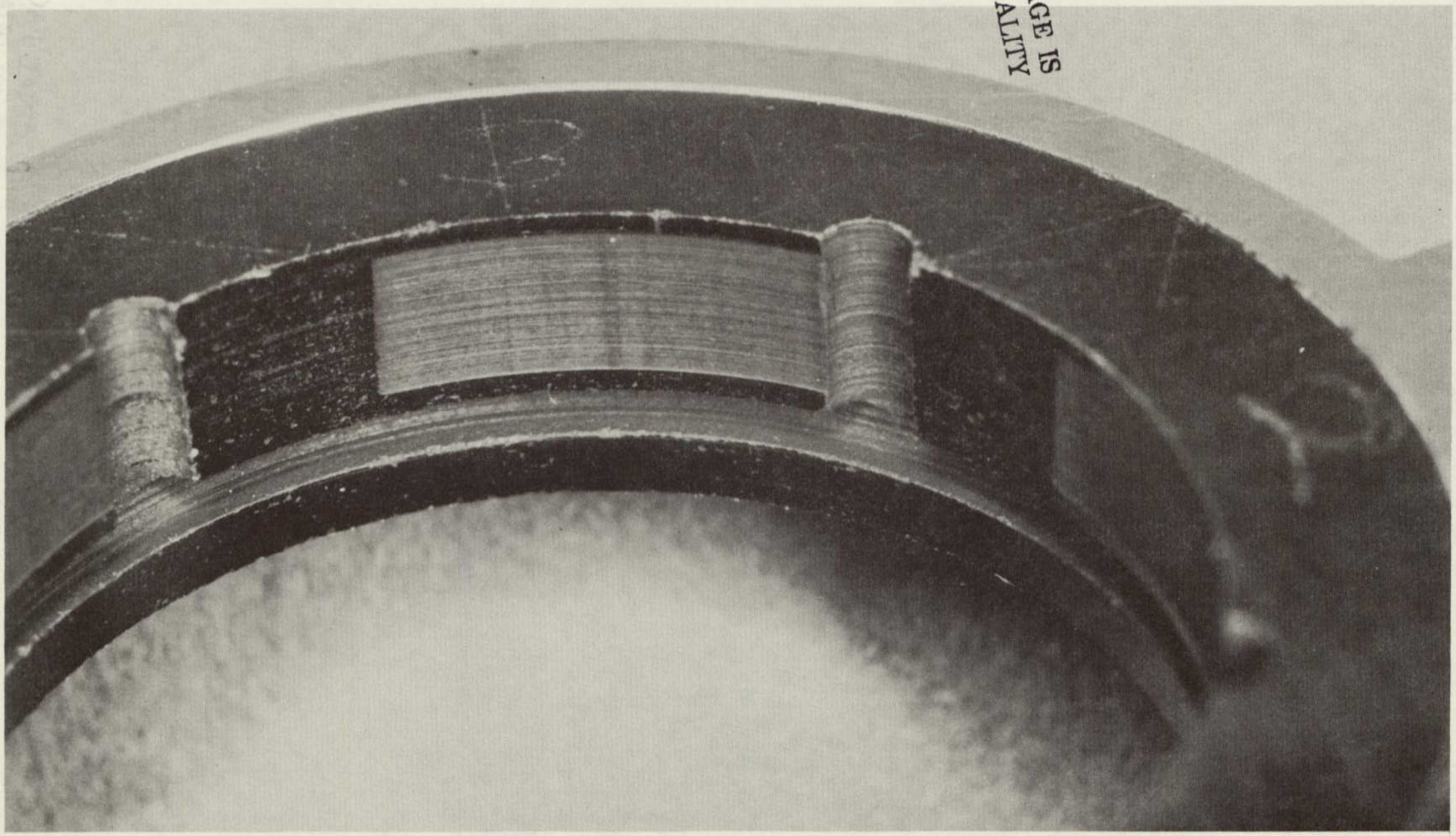
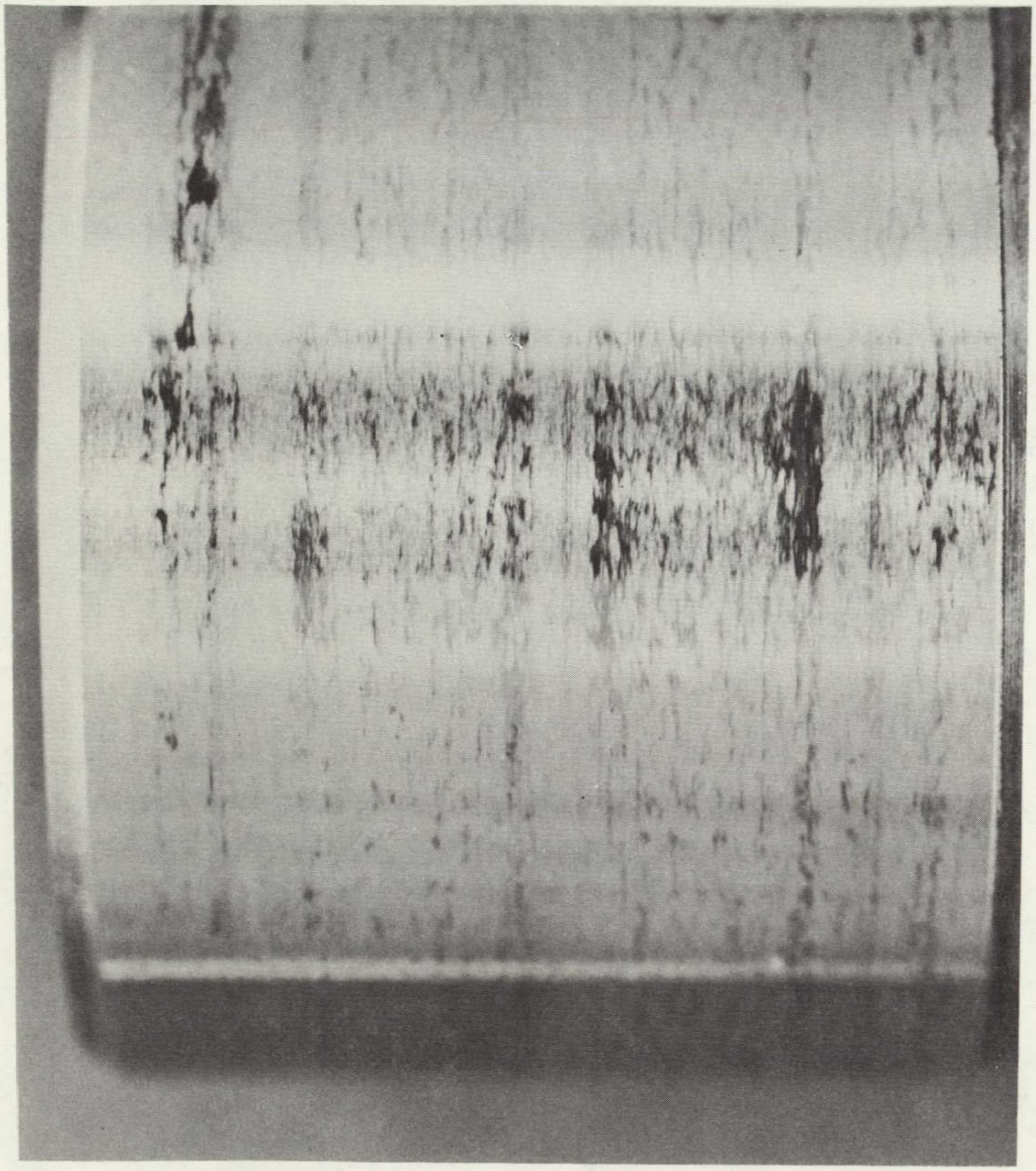


Figure 74. Helium Seal Turbine Side Ring (P/N RS009694X, S/N 01, Posttest 088)



Build 5 Disassembly. Posttest inspection revealed the tester bearings to be completely failed. The seals were damaged by excessive shaft radial and axial movements when the bearings failed. The LOX seal carbon was broken and the housing was rubbed by the mating ring when the seal was bottomed out in the axial direction. The surface of the carbon was polished and lightly scored from rubbing contact. The mating ring spiral groove surface was worn slightly on one side from rubbing contact, but was in relatively good condition considering the seal ran in an extreme overload condition. Photographs of the LOX seal hardware are shown in Fig. 76 and 77.

The helium seal carbon rings were chipped and worn due to excessive shaft radial movements. The helium mating ring surface was worn and grooved from the extreme radial load. The seal was in good condition otherwise. There were no structural failures. Photographs of the helium seal hardware are shown in Fig. 78 through 80.

Build 6 Assembly. The tester was reassembled with a new LOX seal carbon ring and spiral groove mating ring, new helium seal and mating ring, new bearings with 0.000013 m (0.0005 in.) smaller balls and the reworked tester hardware.

Tests 093-111. A total of 19 tests for 66.4 minutes, including the required ten 6-minute-duration tests, were performed to complete the remaining GN_2 checkout tests on the spiral groove LOX seal (Table 13). All tests were performed at 8062 $\pm$105 rad/s (77,000 $\pm$1000 rpm) and a helium purge pressure of 206,843 $\pm$34,474 N/m^2g (30 $\pm$5 psig). The LOX seal gaseous nitrogen pressure was increased from 1.034214 to 2,068,427 N/m^2g (150 to 300 psig) in 344,738 N/m^2 (50 psi) increments. A total of seven tests for 42.0 minutes were performed at 2,068,427 N/m^2g (300 psig).

Helium seal leakage increased from 0.142 to 0.187 m^3/minute (5.0 to 6.6 scfm) during the test series. The average leakage was 0.164 m^3/minute (5.78 scfm). LOX seal leakage repeated previous test values of 0.062 m^3/minute (2.2 scfm) at 1,034,214 N/m^2g (150 psig). Leakage increased with seal pressure as shown below:

Sealed Pressure, N/m^2g (psig)	Average GN_2 Leakage, m^3/minute (scfm)	Average Drain Pressure, N/m^3g (psig)
1,034,214 (150	0.062 (2.2)	4137 (0.6)
1,378,951 (200)	0.085 (3.0)	8963 (1.3)
1,723,689 (250)	0.108 (3.8)	11,721 (1.7)
2,068,427 (300)	0.130 (4.6)	15,168 (2.2)

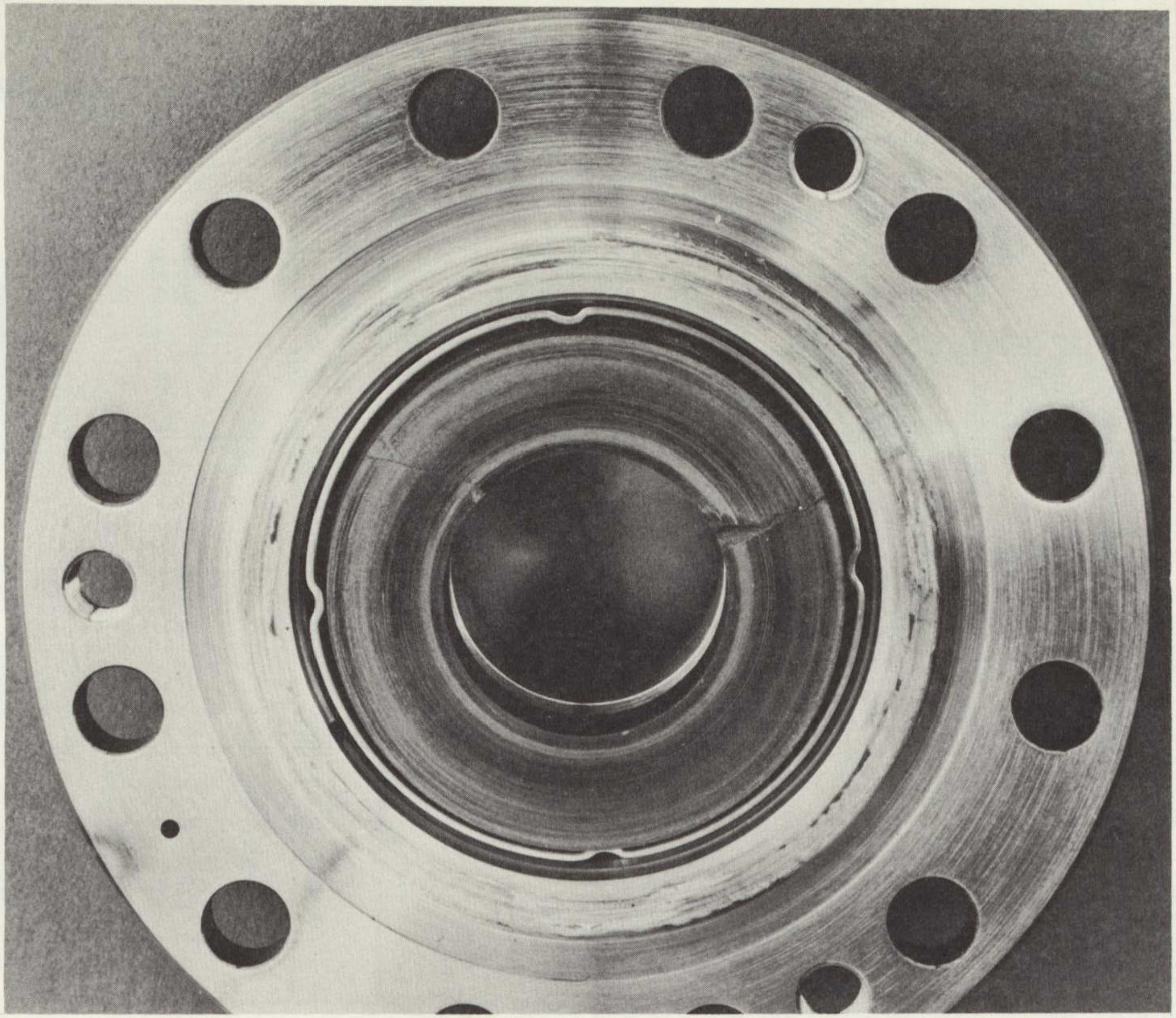


Figure 76. Spiral Groove LOX Seal (P/N RS009695X, S/N 01, Damaged by Bearing Failure Posttest 092)

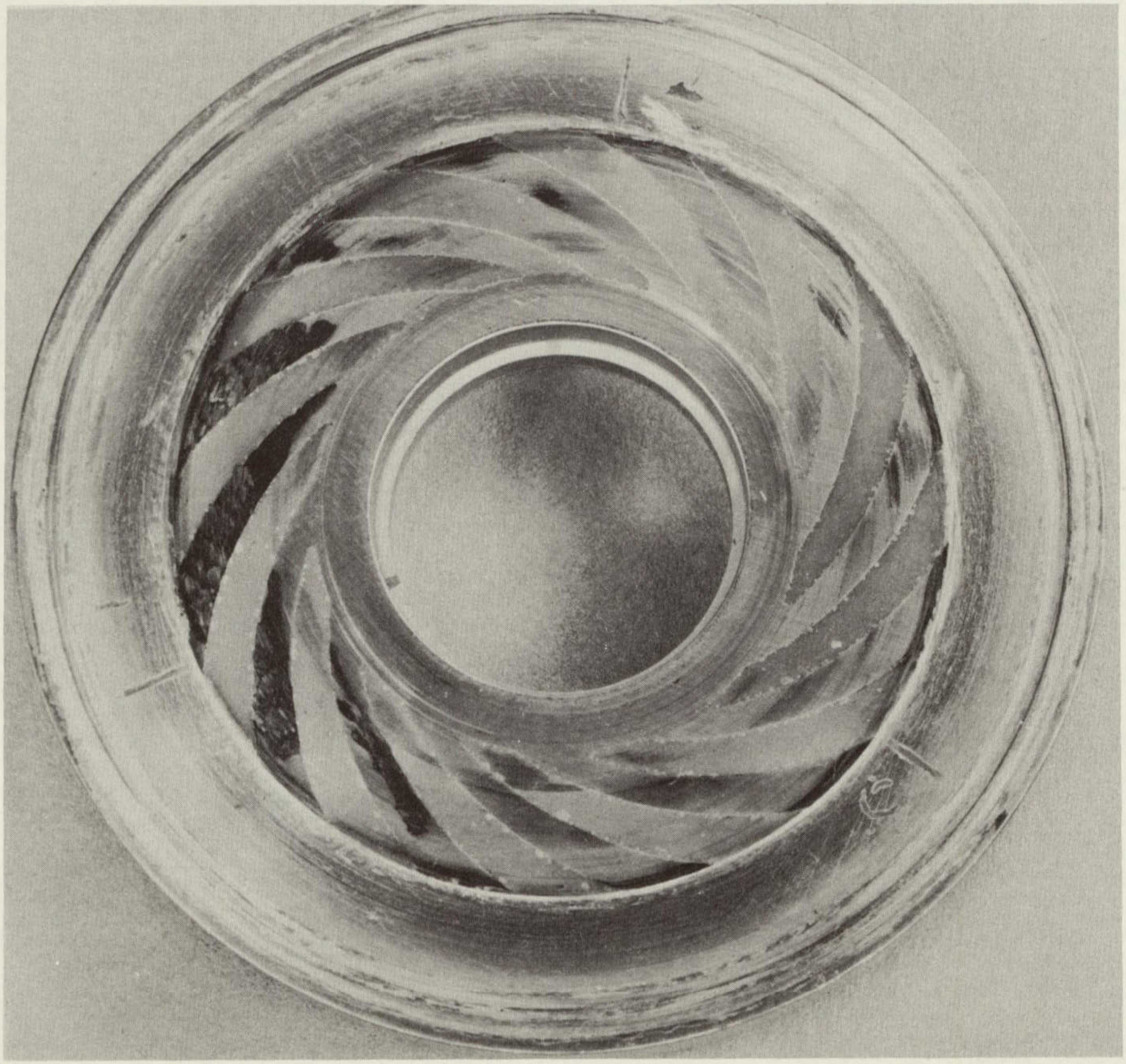


Figure 77. Spiral Groove LOX Seal Mating Ring (P/N C28-0812-10, S/N 01, Damaged by Bearing Failure Posttest 092)

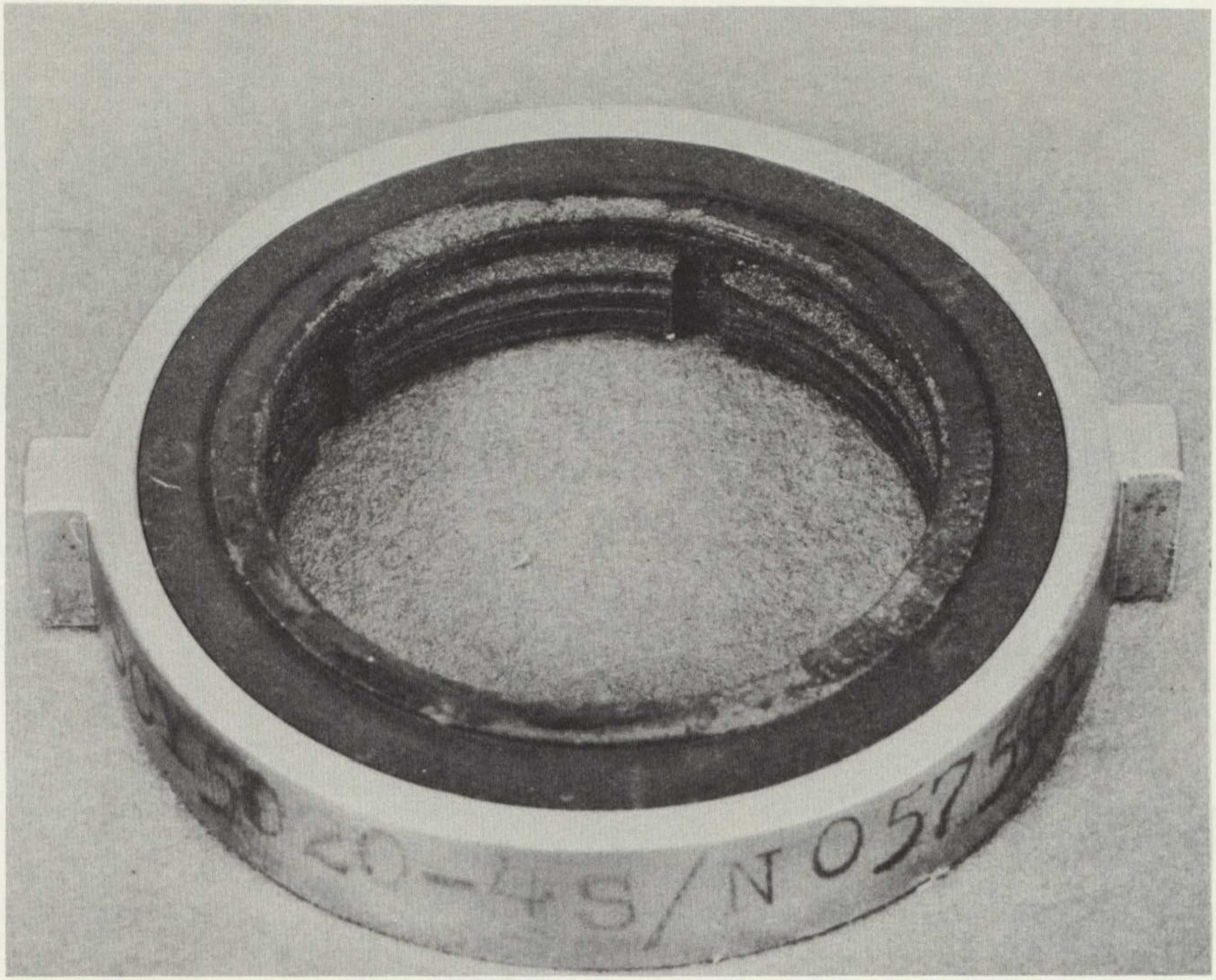


Figure 78. Helium Seal LOX Side Ring (P/N RS0096393X, S/N 01, Damaged by Bearing Failure Posttest 092)

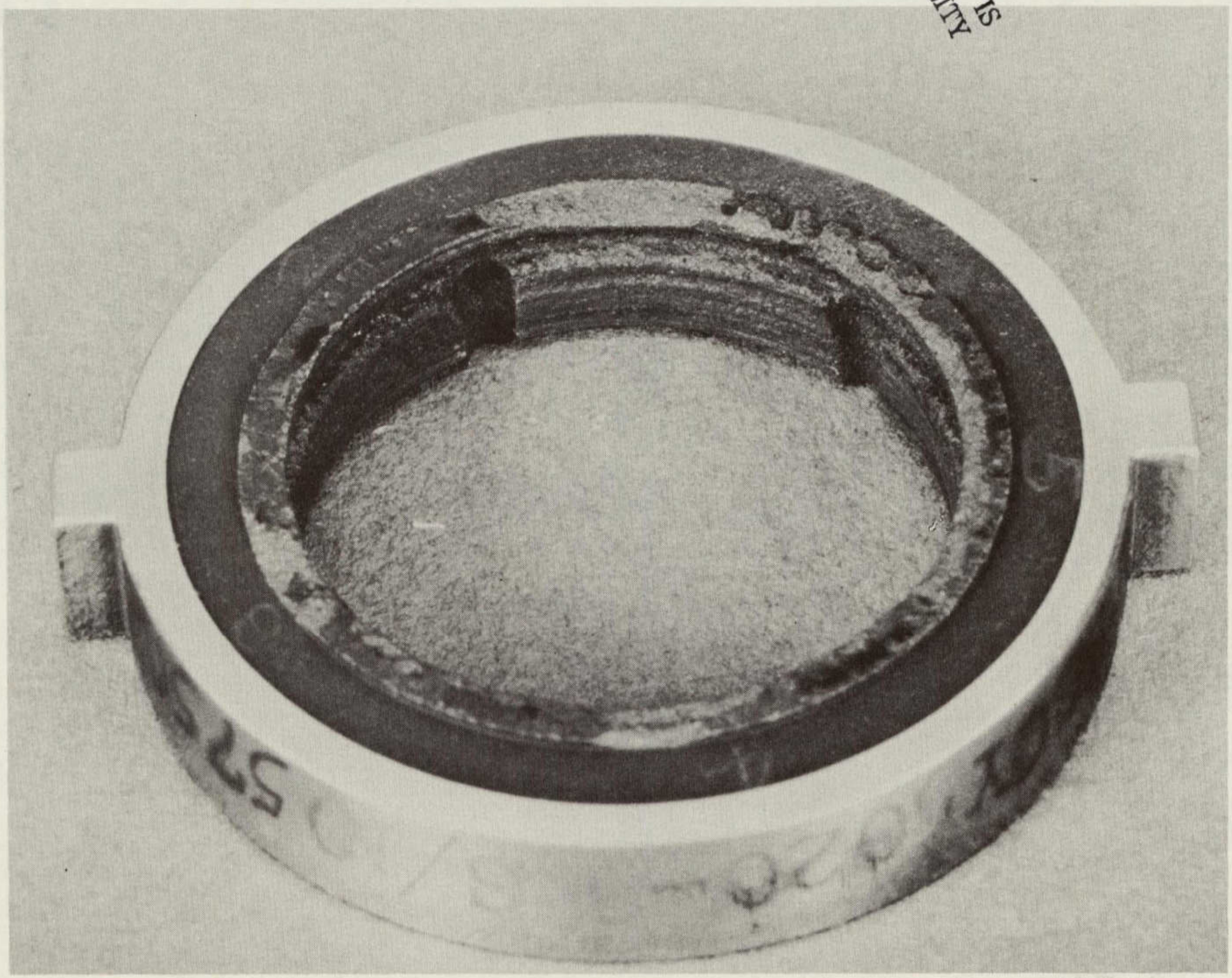
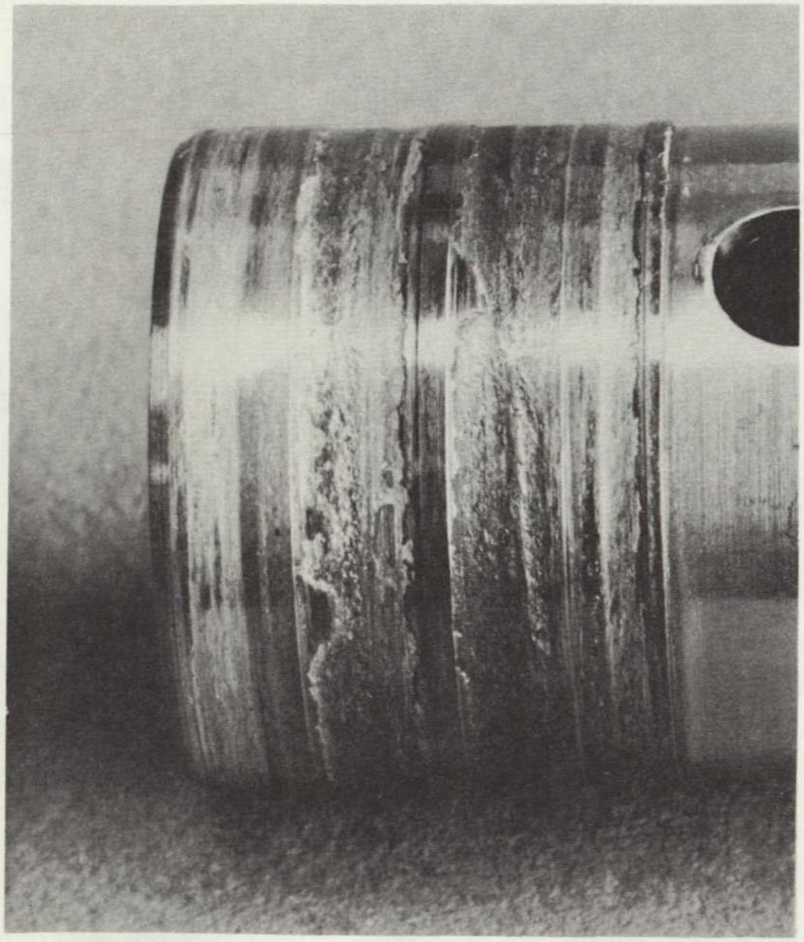


Figure 79. Helium Seal Turbine Side Ring (P/N RS009694X, S/N 01, Damaged by Bearing Failure Posttest 092)



TURBINE SIDE LOX SIDE

Figure 80. Helium Mating Ring (P/N RS009667X, S/N 002, Damaged by Bearing Failure Posttest 092)

Build 6 Disassembly. The spiral groove LOX seal was in good condition. Slight rub patterns were found on the mating ring and carbon face as shown in Fig. 81 and 82. A profile trace of carbon ring (Fig. 83) indicated slight wear near the inside diameter with a maximum depth of 0.00001 m (0.0004 in.). The spiral groove pad depth was 0.00001 m (0.0004 in.) pretst and posttest. The posttest static leakage was comparable with pretetest as shown in Table 9.

The helium seal was in good condition, except for carbon wear. The carbon ring recess pads were nearly worn away, as shown in Fig. 84 through 86. The profile traces indicated that the carbon ring wear ranged from 0.00001 to (0.0004 to 0.00002 m (0.0004 to 0.0008 in.) The carbon ring inside diameter was worn 0.000033 m (0.0013 in.). The static leakage at 206,843 N/m^2g (30 psig) increased from an average of 0.024 m^3/minute (1450 scim) pretest to 0.069 m^3/minute (4200 scim) posttest (Table 11). The helium seal mating ring had a slight rub pattern on one side as shown in Fig. 87. The other side appeared clean, indicating possible rotation off center. Fig. 88 shows the profile trace across the rub pattern area, indicating grooving due to the carbon rings with a maximum depth of 0.0000038 m (0.000150 in.).

Results and Conclusions. A total of 34 tests for 1 hour, 40.2 minutes, on three tester builds was performed. Test leakage is shown in Fig. 89 indicating 0.119 to 0.139 m^3/minute (4.2 to 4.9 scfm) at 2,068,427 N/m^2 (300 psi) and 8062 rad/s (77,000 rpm). Static GN_2 leakage was higher than running, ranging from 0.221 to 0.374 m^3/minute (7.8 to 13.2 scfm). No predicted GN_2 leakages were available.

LIQUID OXYGEN TESTS

Spiral Groove Piston Ring LOX Seal

Build 7 Assembly. The tester was reassembled with the same spiral groove LOX seal assembly. The carbon ring was lapped flat and the mating ring was lapped clean. A new helium seal assembly and mate ring was installed for the LOX testing.

Tests 112-186. The test objective was four 3-minute tests with liquid oxygen as the sealed fluid at speeds from 5235 to 8062 rad/s (50,000 to 77,000 rpm) and sealed pressures from 861,845 to 2,757,903 N/m^2g to 400 psi), on the spiral groove LOX seal. Helium seal purge pressure was set at 206,843 N/m^2g (30 psig) before and during each test.

A total of 38 tests for 42.75 minutes was required to achieve the first test point of 5236 rad/s (50,000 rpm) and 861,845 N/m^2g (125 psig) sealed pressure for 3 minutes (Table 13). Facility problems included inadequate ranges of LOX seal upstream pressure control and drive turbine pressure control. LOX seal performance was good at 0.051 m^3/minute (1.8 scfm) leakage and 3447 N/m^2g (0.5 psig) drain pressure. The helium seal purge pressure was 209,601 N/m^2g (30.4 psig) and total leakage was 0.181 m^3/minute (6.4 scfm).

A total of 10 tests for 16.25 minutes was required to achieve the second test point of 8062 rad/s (77,000 rpm) and 1,034,214 N/m^2g (150 psig) sealed pressure

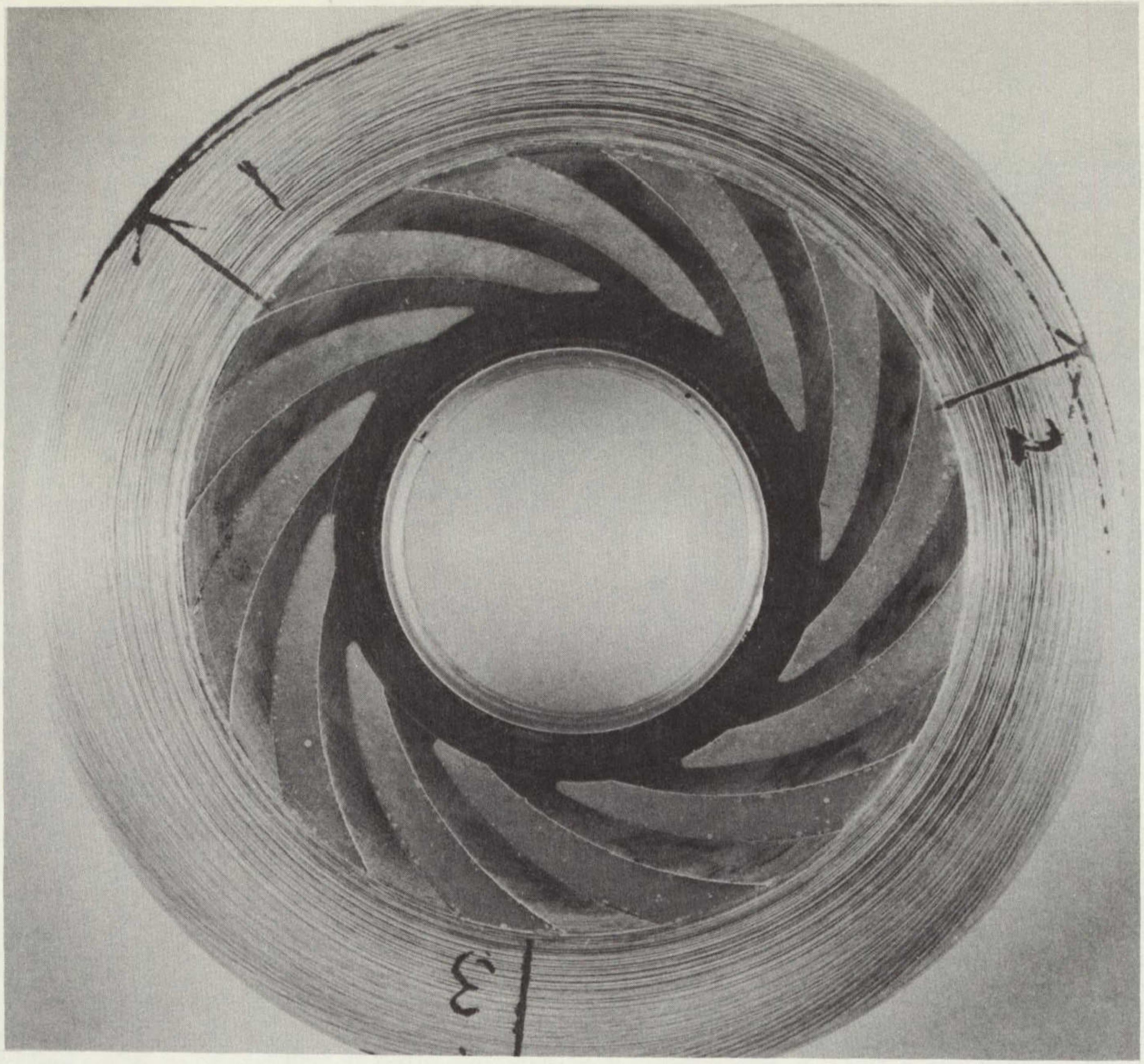


Figure 81. Spiral Groove LOX Seal Mating Ring
(P/N CF-SP-41118, S/N 02, Posttest 111)

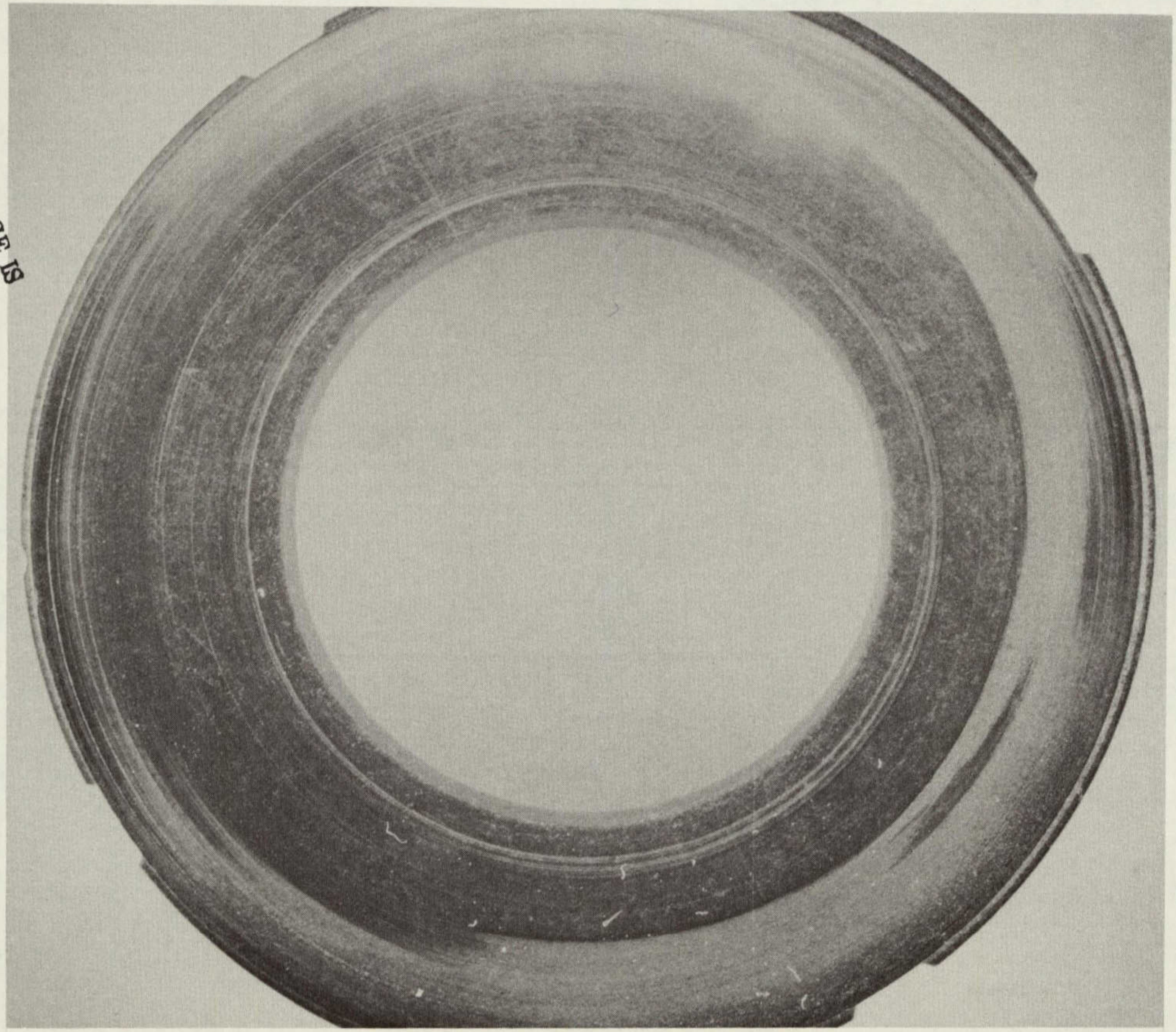


Figure 82. Spiral Groove LOX Seal Carbon Ring
(P/N A28-0812-11, S/N 02, Posttest 111)

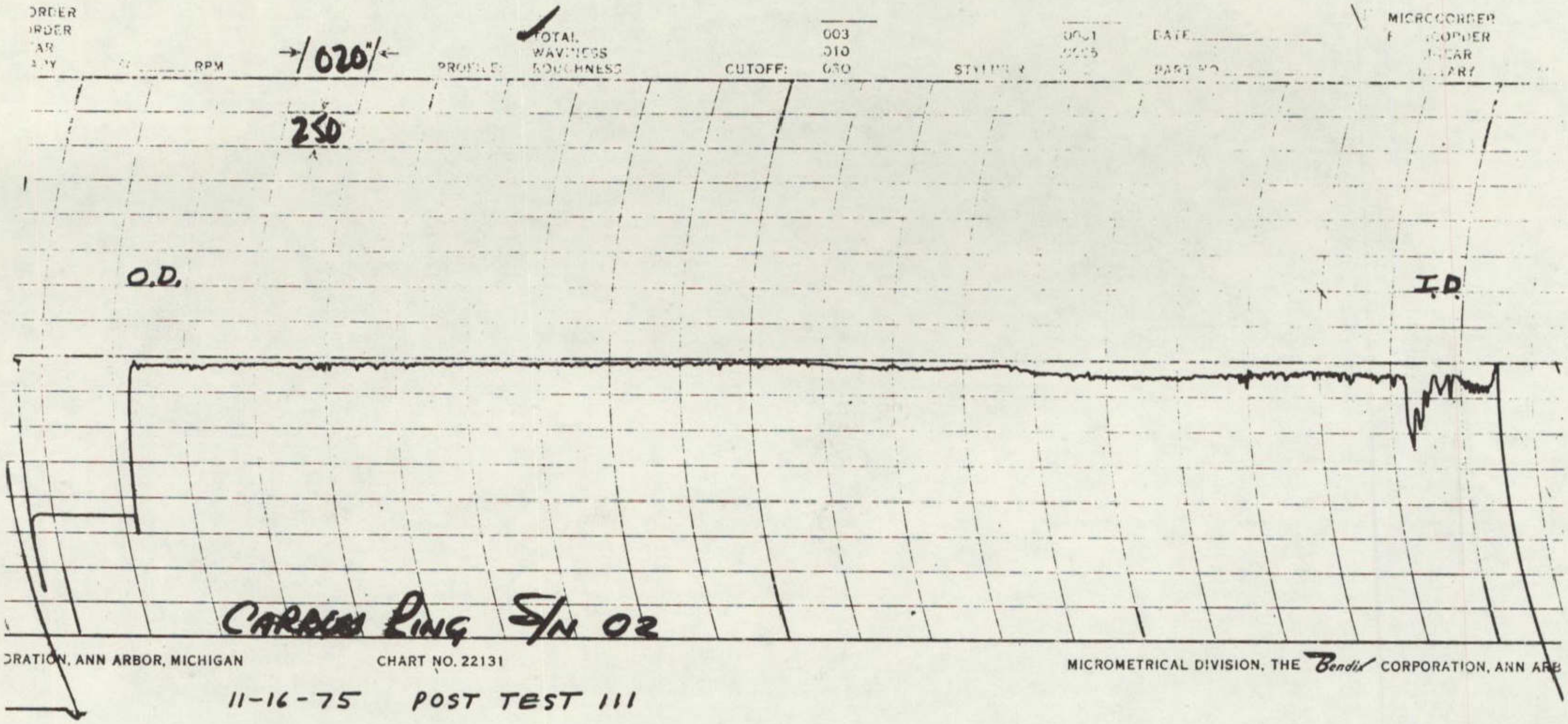


Figure 83. Typical Profile Trace of Spiral Groove LOX Seal Carbon Face (P/N A28-0812-11, S/N 02, Posttest 111)

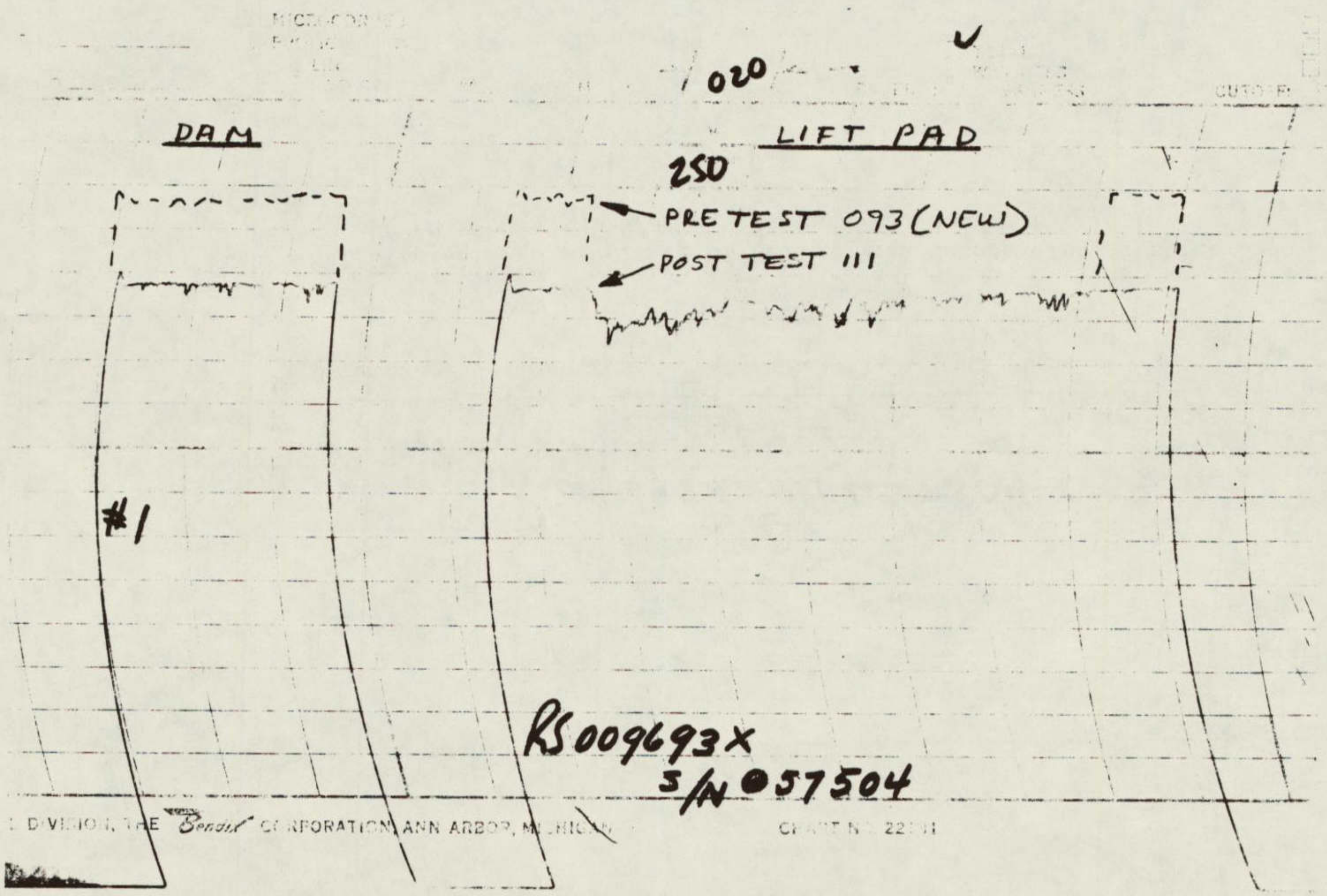


Figure 84. Typical Profile Trace of Helium Seal Carbon Ring, LOX Side
(P/N RS009693X, S/N 04, Pretest 093 and Posttest 111)

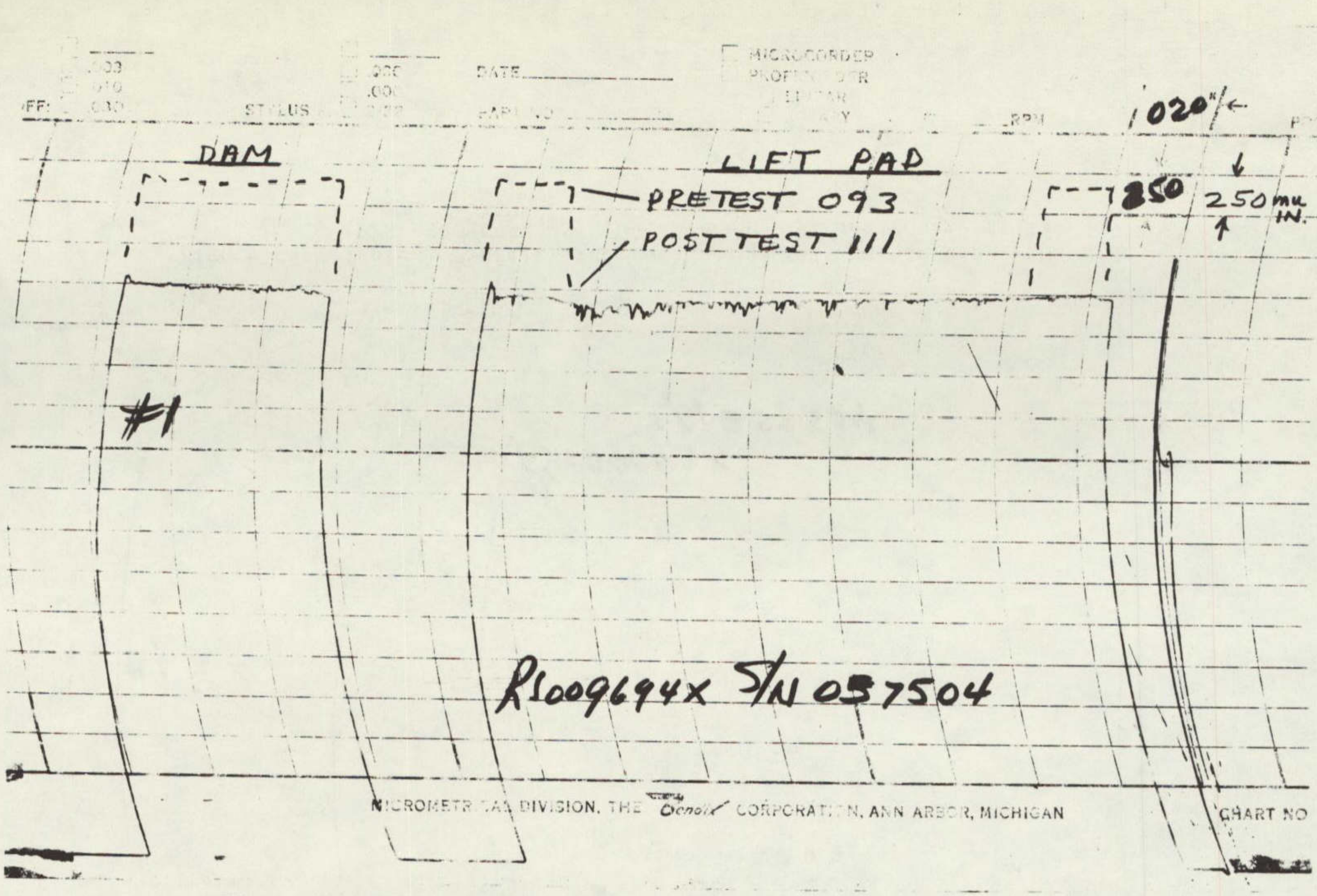


Figure 85. Typical Profile Trace of Helium Seal Carbon Ring, Turbine Side (P/N RS009694X, S/N 04, Pretest 093, Posttest 111)

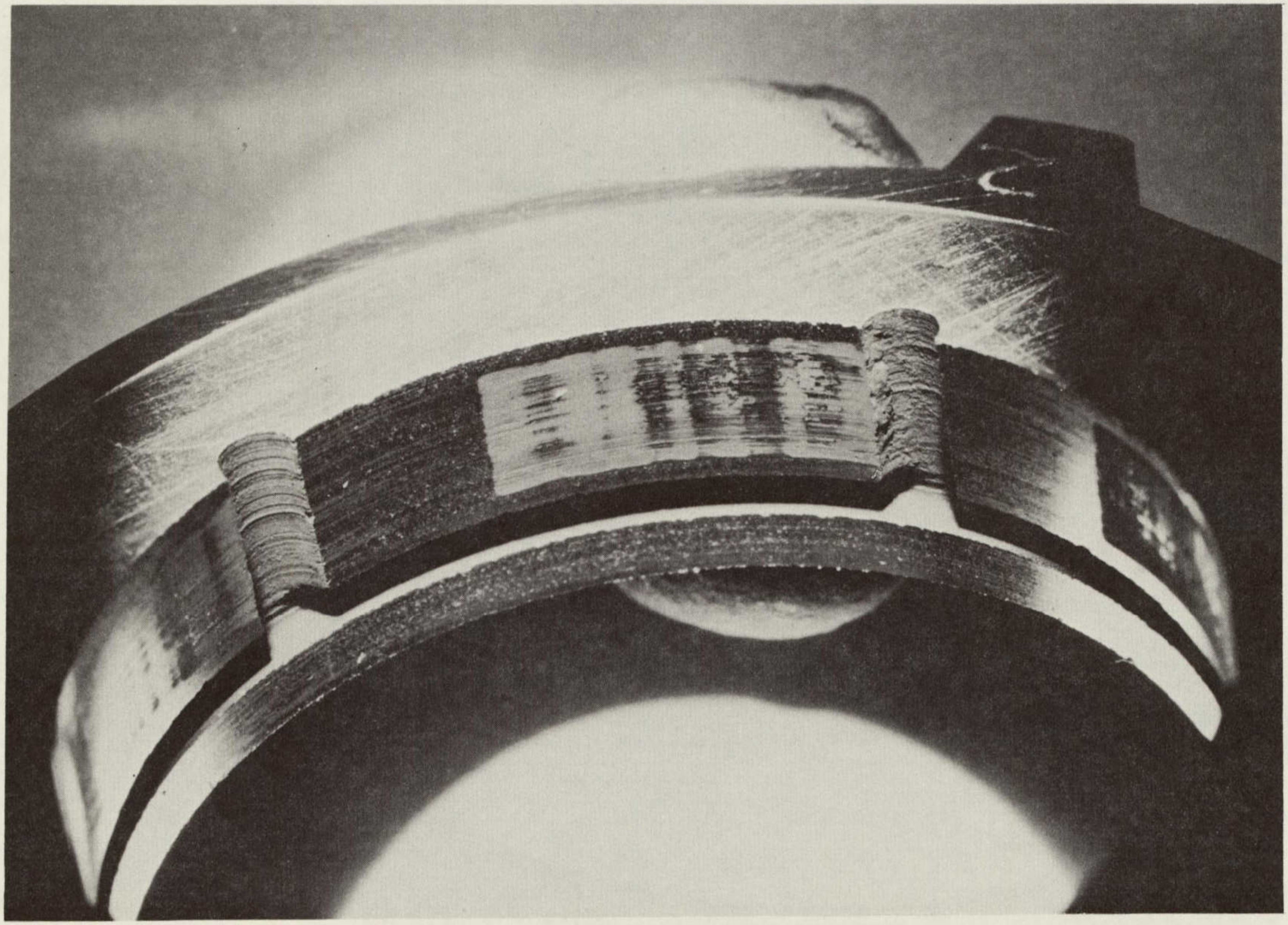
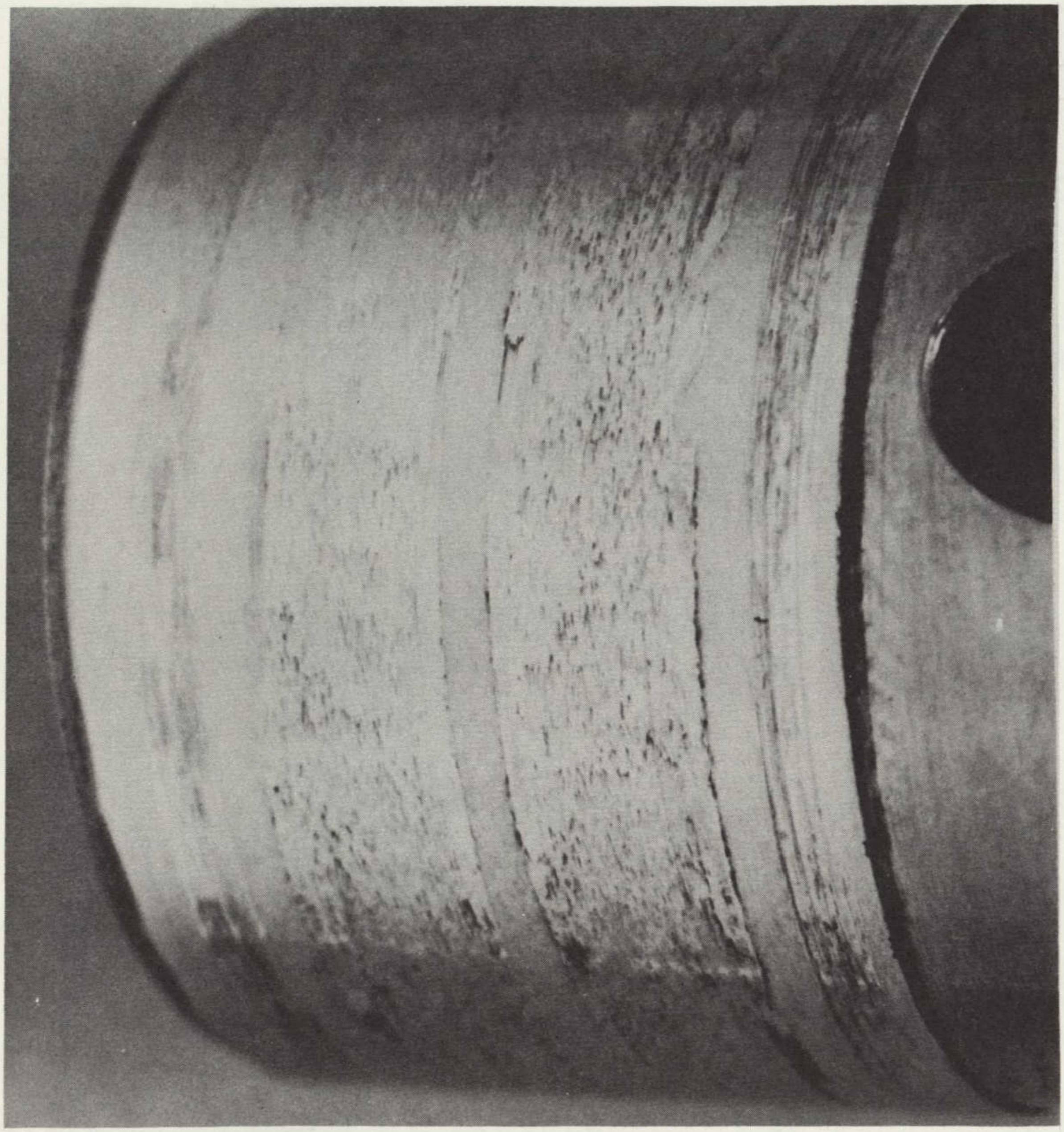


Figure 86. Helium Seal Turbine Side Ring (P/N RS009694X, S/N 04, Posttest 111)



TURBINE SIDE LOX SIDE

Figure 87. Helium Mating Ring (P/N RS009667X, S/N 001, Posttest 111)

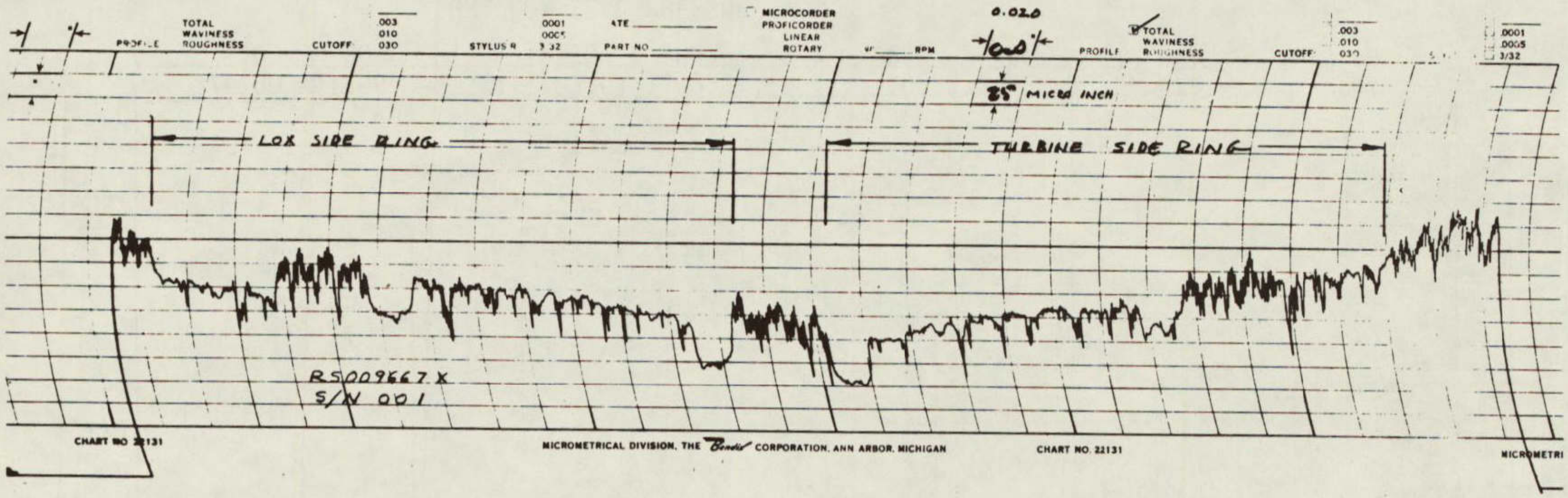


Figure 88. Profile Trace of Helium Seal Mating Ring Surface at High Magnification (P/N RS009667X, S/N 02, Posttest 111)

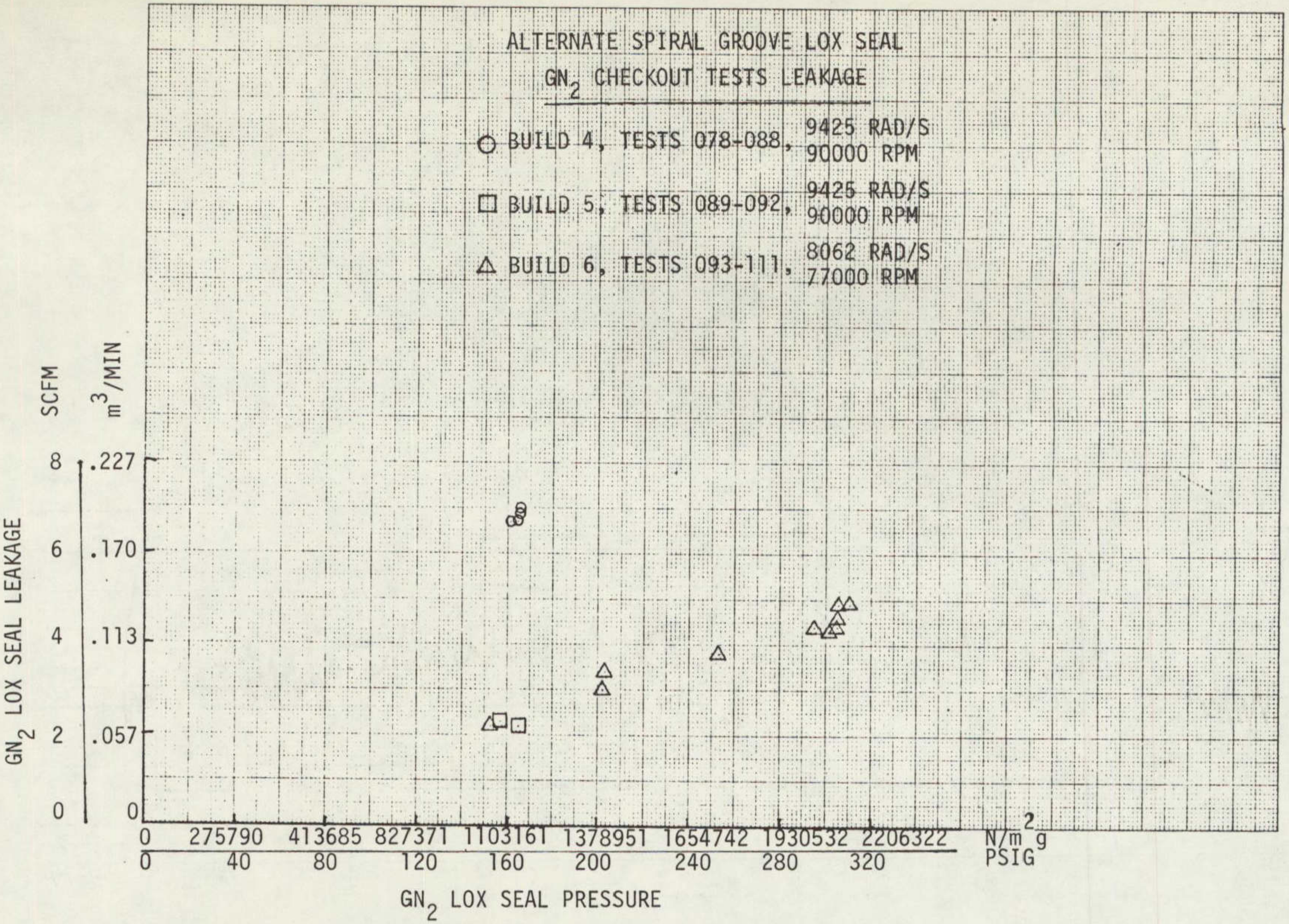


Figure 89. Test Leakage

for 3 minutes (Table 13). The LOX seal leakage was less than the first test point at 0.040 m^3/minute (1.4 scfm) with a drain pressure of 1379 N/m^2g (0.2 psig). The helium seal purge pressure was 208,911 N/m^2g (30.3 psig) and total leakage was 9.181 m^3/minute (6.4 scfm).

A total of 76 tests for 1 hour, 24 minutes, was made on build 7. Nine tests were over 2 minutes duration and two of the test points were achieved. The tester control was very difficult. LOX seal leakage is shown in Fig. 90 .

The tester was removed for inspection after high shaft torque and high seal leakages were experienced following an accidental dry spinup of the tester for approximately 20 seconds during an electrical checkout of the fast-start turbine drive system at Wyle Laboratories. The tester was extensively damaged by the dry spin.

Build 7 Disassembly. Tester shaft turning torque was high and rough, and static LOX seal leakage was excessive.

Tester disassembly revealed:

1. Helium seal and mating ring completely failed as shown in Fig. 91 due to high-speed rubbing and excessive shaft deflection.
2. Spiral groove LOX seal carbon ring shattered, as shown in Fig. 92 , due to excessive shaft deflection.
3. Spiral groove LOX seal mate ring sheared the shaft key, as shown in Fig. 93 ; rotated on the pilot diameter, failing the static seal; and rubbed against the seal housing.
4. Both bearings were completely failed.

Results and Conclusions. Analysis indicates that the speed ran away when the turbine gas supply valve was opened at full turbine pressure of 1,034,215 N/m^2g (150 psig) with the tester dry and unloaded.

The test data prior to the dry spin indicates normal tester operation. The LOX and helium seal leakages (Table 13) were normal on the last test (186) prior to the dry spin, indicating that the seals were in good condition at completion of testing. The seal leakage increased excessively after the dry spin without any additional tester rotation, except for hand torquing. Therefore, it was concluded that the seal damage occurred during the dry spin.

The test plan was revised to delete test points 3 and 4 of test schedule II. The test schedule II LOX testing was continued with 300 three-minute acceleration-deceleration tests from 0 to 8062 rad/s (77,000 rpm) and from 37,895 to 2,757,903 N/m^2d (20 to 400 psid) LOX seal pressure using a new spiral groove LOX seal for a total time of 15 hours.

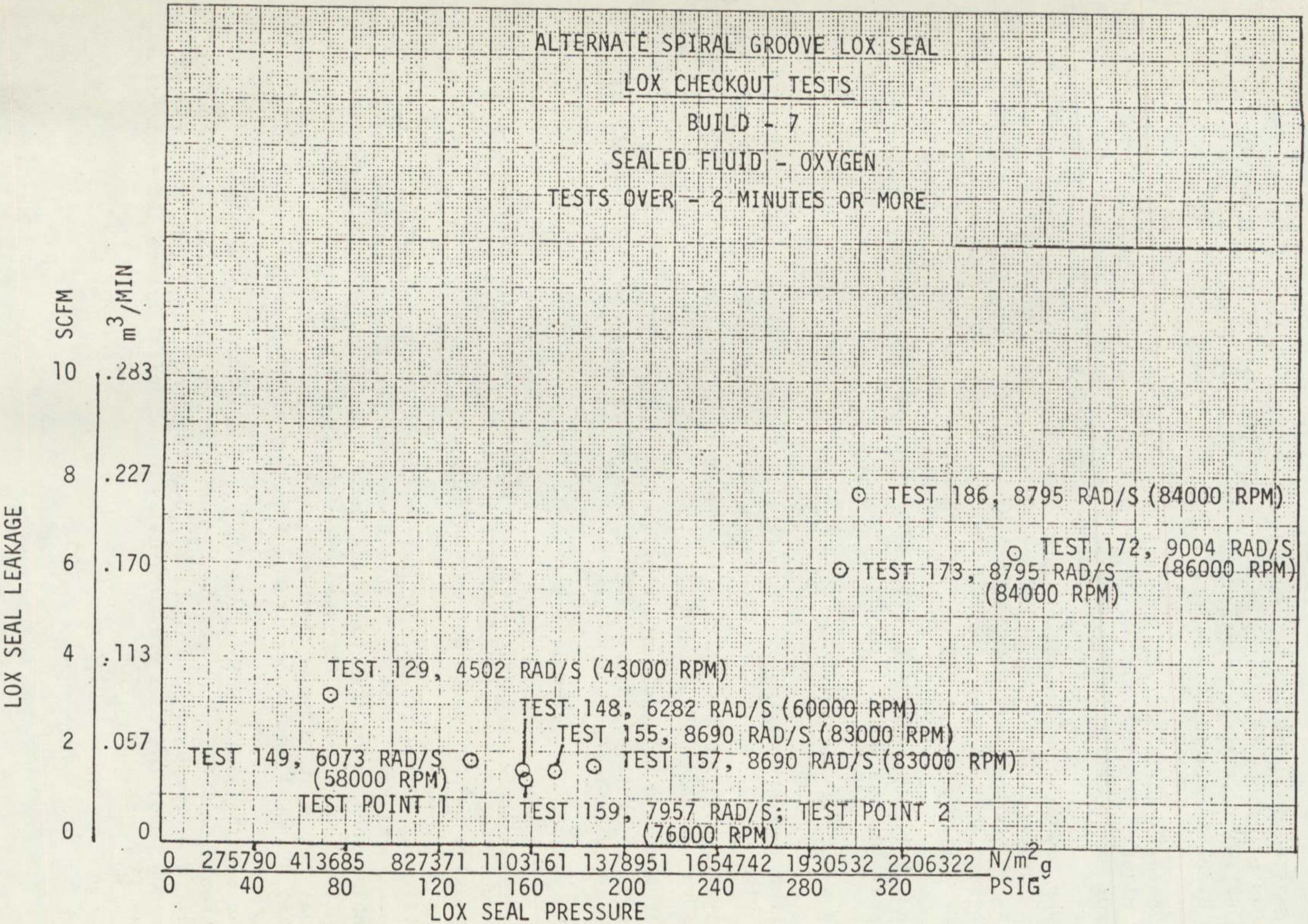


Figure 90. Seal Leakage

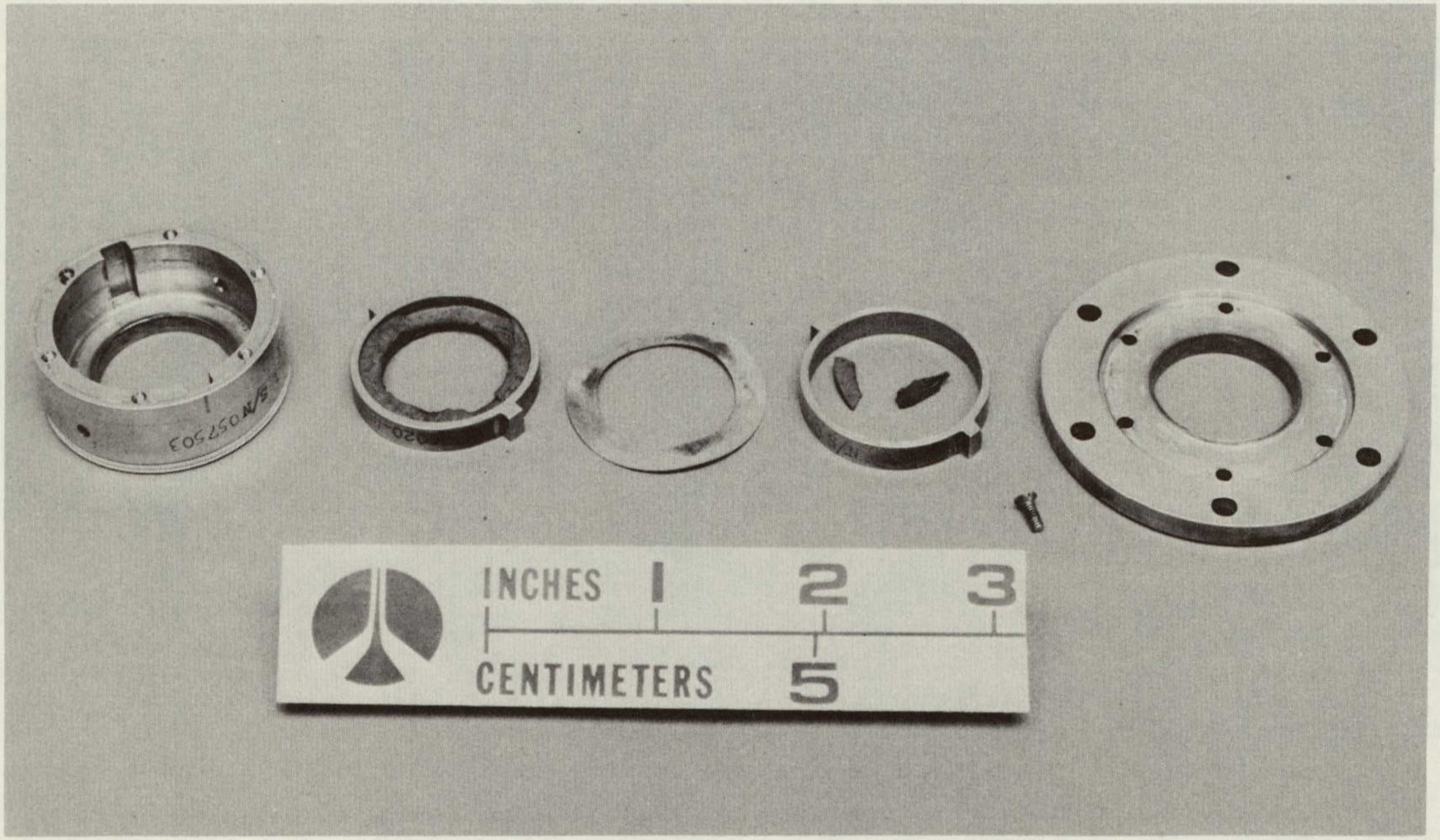


Figure 91. Helium Seal Assembly (Posttest 186 Spinup)

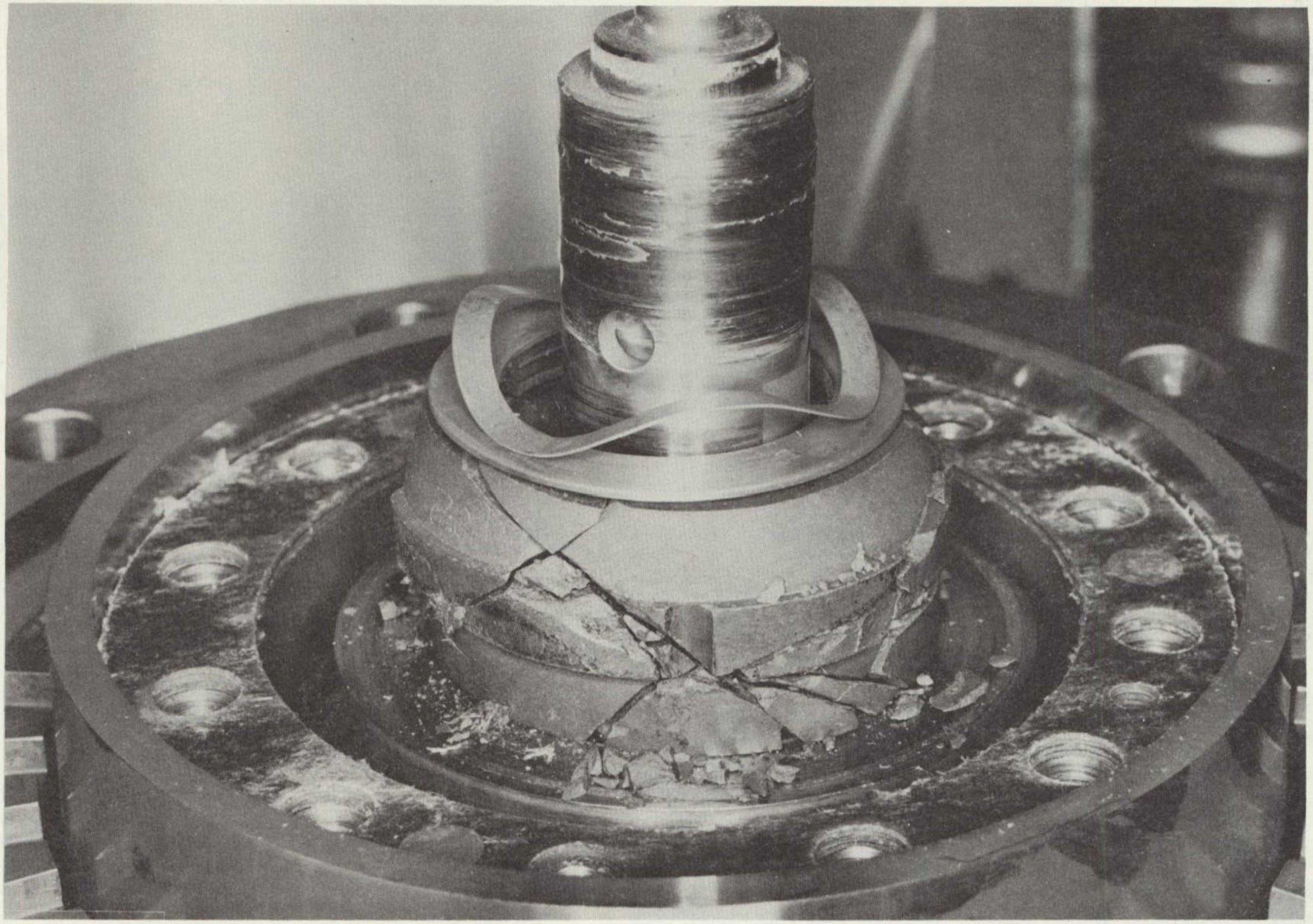


Figure 92. Spiral Groove LOX Seal Carbon Ring (Posttest 186 Spinup)

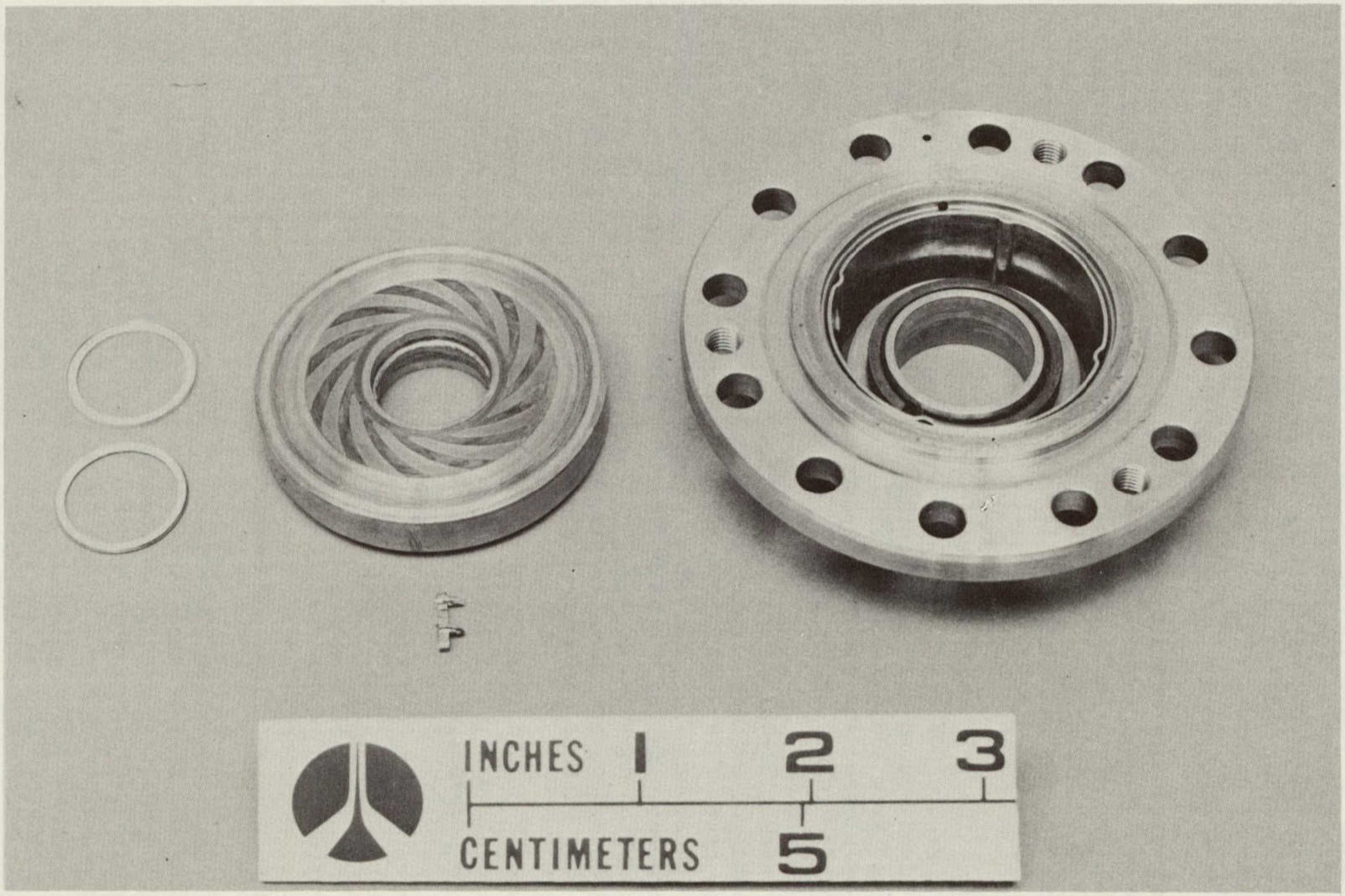


Figure 93. Spiral Groove LOX Seal Mate, Key, Static Seal, and Housing (Posttest 186 Spinup)

Build 8 Assembly. The tester assembly was completed with a new spiral groove alternate design LOX seal. The installed length spring load was 16.24 N (3.65 pounds). The spiral groove mating ring was nicked in the seal dam area during removal when balancing the rotating hardware. The mating ring was relapped prior to assembly; however, the nick was not removed. The LOX seal GN_2 static leakage was 0.374 m^3/minute (13.2 scfm) at 2,068,427 N/m^2g (300 psig).

A new helium purged intermediate seal was installed with 0.000028 m (0.0011 in.) ambient diametral clearance on the LOX side and 0.000033 m (0.0013 in.) on the turbine side. The static helium leakage at 206,843 N/m^2g (30 psig) was 0.015 m^3/minute (0.52 scfm) for the LOX side and 0.031 m^3/minute (1.09 scfm) on the turbine side. The LOX and helium seal build data are listed in Tables 9 and 11.

Tests 187-332. The test objective was 150 starts, or a total time of 5 hours on the spiral groove LOX seal. The speed was ramped from 0 to 8062 rad/s (77,000 rpm) in 2 seconds using the turbine fast-start system. The seal pressure was ramped from 206,843 to 2,757,903 (30 to 400 psig) in the same time. The tester was stopped and the seal pressure was vented in less than 4 seconds using the turbine reversing nozzles.

The initial tests (187-227) were facility checkout tests. Limited turbine pressure capability prevented reaching test point conditions for tests 187-202. The final two tests (226 and 227) were satisfactory duration tests, completing the facility checkout. The fast-start speed and LOX seal pressure start transients are shown in Fig. 94 and 95. The LOX seal pressure ramp rate as a function os speed is shown in Fig. 96. The shutdown transient speed and LOX seal pressure data are shown in Fig. 97 and 98. The deceleration requirements were met without using the tester brake system.

Tests 228 through 327 included 79 duration tests and premature cuts due to problems with operation of the turbine valves. Tests 328 through 331 were terminated due to problems with the turbine drive valves.

Test 332 was cut during the fast start by a bearing cavity overpressure and tester accelerometer redline. The bearing drain temperature was offscale warm 144.3 K (-200 F). Posttest inspection revealed carbon debris in the turbine side drain ports. The tester shaft torque was in excess of 1.695 N•m (15 in.-lb) compared to previous values of less than 0.11299 N•m (1 in.-lb). The inspection and test data indicated a bearing failure with damaged seals.

A summary of the steady-state LOX and helium seal leakages is presented in Table 13. The LOX seal leakage varied from 0.544 to 1.441 m^3/minute (19.2 to 50.9 scfm). The LOX seal leakage on the short tests was generally higher (up to approximately 1.982 m^3/minute; 70 scfm) during the start transient. The steady-state leakage stabilized at approximately 0.850 to 1.416 m^3/minute (30 to 50 scfm) after the first half hour of testing. The helium seal leakage held steady during the test series at approximately 0.396 to 0.453 m^3/minute (14 to 16 scfm).

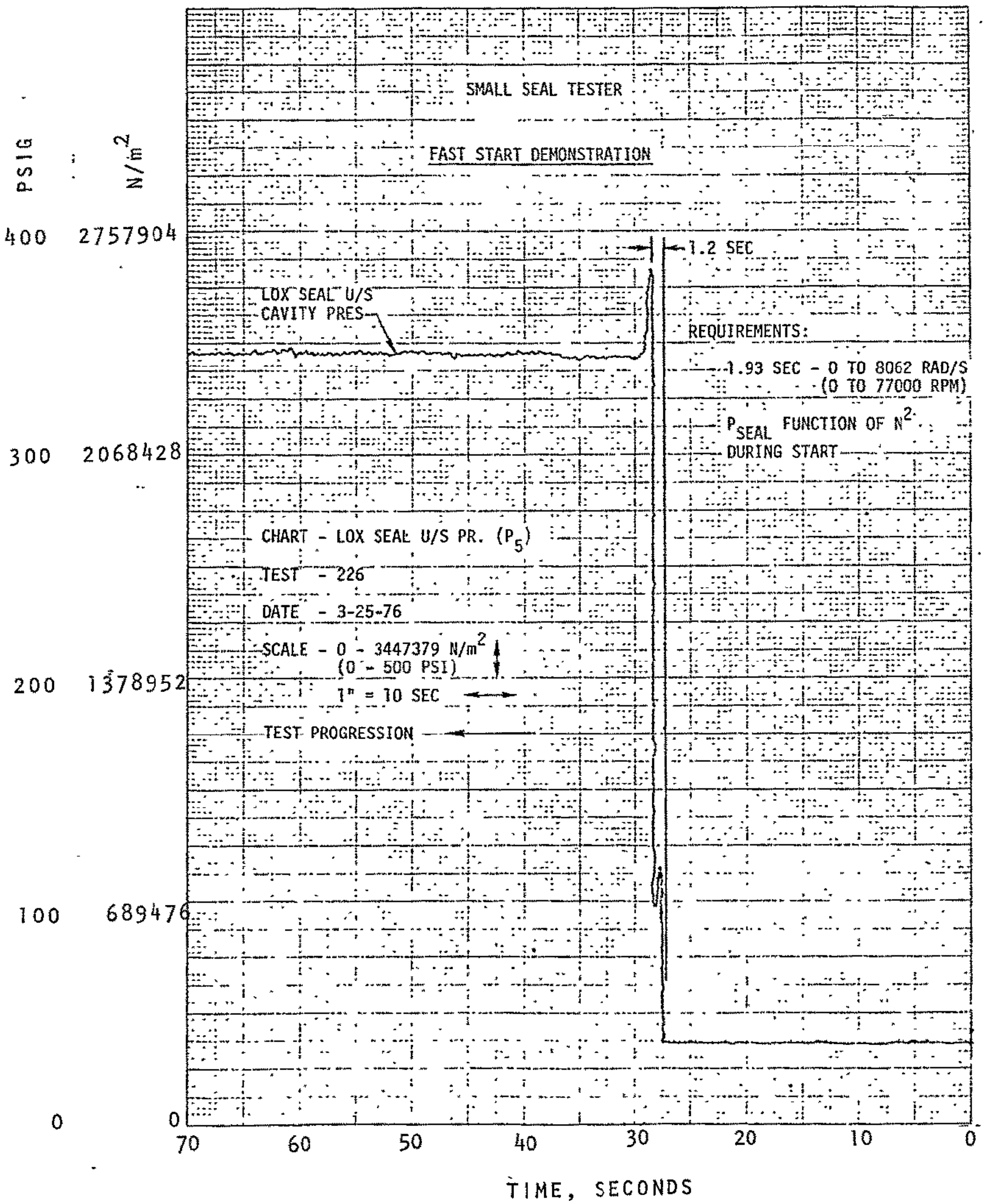


Figure 95. Small Seal Tester

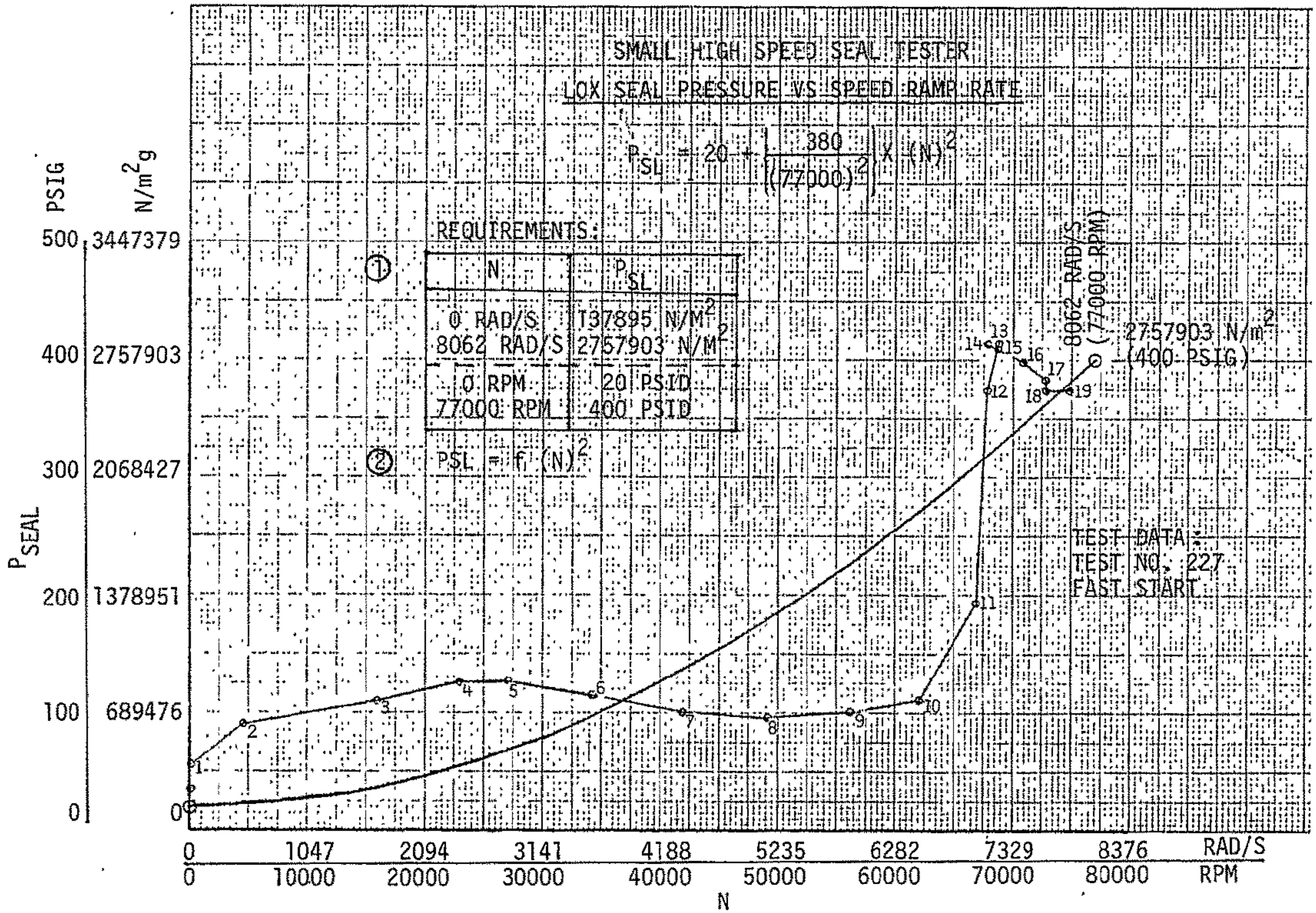


Figure 96. Seal Pressure vs Speed for Acceleration Testing

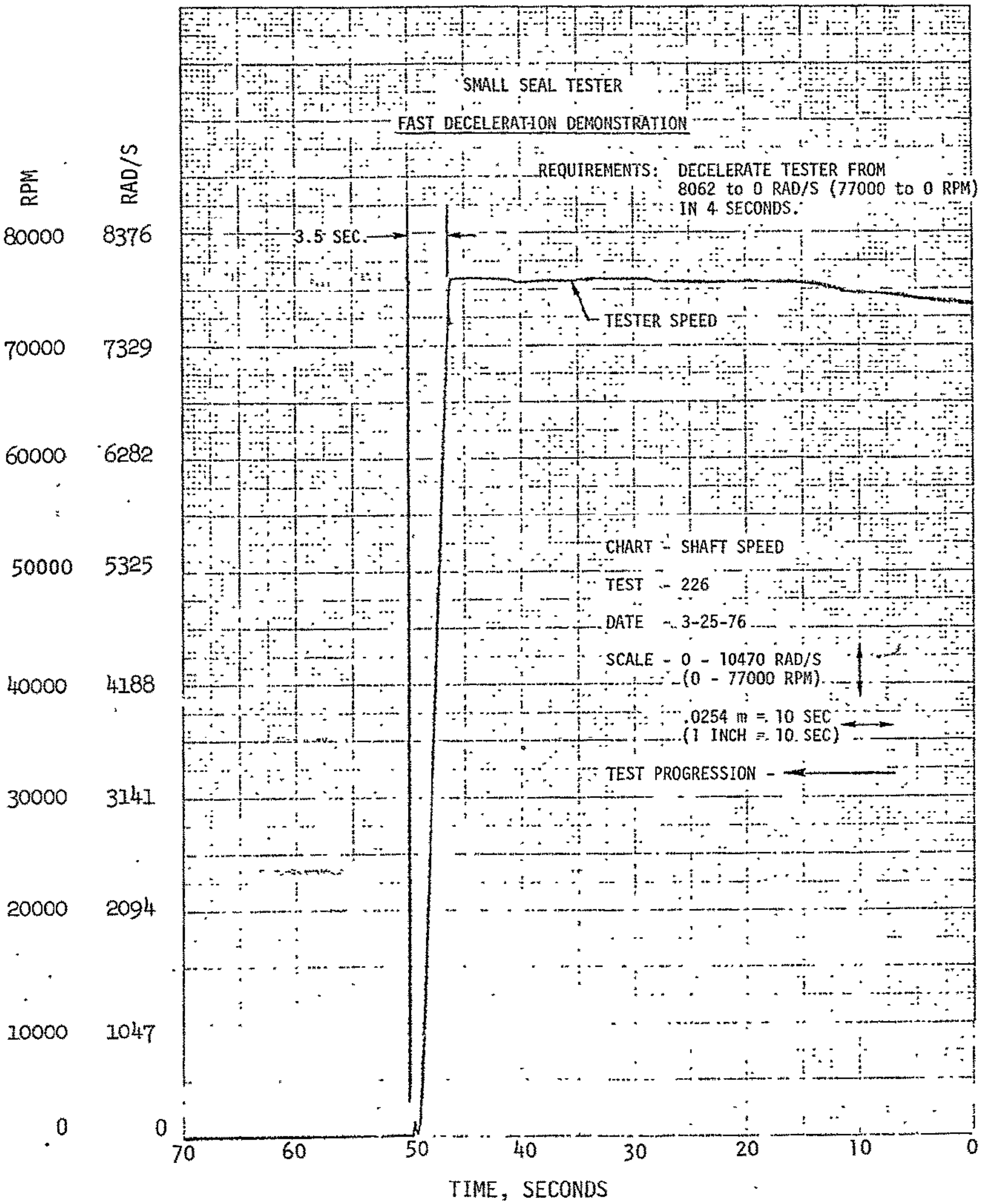


Figure 97. Deceleration Testing (rpm)

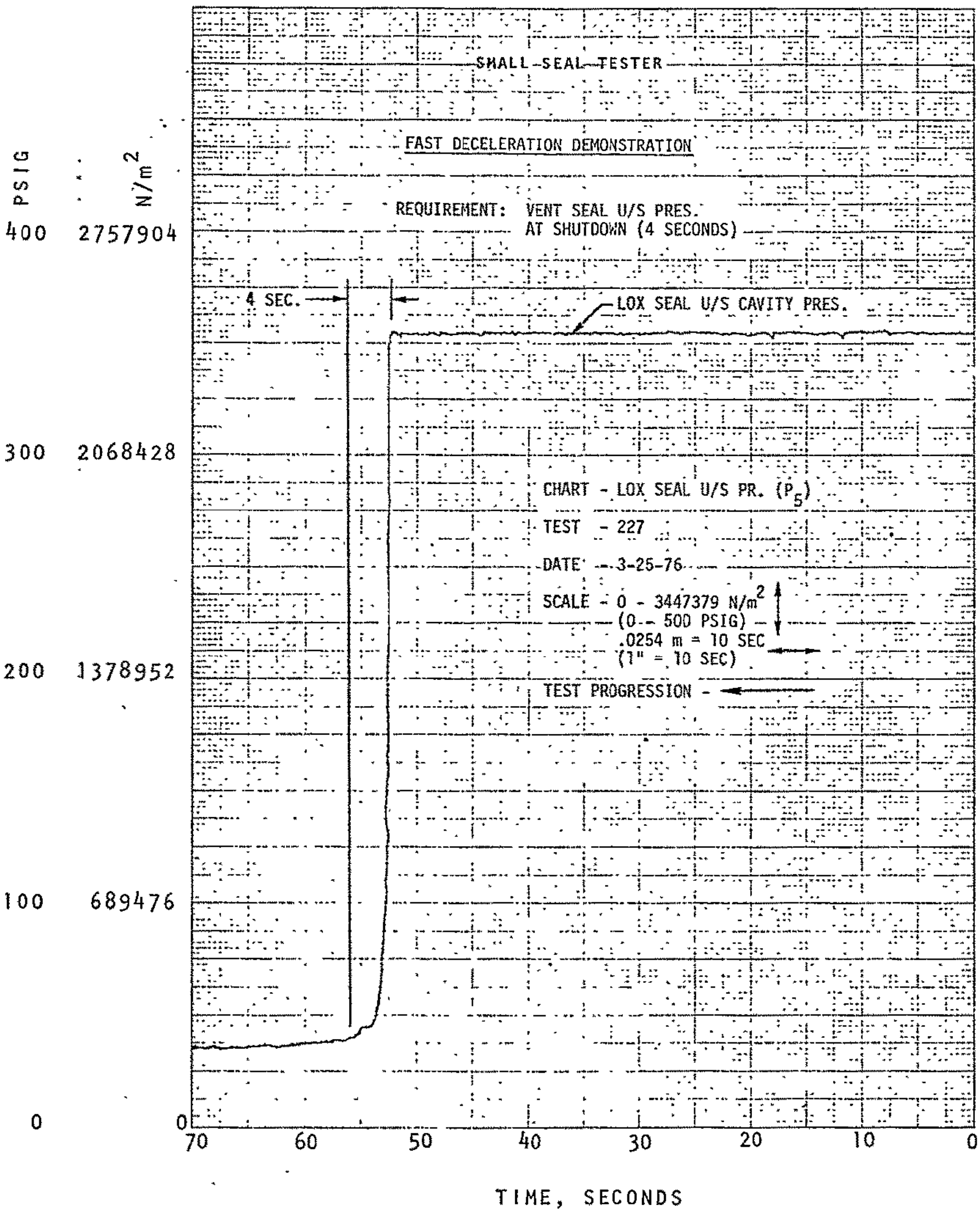


Figure 98. Deceleration Testing (pressure)

Build 8 Disassembly. Inspection revealed both bearings to be completely failed. The spiral groove LOX seal carbon seal ring was shattered from the shaft thrust load after the bearings failed. The spiral groove mating ring surface was heavily rubbed and scored by the excessive thrust load. Since the seal leakage was consistent on the tests prior to the bearing failure, it is concluded that the mating ring rubbing occurred after the bearing failed.

The helium seal carbon rings and mating ring sleeve were heavily rubbed and worn from excessive misalignment after the bearings failed. The seal housing was damaged by rubbing contact at the mating ring.

The damaged seal hardware is shown in Fig. 99 through 104.

Rayleigh Step Piston Ring LOX Seal

Build 9 Assembly. A new Rayleigh step LOX seal was installed with a new mating ring. The seal was assembled with four springs for an installed load of 9.207 N (2.07 pounds). The spring load was reduced from the 12.454 N (2.8 pounds) load used on the last Rayleigh step seal tested to reduce wear. The seal static leakage was 0.018 m^3/minute (1090 scim) at 2,068,427 N/m^2g (300 psig).

A used helium seal from build 6 was installed. The carbon lift pads were partially worn; however, the seal was in satisfactory condition. The recess pad depth varied from 0 to 0.000013 m (0.0005 in.). The seal ring diametral clearance was 0.00005 m (0.0021 in.) on the LOX side and 0.000061 m (0.0024 in.) on the turbine side. The static He leakage at 206,843 N/m^2g (30 psig) was 0.065 m^3/minute (3980 scim) on the LOX side and 0.080 m^3/minute (4900 scim) on the turbine side.

Tests 333-412. The test objective was to complete a minimum of 75 starts for a total time of 2.5 hours on the Rayleigh step LOX seal prior to a scheduled inspection. The scheduled test duration was 3 minutes. The tests were part of the 300 starts and 10 hours required for the schedule II fast-start LOX testing. The speed was ramped from 0 to 8062 rad/s (77,000 rpm) in 2 seconds.

The LOX seal pressure was ramped from 206,843 to 2,757,903 N/m^2g (30 to 400 psig) in the same time. A total of 80 tests for 2.5 hours was performed to complete the test objective (Table 13). The initial tests (333 through 339) were all over-speed cutoffs with indicated maximum speeds in excess of 10,470 rad/s (100,000 rpm). The overspeed cutoffs were apparently caused by the tester drag torque being lower, since the turbine start pressures were the same as the last build. The turbine start pressure was lowered and most of the remaining tests were scheduled duration. A total of 50 duration tests (3 minutes) were performed.

The steady-state LOX seal leakage was consistent from the beginning of the test series until the end at approximately 0.793 to 0.850 m^3/minute (28 to 30 scfm), indicating no deterioration of the sealing surfaces. The LOX seal drain pressure also was consistent at approximately 27,579 to 34,474 N/m^2g (4 to 5 psig).

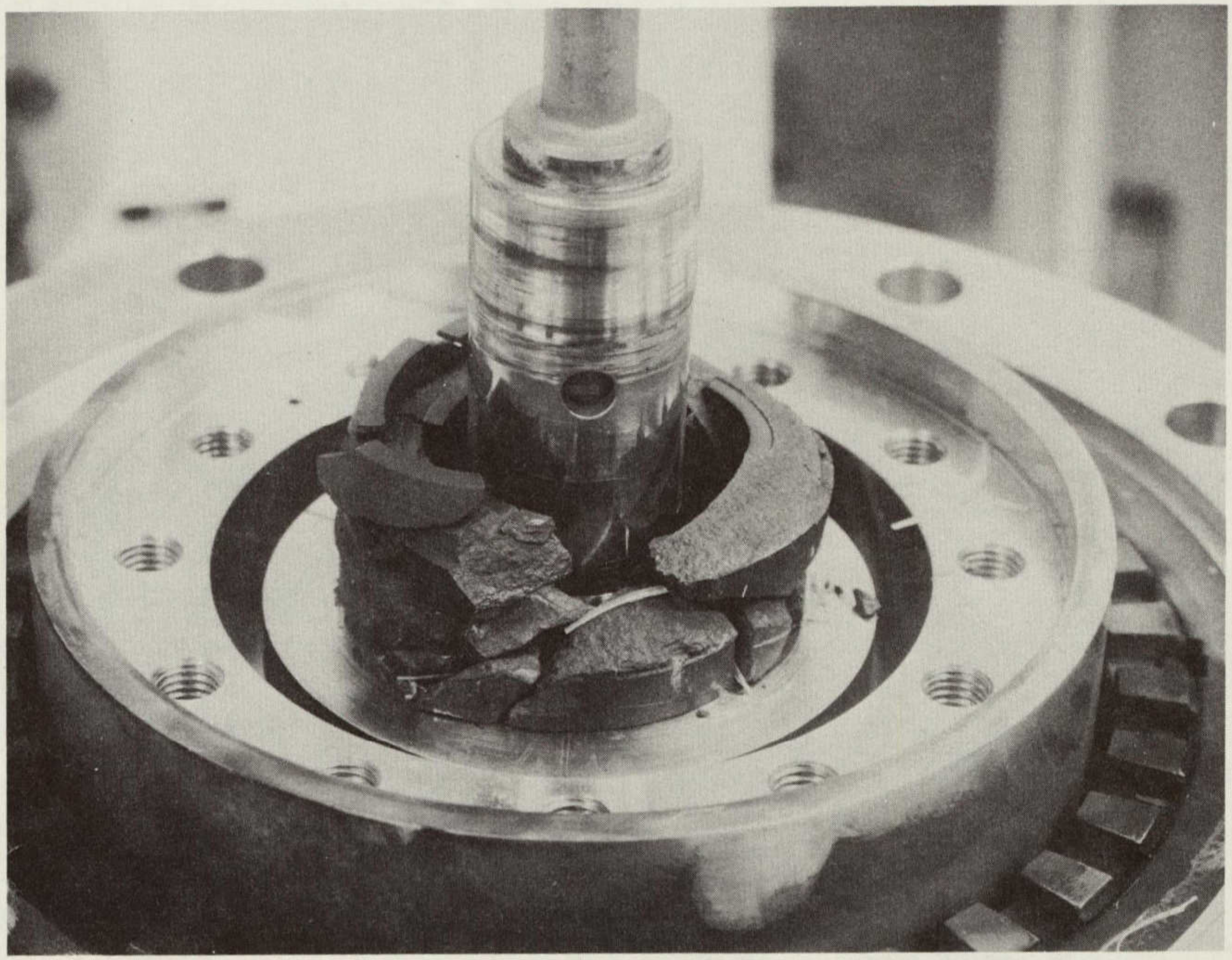


Figure 99. Shattered Spiral Groove LOX Seal Following Bearing Failure (Build 8, Posttest 332)

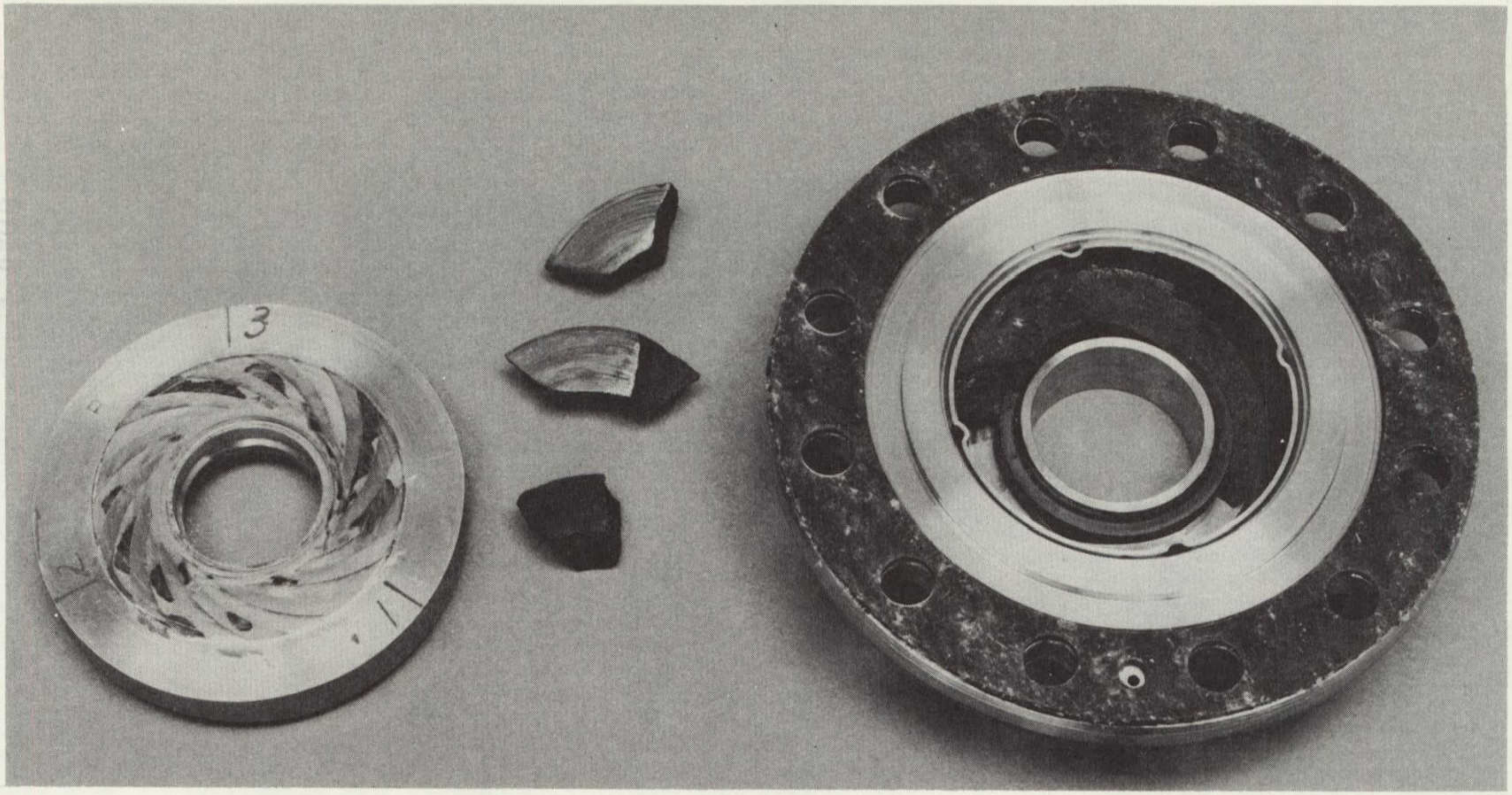
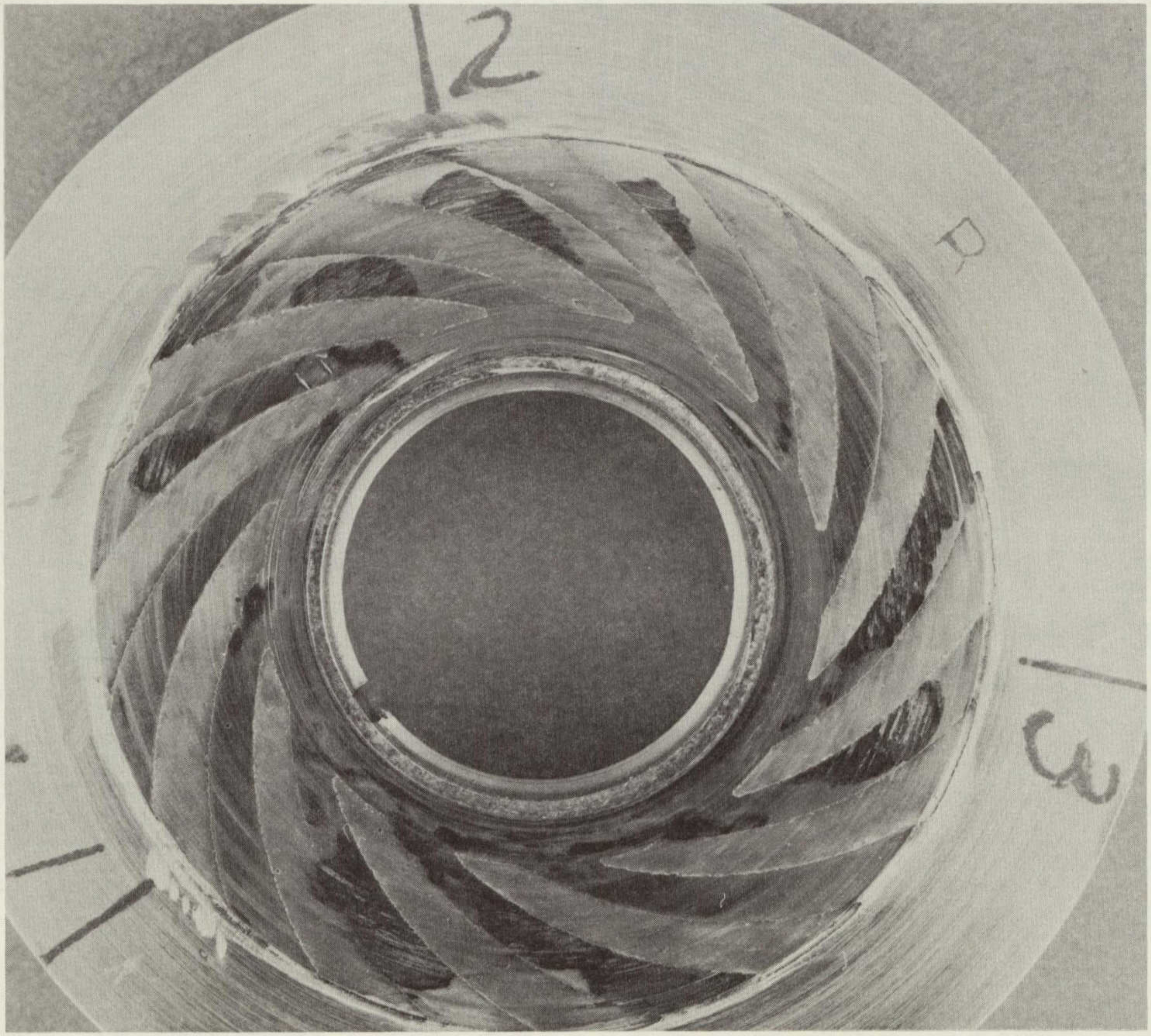


Figure 100. Spiral Groove LOX Seal Mate Ring, Some Carbon Pieces, and Housing (Build 8, Posttest 332)



1SM95-4/8/76-C
Figure 101. Spiral Groove LOX Seal Mate Ring (Build 8, Posttest 332)

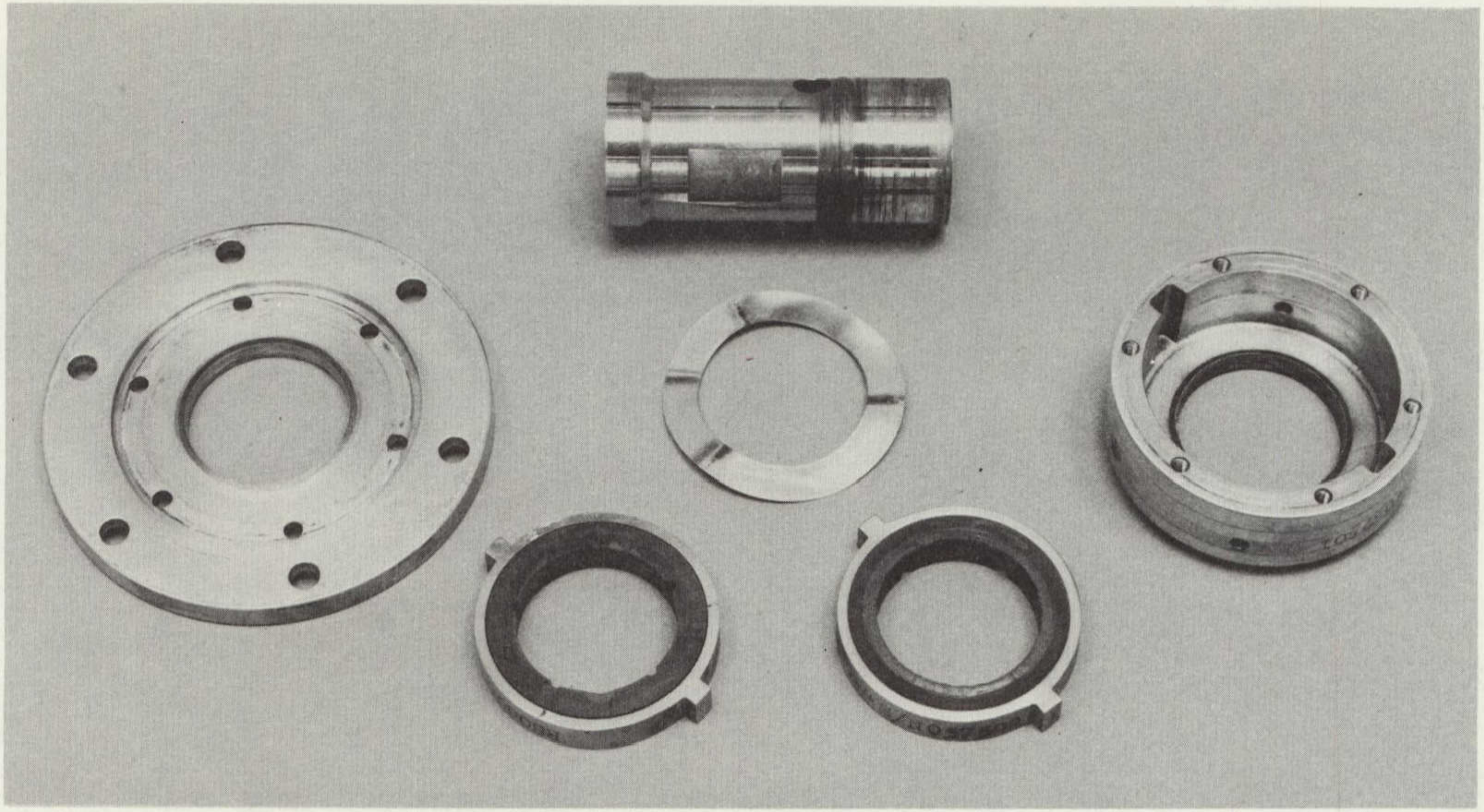


Figure 102. Helium Seal Assembly Following Bearing Failure (Build 8, Posttest 332)

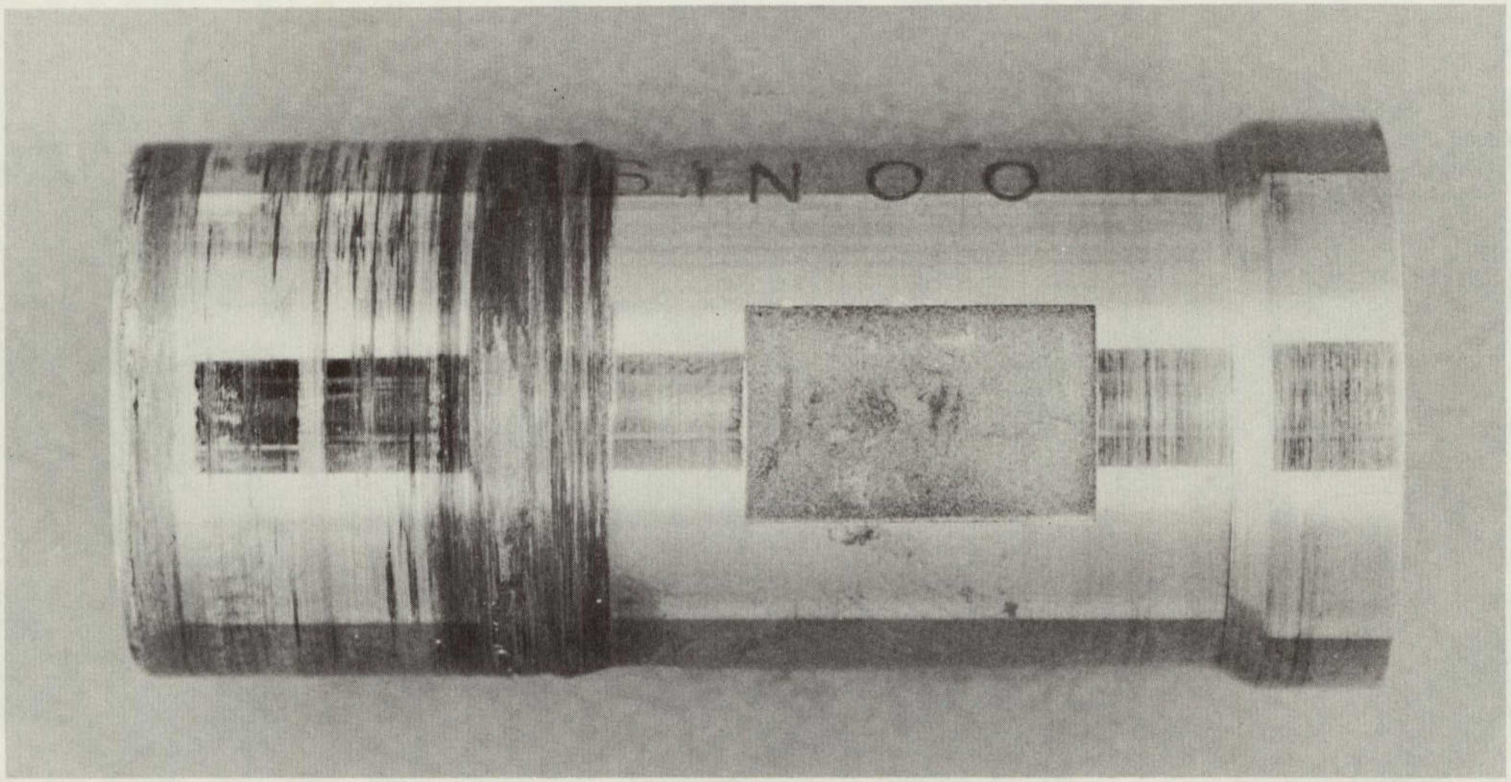
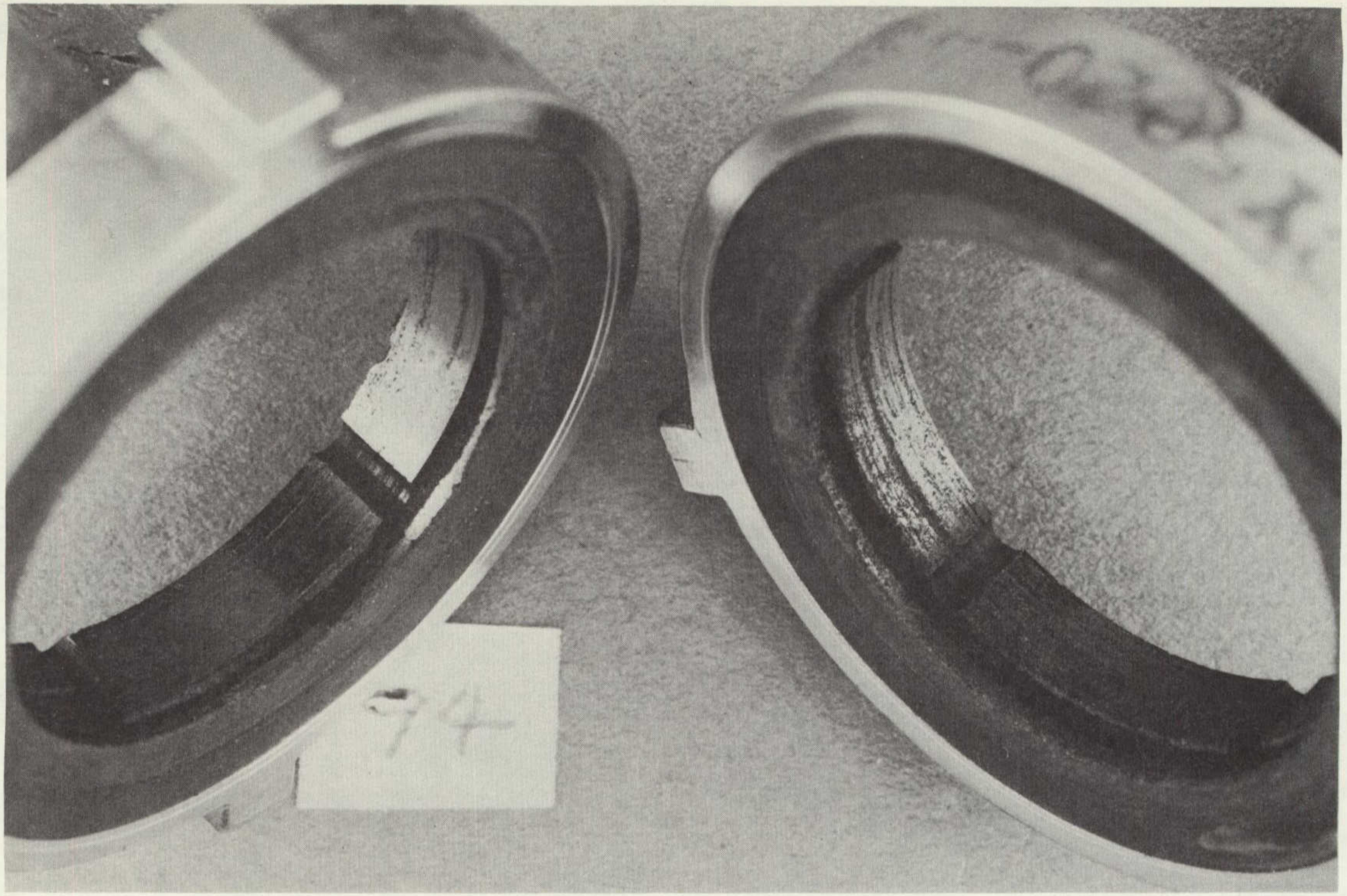


Figure 103. Helium Seal Mate Ring (Build 8, Posttest 332)



TURBINE SIDE LOX SIDE

Figure 104. Helium Seal Carbon Rings (Build 8, Posttest 332)

Build 10 Disassembly. The scheduled inspection after an additional time of 2.61 hours for a total of 5.12 hours revealed the Rayleigh step piston ring LOX seal to be in excellent condition. The carbon face was polished with very slight circumferential scratches from minute particles in the sealed fluid. There was no measurable wear or deterioration. The mating ring surface had a uniform polished trace in the area of the seal dam and lift pads, indicating that the mating ring and seal ring surfaces are remaining flat during operation. The posttest static leakage was approximately the same as pretest (Table 9).

The helium seal condition was the same as pretest 413. There was no significant additional wear on the carbon seal rings. The mating ring surface appeared the same as pretest with a heavy contact pattern, but no measurable wear. The measured posttest static leakage was less than pretest (Table 11).

Build 11 Assembly. The tester was reassembled with the same seal hardware without any rework. The Rayleigh step LOX seal static GN_2 leakage was 0.027 m^3/minute (1625 scim) at 2,068,427 N/m^2g (300 psig) (Table 9).

The helium seal ring diametral clearance was 0.000/m (0.0045 9n.) on the LOX side and 0.00013 m (0.0050 in.) on the turbine side. The static healium leakage at 206,843 N/m^2 (30 psig) was 0.123 m^3/minute (7500 scim) on the LOX side and 0.146 m^3/minute (8900 scim) on the turbine side (Table 11).

Tests 518-559. The test objective was to complete a minimum of 75 fast-start tests for a total time of 2.5 hours on the Rayleigh step LOX seal.

A total of 42 starts for 1.2 hours was performed (Table 13). The scheduled test duration was 3 minutest. Nineteen of the tests were of scheduled duration. The remainder were terminated due to speed control and other operation problems. The last test was terminated when the tester vibration level increased to 6 g(p-p) with spikes up to 10 g(p-p). The tester was removed for inspection due to the high vibration level.

The LOX seal leakage varied from approximately 0.566 to 0.850 m^3/minute (20 to 30 scfm) at 2,757,903 N/m^2g (400 psig). The LOX seal drain pressure varied from 19,995 to 39,990 N/m^2g (2.9 to 5.8 psig). The leakage and drain pressure during this test series was approximately the same as the initial test series when the seal was new.

The helium seal leakage varied from 0.265 to 0.283 m^3/minute (9.35 to 10 scfm) to approximately 206,843 N/m^2g (3o psig) purge pressure. The leakate has not changed significantly during the last 6.34 hours.

Build 11 Disassembly. The tester inspection revealed the hardware to be in good condition. The bearing race wear tract indicated that the bearings had run unloaded during part of the testing. The bearings were in good condition otherwise. Measurements indicated that the bearing preload spring compression had decreased slightly. It was concluded that the high vibration was caused by the bearings unloading due to the lower preload and high bearing cavity pressure.

The LOX seal condition did not appear to change during the additional 1.2 hours. The carbon face was polished with very slight circumferential scratches and no measureable wear. The mating ring surface also appeared the same with a uniform polished trace in the area of the seal dam and lift pads. The post-test static leakage was approximately the same as pretest (Table 9).

The helium seal and mating ring condition has not changed since the initial wear which occurred on builds 6 and 9 (Fig. 86 and 87). The posttest static leakage was nearly the same as pretest (Table 11).

Build 12 Assembly. The tester was reassembled with the same seal hardware without any rework. The static leakages are given in Tables 9 and 11.

Tests 560-632. The test objective was to complete 75 fast start tests for a total time of 2.5 hours on the Rayleigh step LOX seal.

A total of 72 starts for 2.58 hours was performed (Table 13) to complete the test objective. Twelve of the tests were of scheduled duration. Steady-state conditions for 1 minute or longer were attained on 42 of the tests. The scheduled test duration was increased from 3 minutest to 6 minutes and then to 10 minutes to accumulate the required starts and total time. Numerous tests were terminated prematurely due to tester overspeed and other problems.

The LOX seal leakage was consistent at approximately 0.850 m^3/minute (30 scfm) during the entire test series. The LOX seal drain pressure varied from approximately 34,474 to 41,369 N/m^2g (5 to 6 psig). The leakages and drain pressures are continuing to be consistent with the initial test series when the seal was new.

The helium seal leakage increased on this build to approximately 0.425 m^3/minute (15 scfm) at 206,843 N/m^2g (30 psig) purge pressure compared to approximately 0.283 m^3/minute (10 scfm) on the prior build (No. 11).

Build 12 Disassembly. The scheduled tester inspection revealed the hardware to be in good condition, except for additional wear on the helium seal. The LOX side carbon ring was worn an additional 0.0002 m (0.008 in. diametral. The turbine side carbon ring was worn an additional 0.00028 m (0.011 in.) diametral. The helium mating ring was grooved approximately 0.000005 m (0.0002 in.) on the LOX side and 0.0000025 m (0.0001 in.) on the turbine side. The mating ring wear was on one side only, indicating eccentric rotation.

The helium seal static leakage decreased from 0.271 m^3/minute (9.55 scfm) pretest to 0.197 m^3/minute (6.94 scfm) posttest, indicating that the additional wear did not have a significant effect on the seal static leakage.

The LOX seal was in excellent condition with no measurable wear. The pretest and posttest static leakages were comparable (Table 9).

Build 13 Assembly. The tester was reassembled with the same seal hardware without any rework. The static leakages are given in Tables 9 and 11.

Tests 633-665. The test objective was to complete the required 300 starts and 10 hours on the Rayleigh step LOX seal. An additional 1.1 hours was required.

A total of 33 starts for 1.2 hours was performed to complete the test objective (Table 13). The scheduled duration of 3 minutes was achieved on 22 tests. The remainder were terminated prematurely due to tester overspeed and other problems.

The LOX seal leakage was steady at 0.736 to 0.821 m^3/minute (26 to 29 scfm). The LOX seal drain cavity pressure varied from 31,026 to 39,300 N/m^2g (4.5 to 5.7 psig). The leakage rates and drain pressures after 10 hours of testing are the same as the first test when the seal was new. The seal performance has been very consistent and repeatable through the entire test series. There has been no measurable degradation in performance.

The helium seal leakage increased on this build (No. 13) to approximately 0.595 m^3/mixture (21 scfm) at 206,843 N/m^2g (30 psig) purge pressure compared to approximately 0.425 m^3/minute (15 scfm) on the last build (No. 12) and approximately 0.142 m^3/minute (5 scfm) when new. The increase in leakage rate corresponds to the measured carbon ring wear.

Build 13 Disassembly. The scheduled tester inspection after an additional time of 1.2 hours for a total accumulated time of 10.12 hours on the Rayleigh step LOX seal revealed the LOX seal to be in excellent condition with no measurable wear or deterioration. The carbon face was polished with very slight circumferential scratches. The surface profile traces (Fig. 105) indicate that the recess pad depth and sealing dam height are the same as new.

The LOX mating ring surface has a polished mark in the area of the sealing dam and faint traces of contact in the area of the lift pads. The mating ring surface profile trace (Fig. 106) shows the polished area at the dam with no significant wear.

The LOX seal secondary element segmented carbon piston ring was in good condition with no visible wear or deterioration.

The helium seal carbon rings and the mating ring surface are worn. The measured wear did not change since the build 12 inspection. The carbon rings have worn a total of 0.00030 m (0.0118 in.) diametral on the LOX side and 0.00034 m (0.0135 in.) diametral on the turbine side since new. The mating ring is grooved approximately 0.000005 m (0.0002 in.) on the LOX side and 0.0000025 m (0.0001 in.) on the turbine side (Fig. 107).

The seal hardware condition is shown in Fig. 108 through 116.

One LOX seal assembly was utilized for the LOX acceleration tests for 332 starts and 10 hours, 18 minutes of accumulated time. No LOX checkout tests were made. LOX seal leakage versus test time is shown in Fig. 117.

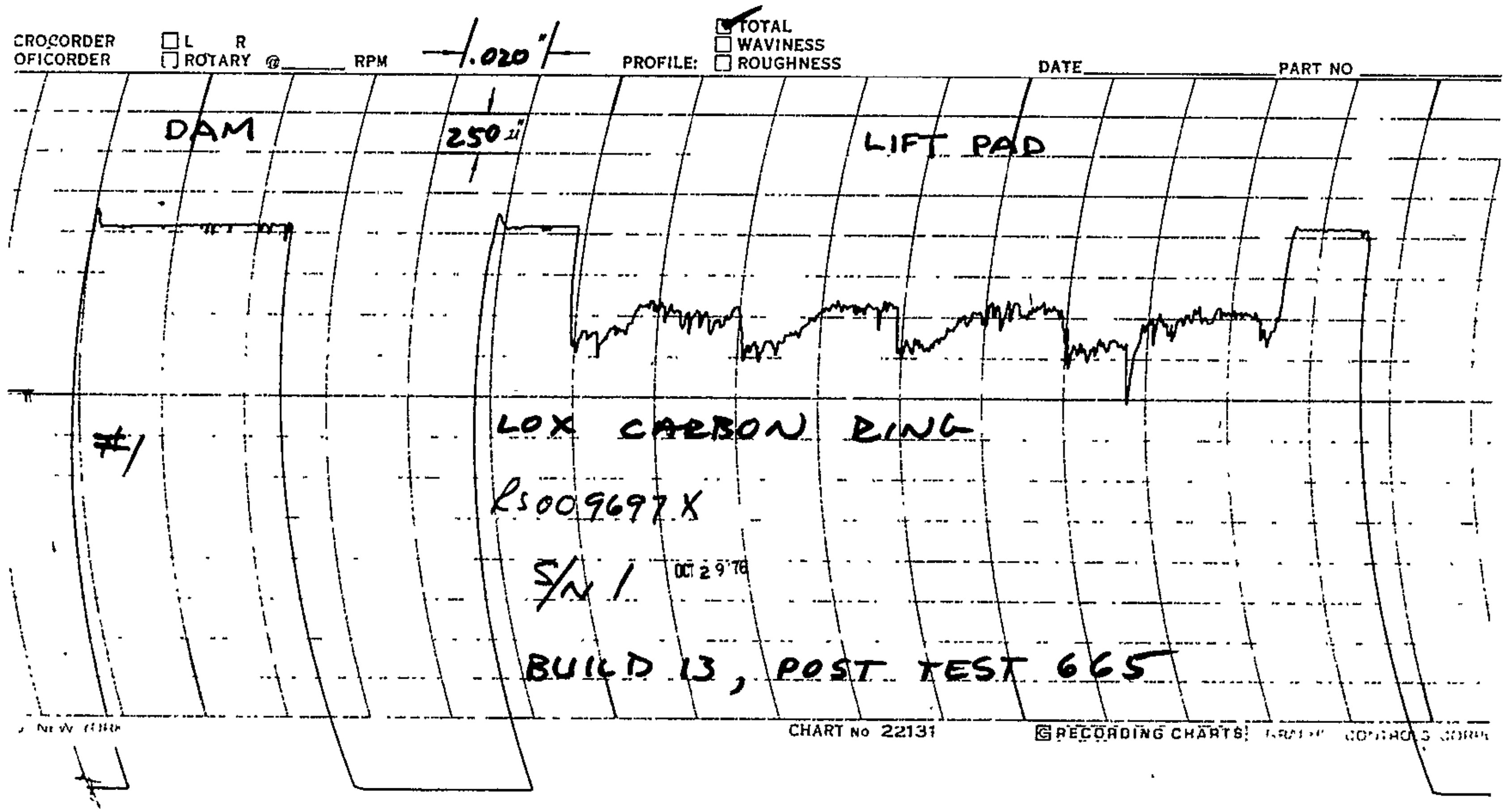


Figure 105. Typical Surface Profile Trace LOX Seal Carbon Ring (RS009697X, S/N 01, Posttest 665, Build 13, After 332 Starts and 10.12 Hours)

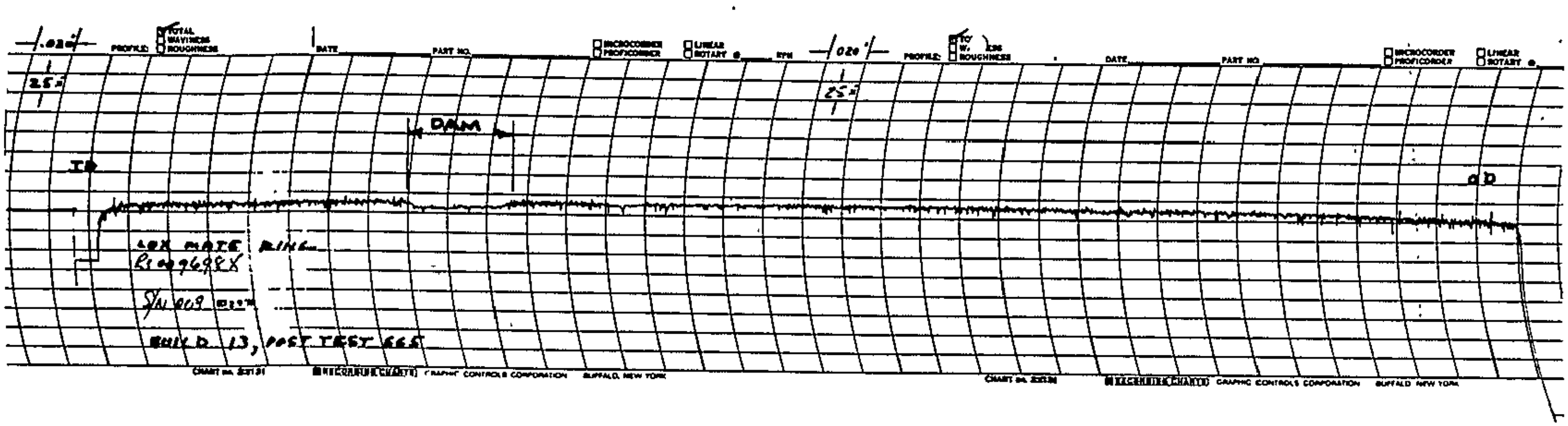


Figure 106. Surface Profile Trace LOX Seal Mating Ring (RS009698X, S/N 03, Build 13, Posttest 665, After 332 Starts and 10.12 Hours)

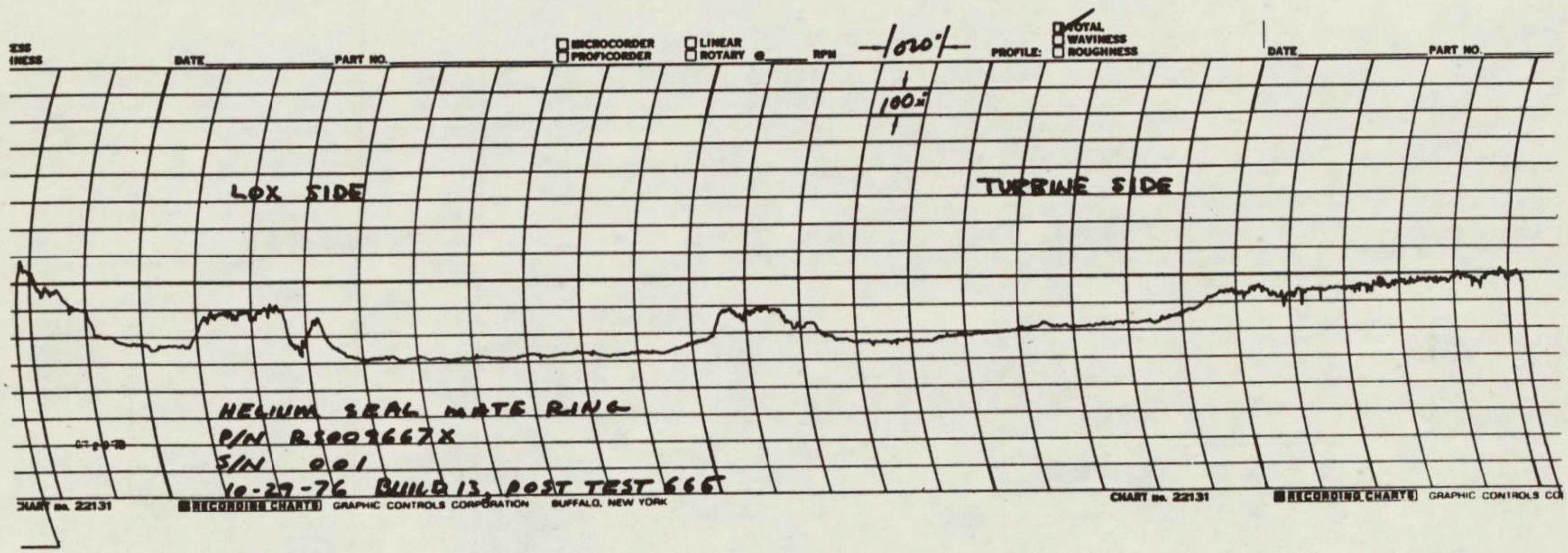


Figure 107. Surface Profile Trace Helium Seal Mating Ring (RS009667X, S/N 001, Posttest 665, Build 13, After 332 Starts and 10.12 Hours0

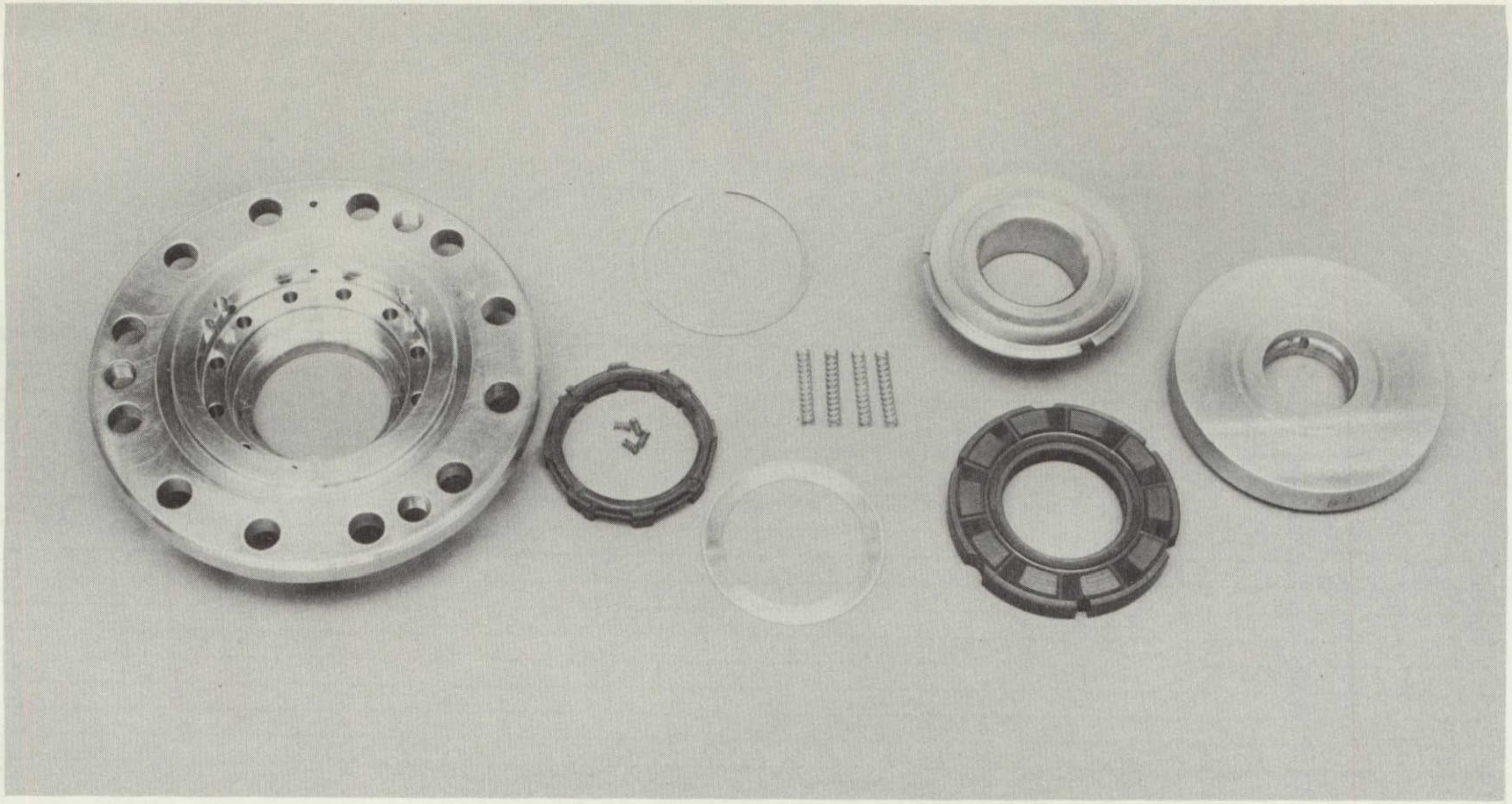


Figure 108. Rayleigh Step Piston Ring LOX Seal Assembly (RS009849X, S/N 02, Build 13, Posttest 665, After 332 Starts and 10.12 Hours)

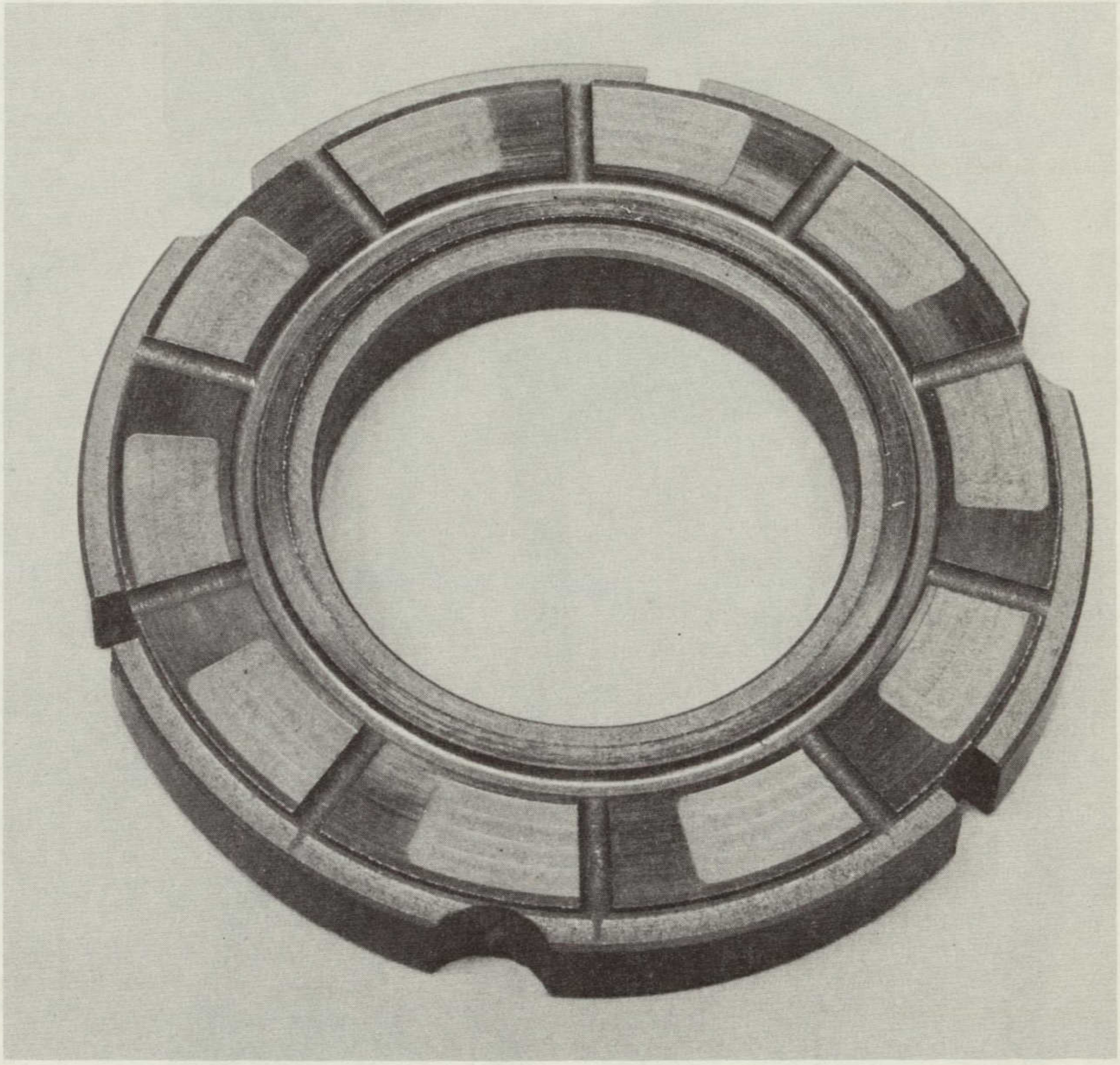


Figure 109. Rayleigh Step LOX Seal Carbon Ring (RS009697X, S/N 01, Build 13, Posttest 665, After 332 Starts and 10.12 Hours)

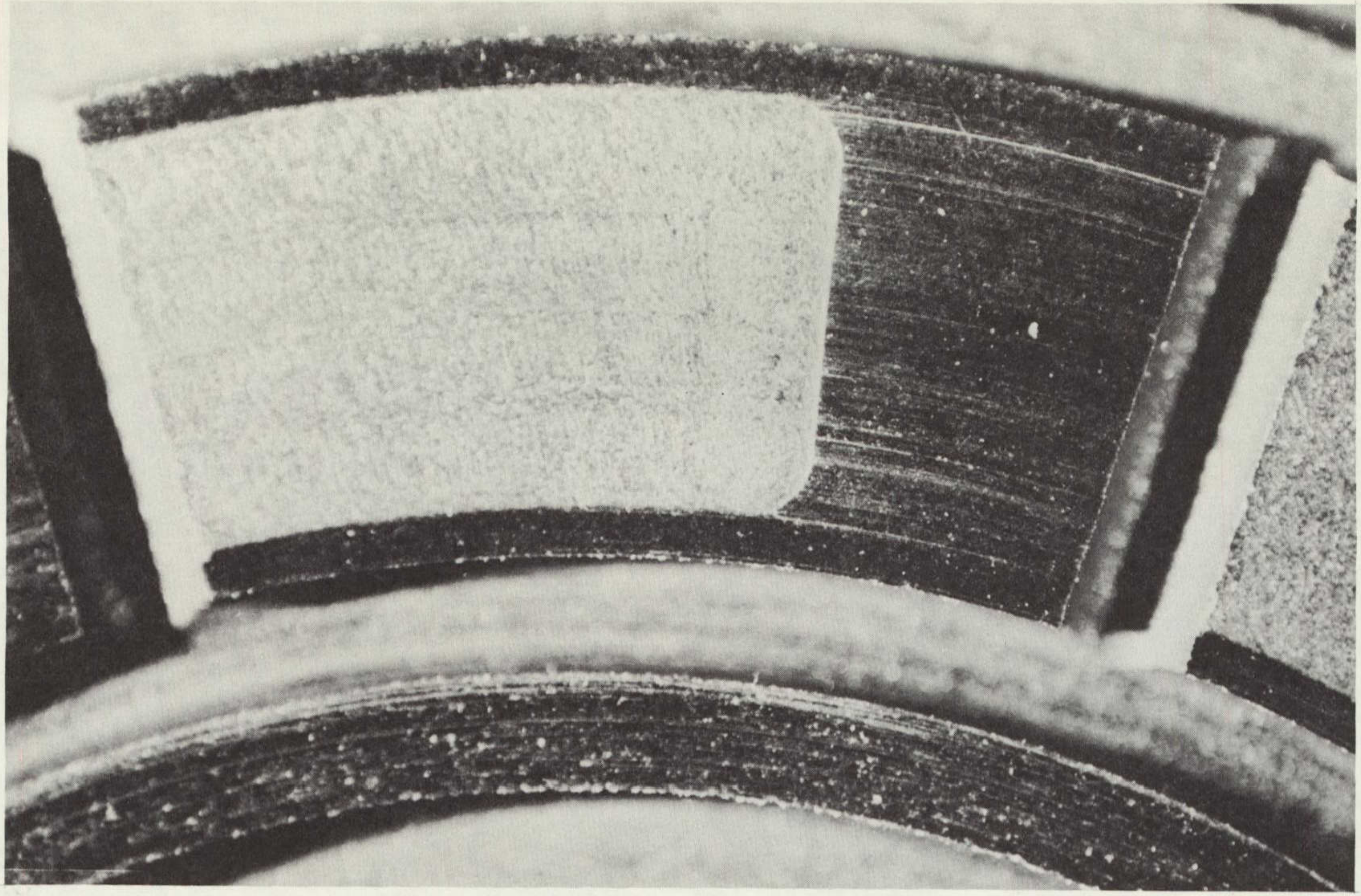


Figure 110. Rayleigh Step LOX Seal Carbon Ring (RS009697X, S/N 01, Typical Lift Pad, Build 13, Posttest 665, After 332 Starts and 10.12 Hours)

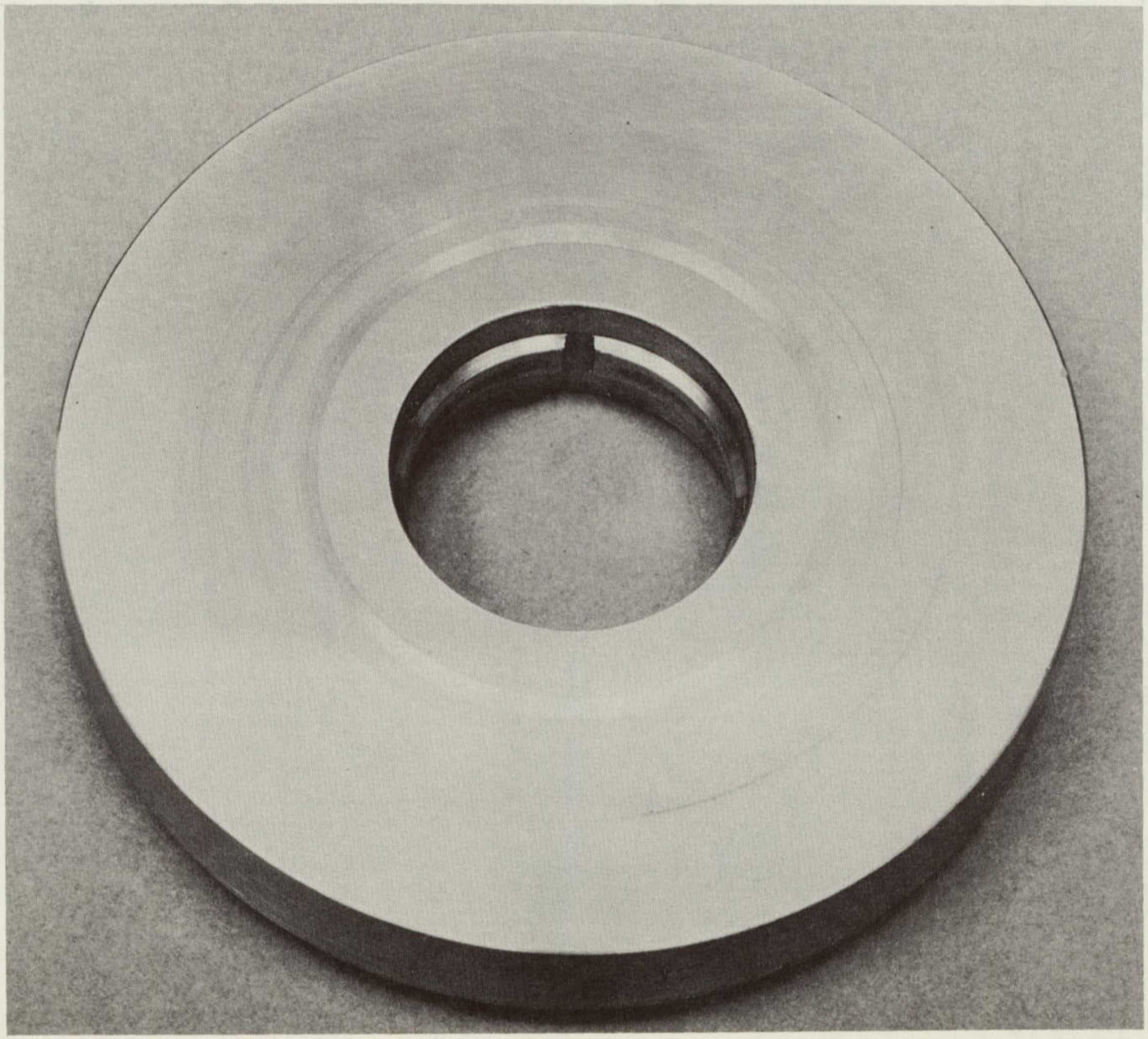


Figure 111. Rayleigh Step LOX Seal Mating Ring (RS009698X, S/N 03, Build 13, Posttest 665, After 332 Starts and 10.12 Hours)

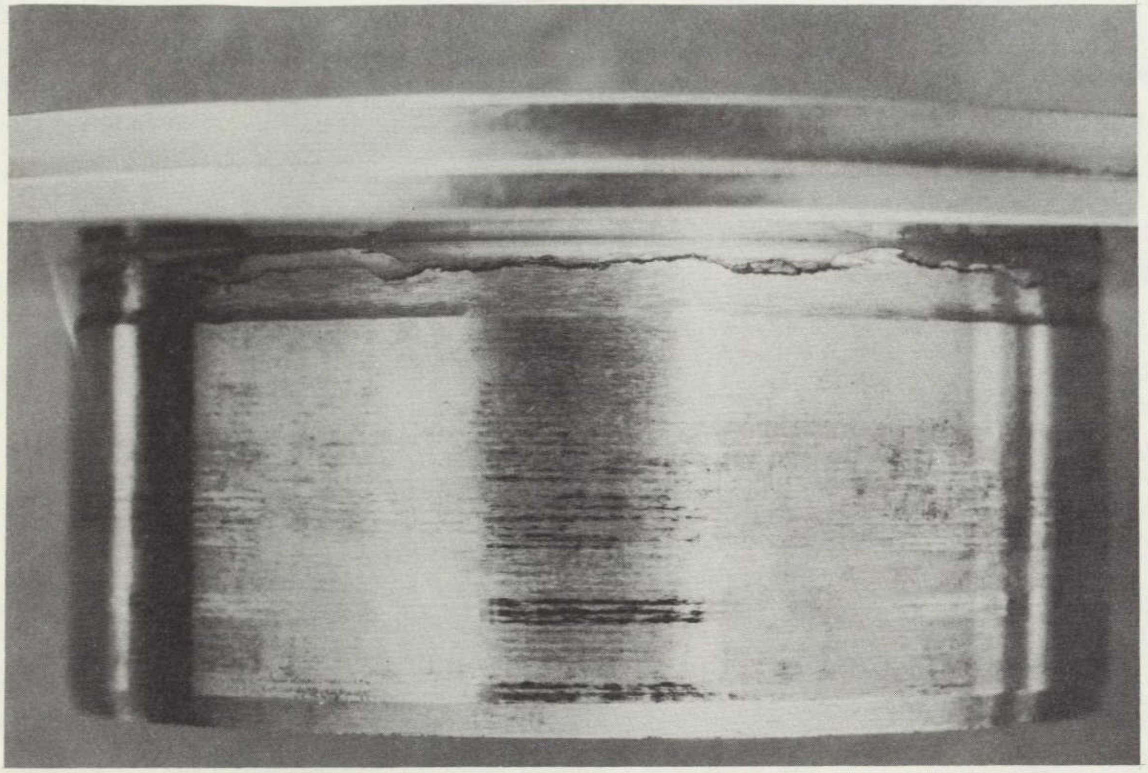


Figure 112. Piston Ring LOX Seal Pilot Ring (RS009848X, S/N 02, Build 13, Posttest 665, After 332 Starts and 10.12 Hours)

C-3

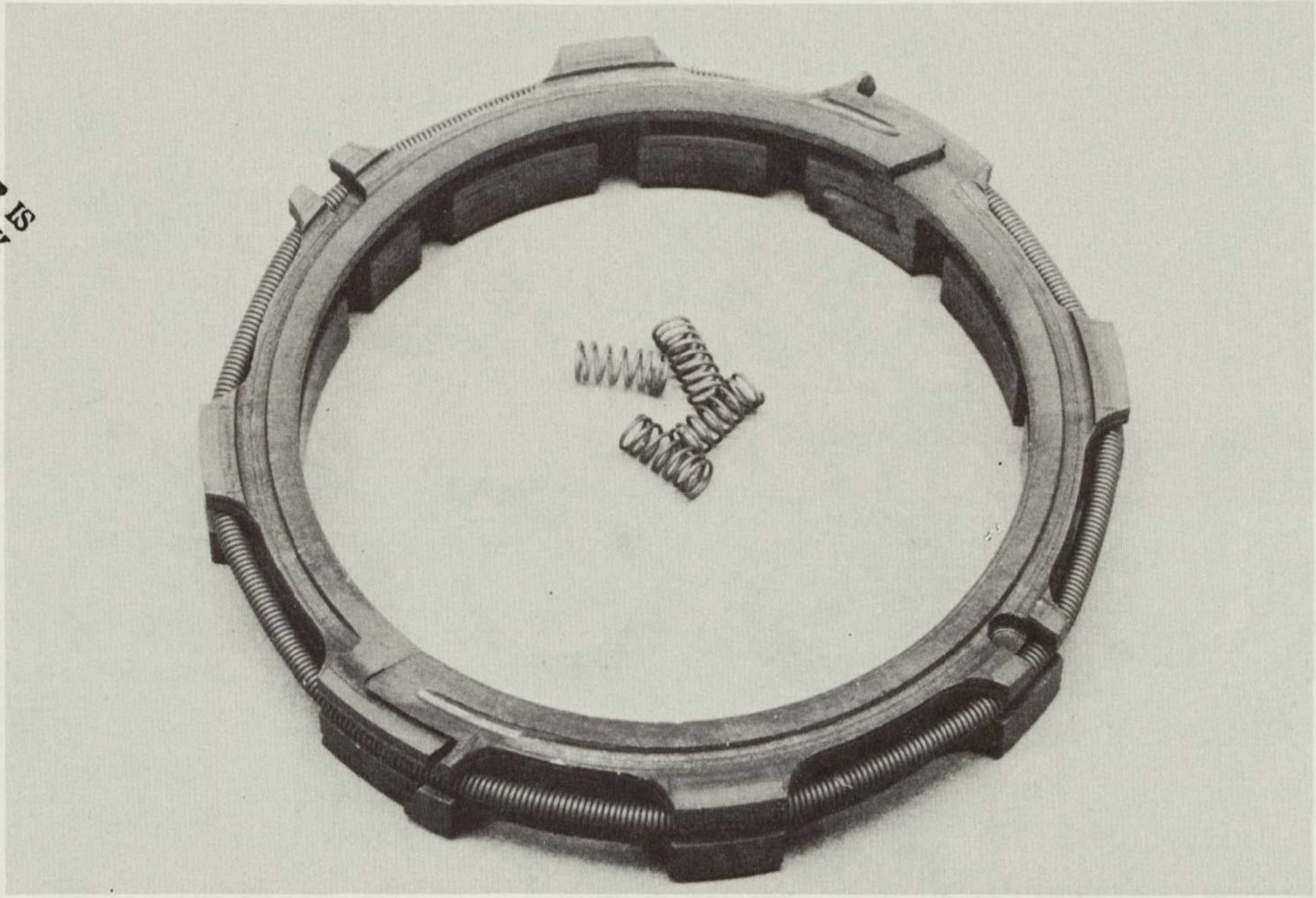


Figure 113. LOX Seal Piston Ring (SSCY 5097-8, S/N 02, Build 13, Posttest 665, After 332 Starts and 10.12 Hours)

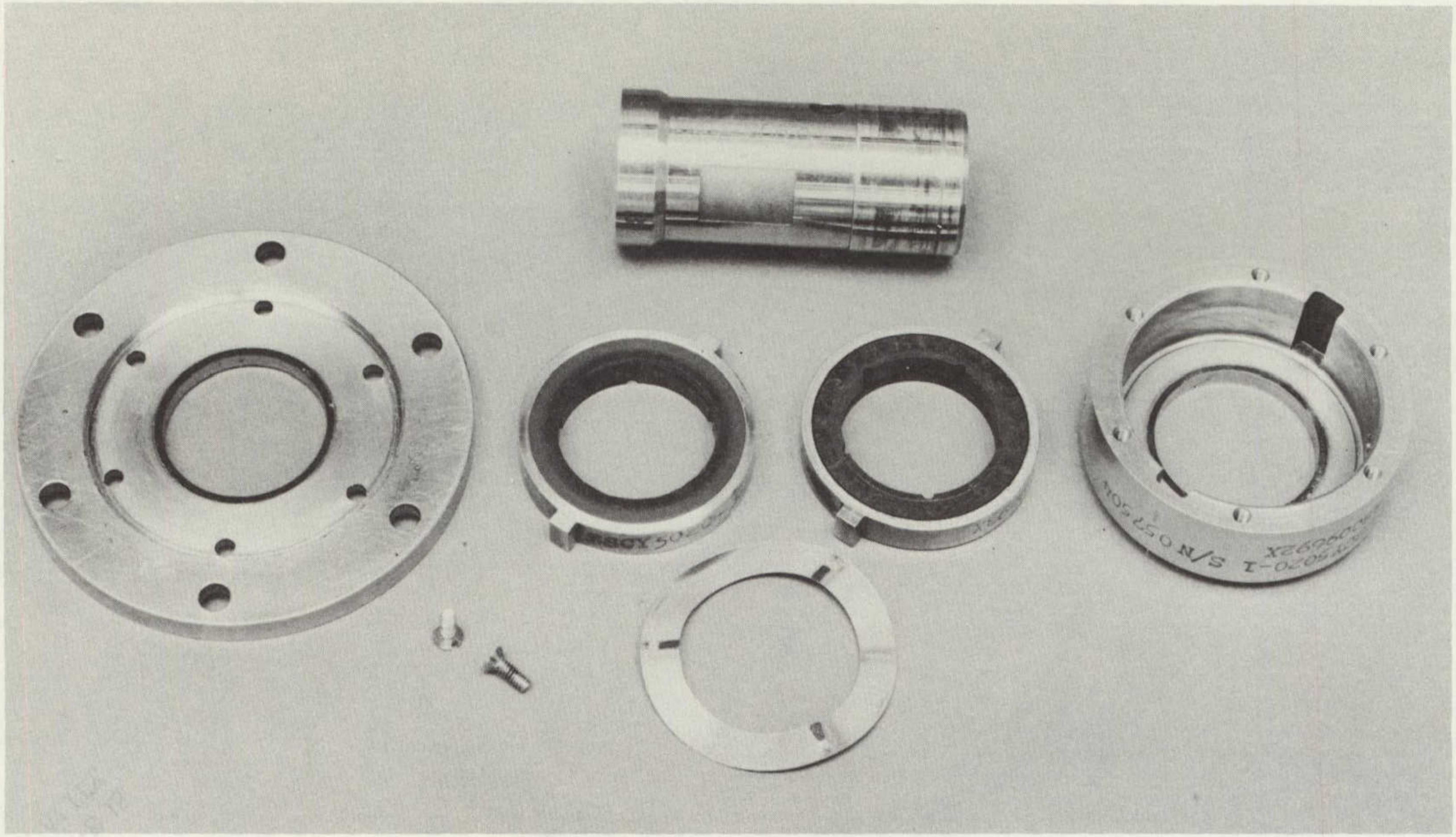


Figure 114. Helium Seal Assembly (RS009690X, S/N 04, Build 13, Posttest 665)

Figure 115. Helium Seal (RS009690X, S/N 04, Build 13, Posttest 665)

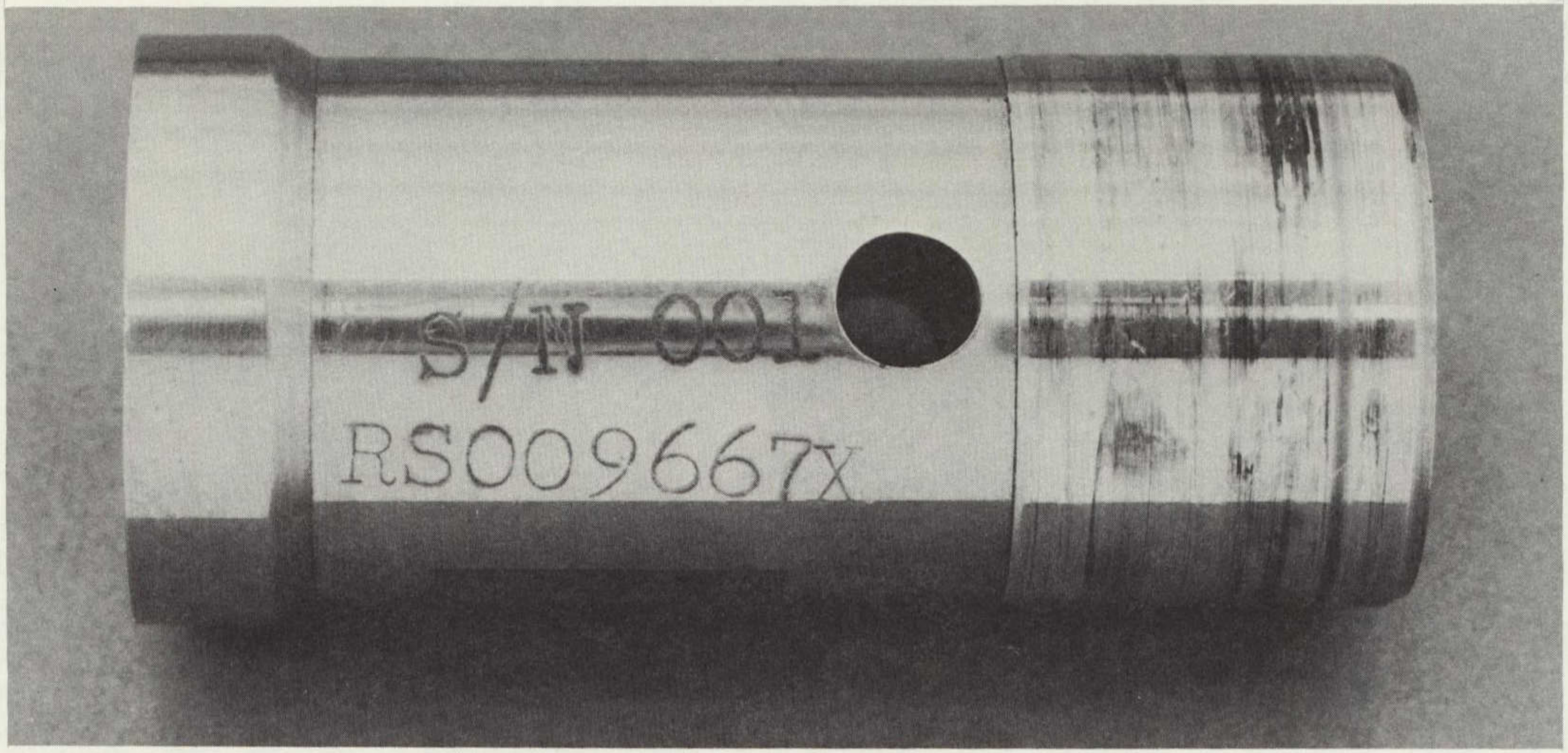


Figure 116. Helium Seal Mating Ring (RS009667X, S/N 001, Build 13, Posttest 665)

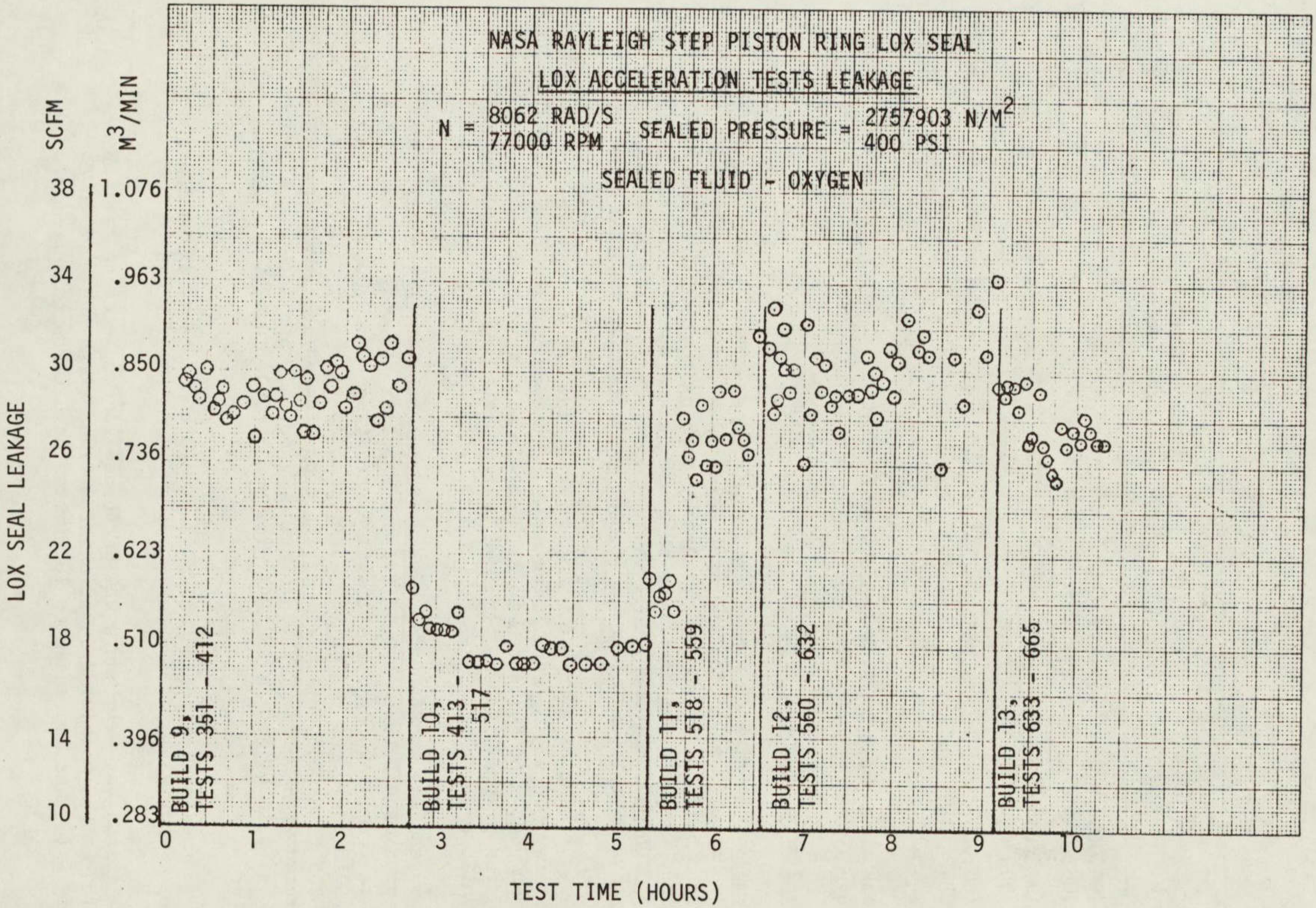


Figure 117. LOX Seal Leakage

Predicted LOX seal leakages are compared with test leakage below:

Speed, rad/s (rpm) and pressure, N/m^2 (psi)	Liquid Oxygen, Predicted, m^3/minute (scfm)	Gaseous Oxygen Predicted, m^3/minute (scfm)	Oxygen Test m^3/minute (scfm)
9425 (90,000 3,206,062 (465)	1.873 (66.13)	0.164 (5.78)	
8062 (77,000 2,757,903 (400)			0487 to 0.934 (17.2 to 33.0)
6282 (60,000) 2,171,848 (315)	1.085 (38.30)	0.112 (3.97)	

GN_2 static leak check leakage at 2,068,427 N/m^2 (300 psi) ranged from 0.017 to 0.027 m^3/minute (0.59 to 0.94 scfm) for the five builds.

Spiral Groove Piston Ring LOX Seal

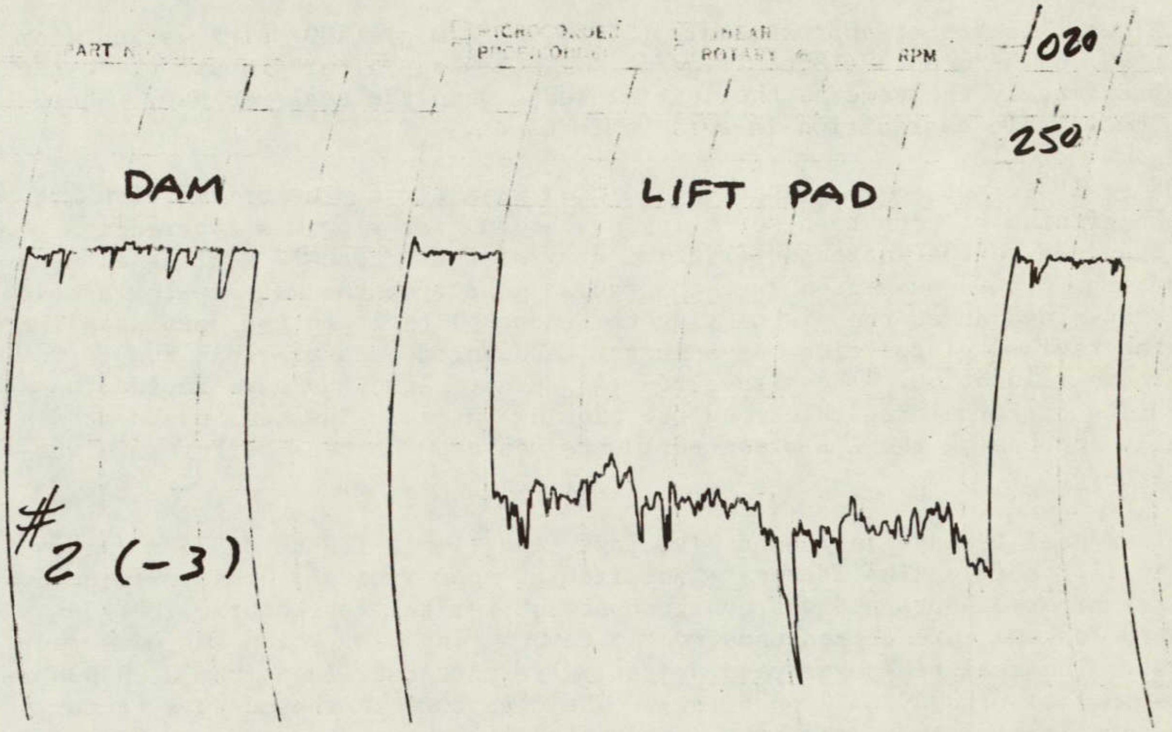
Build 14 Assembly. The tester was assembled with a reworked spiral groove LOX seal and a new Rayleigh step floating ring helium seal. The spiral groove mating ring from build 8, which was damaged by rubbing contact when the tester bearings failed, was lapped slightly to partially clean up the surface scoring. Approximately 0.0000025 m (0.0001 in.) was removed from the surface to reduce the spiral groove depth from 0.00001 m (0.0004 in.) to 0.000008 m (0.0003 in.).

The LOX seal was assembled with a new carbon seal ring and a new carbon seal ring and a new revised piston ring. The new piston ring had the pressure balance groove and vent slot relocated to eliminate a direct leak path. A wave spring around the piston ring was utilized to seat the ring. The housing and spring from build 8 was used.

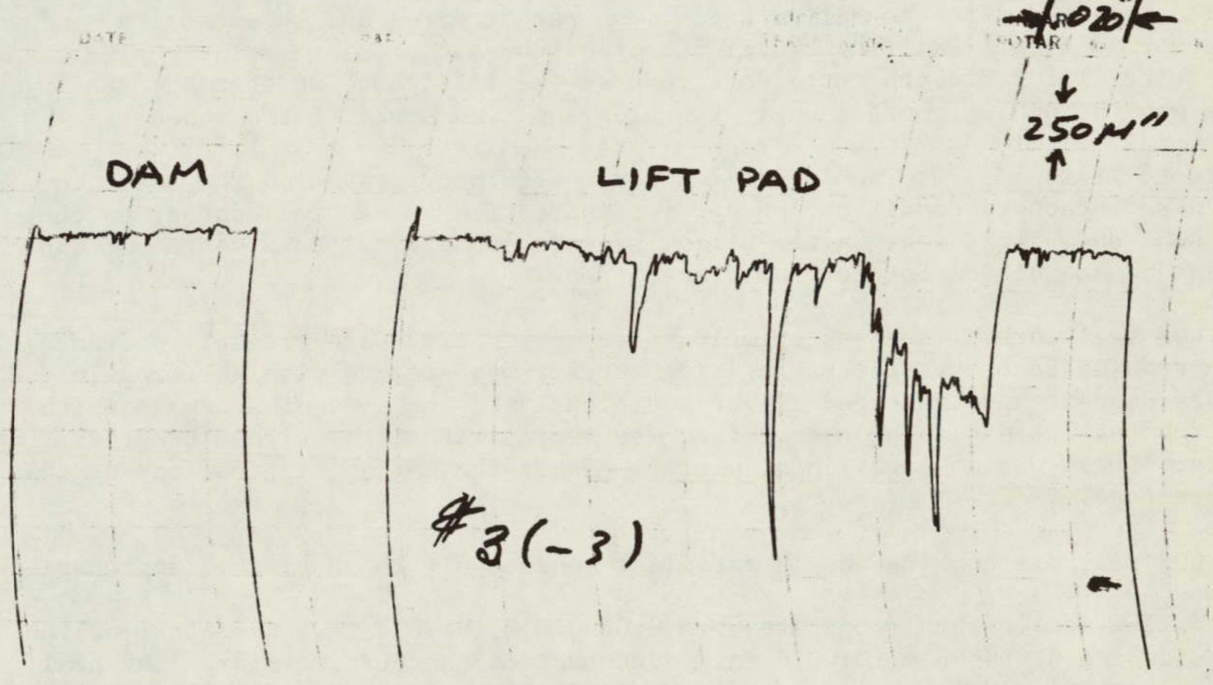
The new helium seal was manufactured by a different supplier (Clevite). The recess pad depths manufactured by a different supplier (Clevite). The recess pad depths were irregular (Fig. 118), with a variation from 0.0000025 to 0.0000033 m (0.0001 to 0.0013 in.) compared to the specification values of 0.000013 to 0.0002 m (0.0005 to 0.0008 in.). The mating ring from build 13 was ground down and replated with chrome. The seal ring diametral clearances at assembly were 0.000036 m (0.0014 in.) on the LOX side and 0.00004 (0.0016 in.) on the turbine side.

Tests 666-749. The test objective was 80 fast-start LOX tests and 4 hours on the spiral groove LOX seal.

A total of 84 starts for 4.16 hours was performed to complete the test objective (Table 13). The scheduled duration of 3 minutes was achieved on 64 tests. The duration was increased to 10 minutes on 6 tests to accumulate additional time.



LOX SIDE - POSITION #2



LOX SIDE - POSITION #3

Figure 118. Surface Profile Traces of Helium Seal (RS009690X, S/N 05, Recess Lift Pads, Pretest 66, Build 14)

The LOX seal leakage at approximately (2,757,903 N/m^2g) (400 psig) varied from 0.510 to 0.765 m^3/minute (18 to 27 scfm). The leakage after 4 hours of testing was approximately the same as the initial tests when the seal was new. There was no measurable degradation in seal performance.

The LOX seal did not seal at static condition when first pressurized with LOX at the beginning of each test series. The carbon seal ring was apparently stuck open due to the increased friction drag of the secondary sealing element piston ring. It is suspected that the radial load from the wave spring around the piston ring caused the piston ring to bindup slightly on the housing pilot. Also, the revised piston ring has a larger unbalanced pressure load due to the vent groove relocation. The higher radial pressure load may have caused the piston ring friction drag to exceed the closing forces. The seal was seated by gradually increasing the LOX pressure. Once seated, the seal performance was satisfactory.

The helium seal leakage increased with test time from 0.128 to 0.334 m^3/minute (4.52 to 11.8 scfm). The leakage stabilized at approximately 0.340 m^3/minute (12 scfm) after 3 hours and was nearly constant for the last hour. The increase in leakage rate corresponds to the carbon ring wear which was measured posttest. The seal ring average diametral clearance increased from 0.000038 m (0.0014 in.) to 0.00009 m (0.0036 in.). The clearance increased by a factor of 2.4 and the leakage increased by a factor of 2.6. The theoretical leakage is directly proportional to clearance.

It is suspected that the helium seal ring wear occurred due to excessive (0.00007 m; 0.0028 in. TIR) radial runout of the mating ring surface. The irregular lift pad depth could have reduced the lift force so that the seal ring was in rubbing contact until the clearance was equal to the runout.

Build 14 Disassembly. The inspection after 4.16 hours revealed the seals to be in satisfactory condition, except for indication of rubbing contact on the LOX seal and slight wear on the helium seal carbon rings. Both seals were in acceptable condition for continued operation.

The LOX seal carbon face and spiral groove mating ring were slightly scored from rubbing contact. The mating ring surface was smeared with an irregular carbon deposit and indicated slight additional rubbing since the damage which occurred on build 8. The carbon face was scored with light circumferential marks. There was no significant wear on either the mating ring surface or the carbon face.

The LOX seal piston ring was in excellent condition with no visible degradation.

The helium seal carbon rings are worn 0.000043 m (0.0017 in.) diametral on the LOX side and 0.000066 m (0.0026 in.) diametral on the turbine side. The seal ring diametral clearance increased from 0.000036 to 0.000076 m (0.0014 to 0.0030 in.) on the LOX side and from 0.00004 m to 0.0001 m (0.0016 to 0.0042 in.) on the turbine side. The static leakage at 206,843 N/m^2g (30 psig) purge pressure increased from 0.043 m^3/minute (2650 scim) pretest to 0.093 m^3/minute (5700 scim) posttest. The dynamic leakage during the test series indicates that the seal ring wear occurred during the first 3 hours with no additional wear during the last hour.

The helium seal lift pads were worn off, except for two which were deeper (0.000031 to 0.000033 m; 0.0012 to 0.0013 in.) when new. The mating ring had a heavy contact pattern with no significant wear.

The seal hardware condition is shown in Fig. 119 through 126.

Results and Conclusions (Tests 187-332 and 666-749). The total test time with liquid oxygen as the sealed fluid was 10 hours and 2.5 minutes for 306 tests. After 4 hours and 28.4 minutes of satisfactory testing on the first build (No. 8), the tester bearings failed and the LOX seal was severely damaged. The test leakage is shown in Fig. **127**.

Seal leakage was increasing with considerable scatter during build 8 testing. Seal leakage was more consistent during build 14 testing. At the beginning of four series of tests for build 14, the LOX seal drain pressure redline was exceeded. The probable cause was the seal not seating at the start of a fast-start test. With slow pressurization, the seal would seat azd fast-start testing could be continued. The LOX seal was in satisfactory condition following build 14 testing of 4 hours, 9.7 minutes, with slight rubbing on the mate ring and carbon ring.

Rayleigh Pad Floating Ring Helium Seal

Results and Conclusions. A total of 749 tests was performed on five helium seal assemblies for a total of 24 hours of operation. The seal proved to be reliable and long lasting.

Three helium seal assemblies were damaged when bearing failures were experienced; seal performance was satisfactory up to bearing failure.

Static leakage at 206,843 N/m^2 (3o psi) versus diametral clearance is shown in Fig. **128**.

Wear rate of seal S/N 01, builds 1 through 5 is shown in Fig. **129**. Wear rate for S/N 04 builds 9 through 13, is shown in Fig. **130**, and wear rate for S/N 05, build 14, is shown in Fig. **131**.

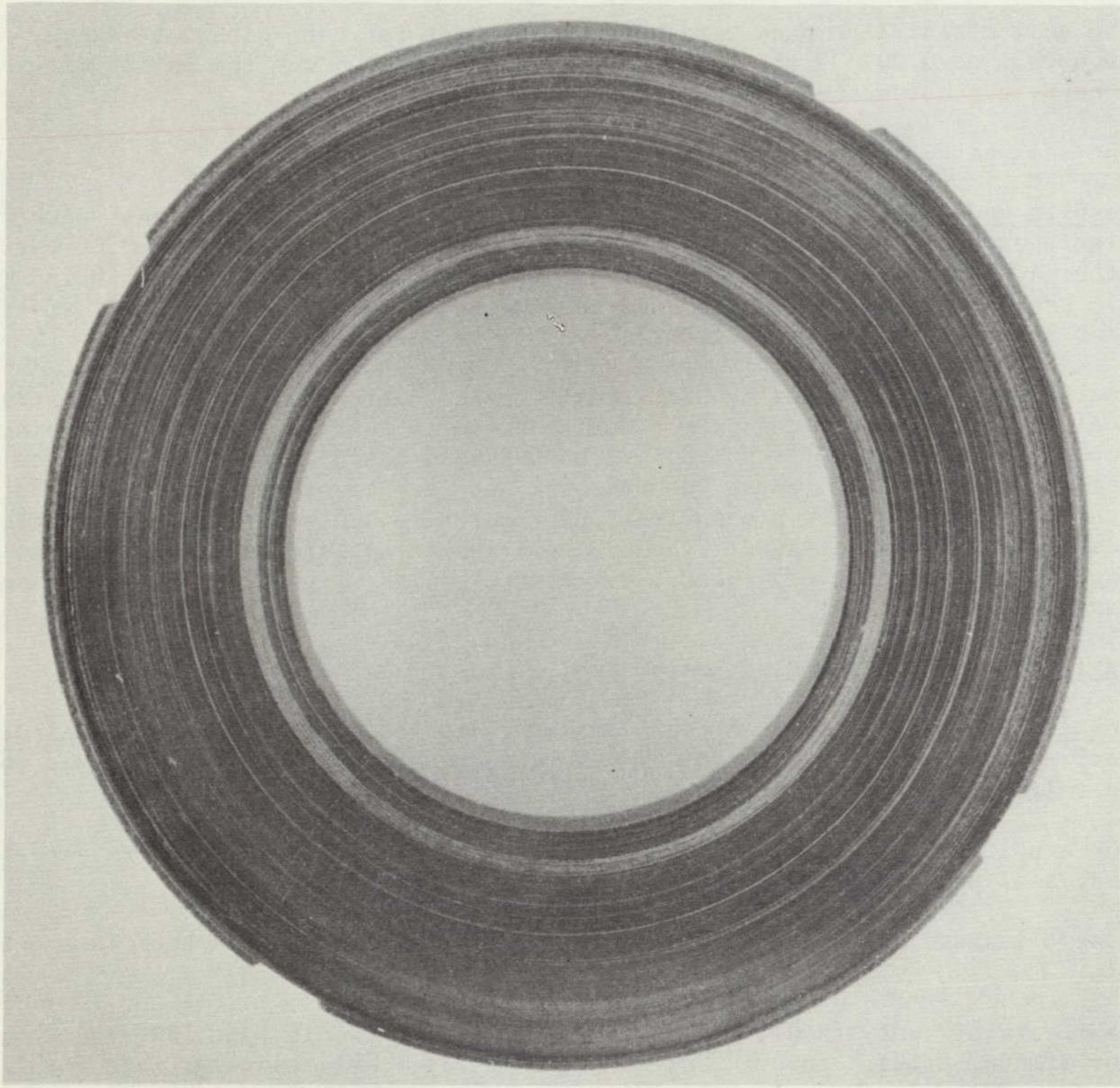


Figure 119. Spiral Groove LOX Seal Carbon Ring (A28-0812-11, S/N 04, Build 14, Posttest 749)

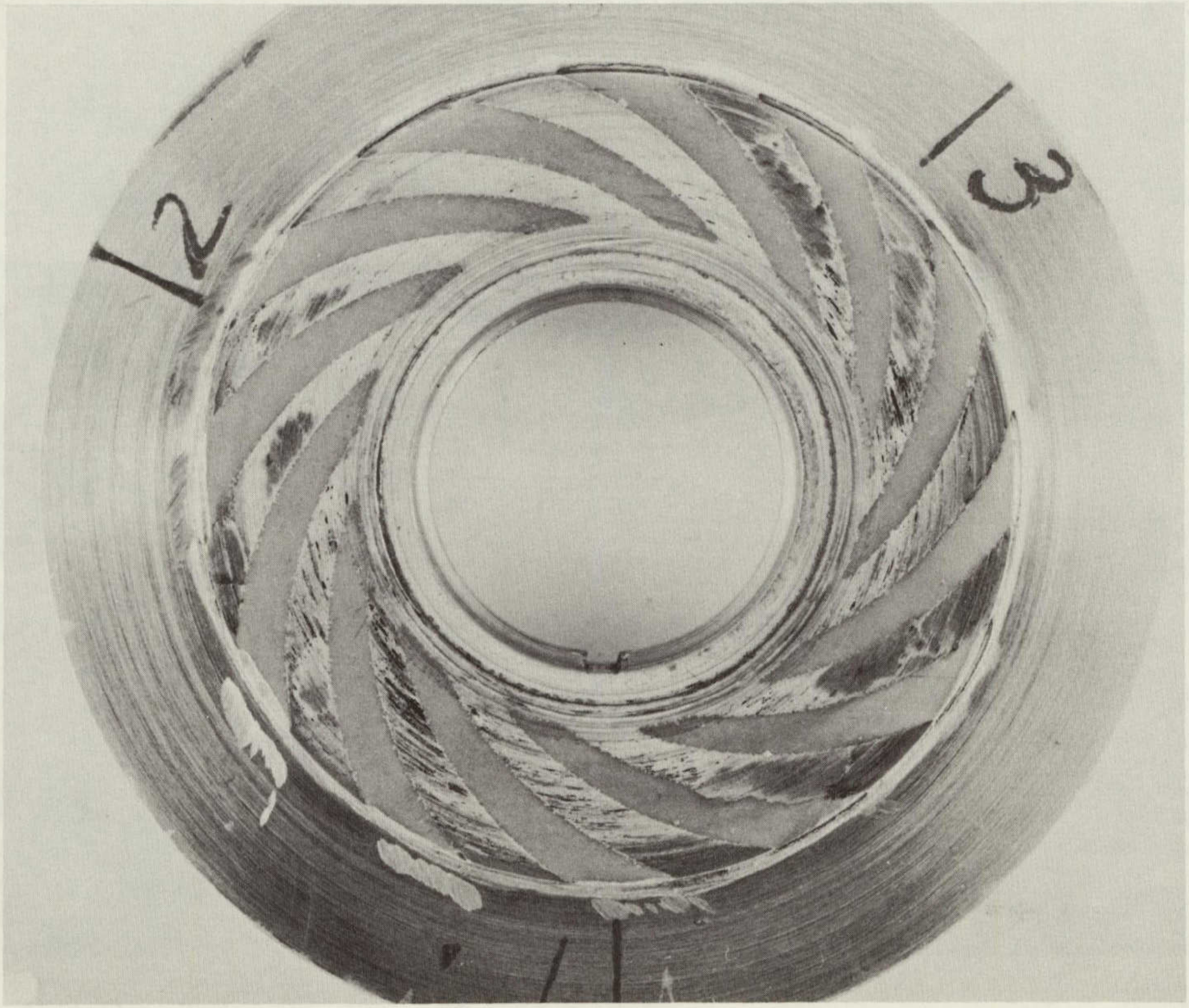


Figure 120. Spiral Groove LOX Seal Mating Ring (C28-0812-10, S/N 03, Build 14, Posttest 749)

Figure 121. Spiral Groove LOX Seal Mating Ring (C28-0812-10, S/N 03, Build 14, Posttest 749)

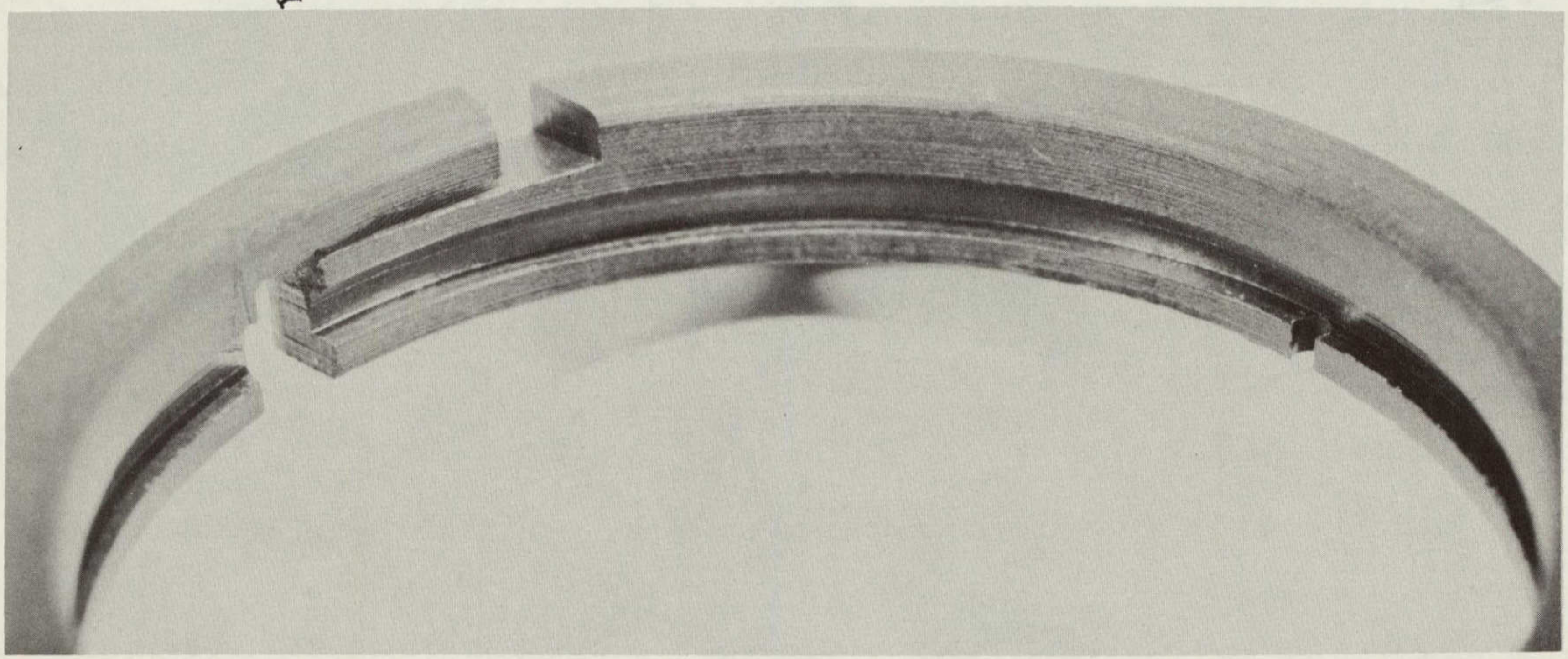


Figure 122. Spiral Groove LOX Seal Piston Ring (A28-0812-12-7456- Rev. C, S/N 03, Build 14, Posttest 749)

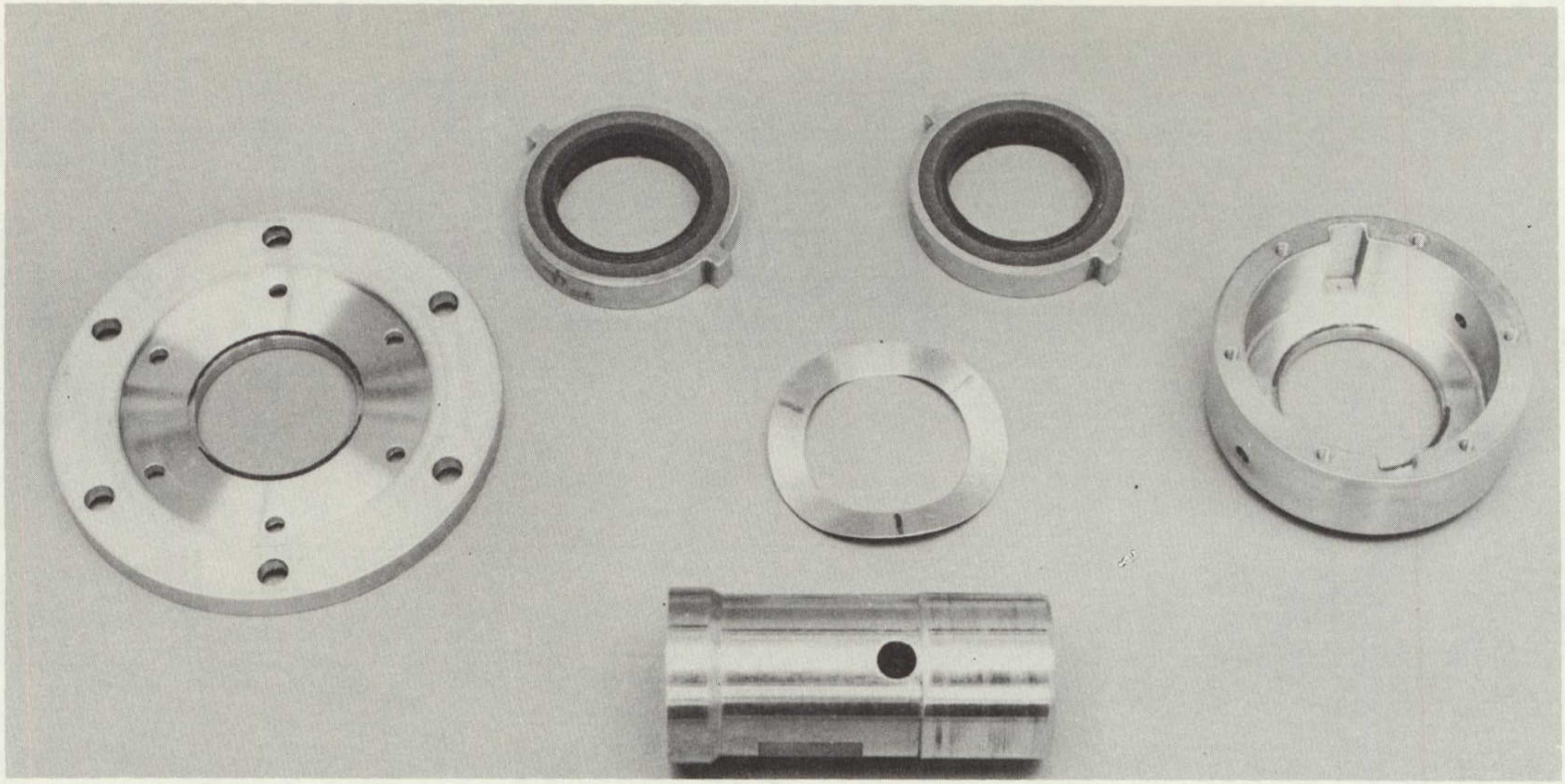


Figure 123. Helium Seal Assembly (RS009690X, S/N 05, Build 14, Posttest 749)

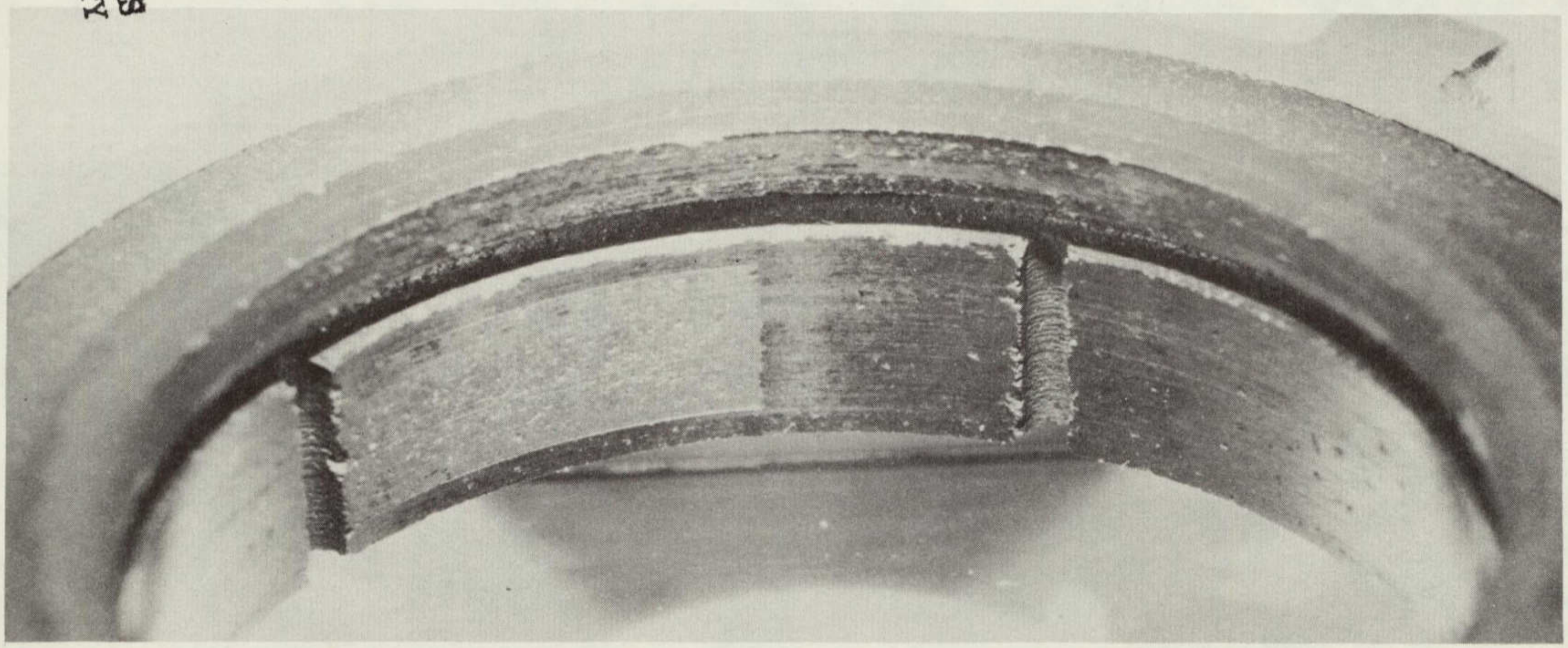


Figure 124. Helium Seal LOX Side Seal Ring (RS009690X, S/N 05, Build 14, Posttest 749)

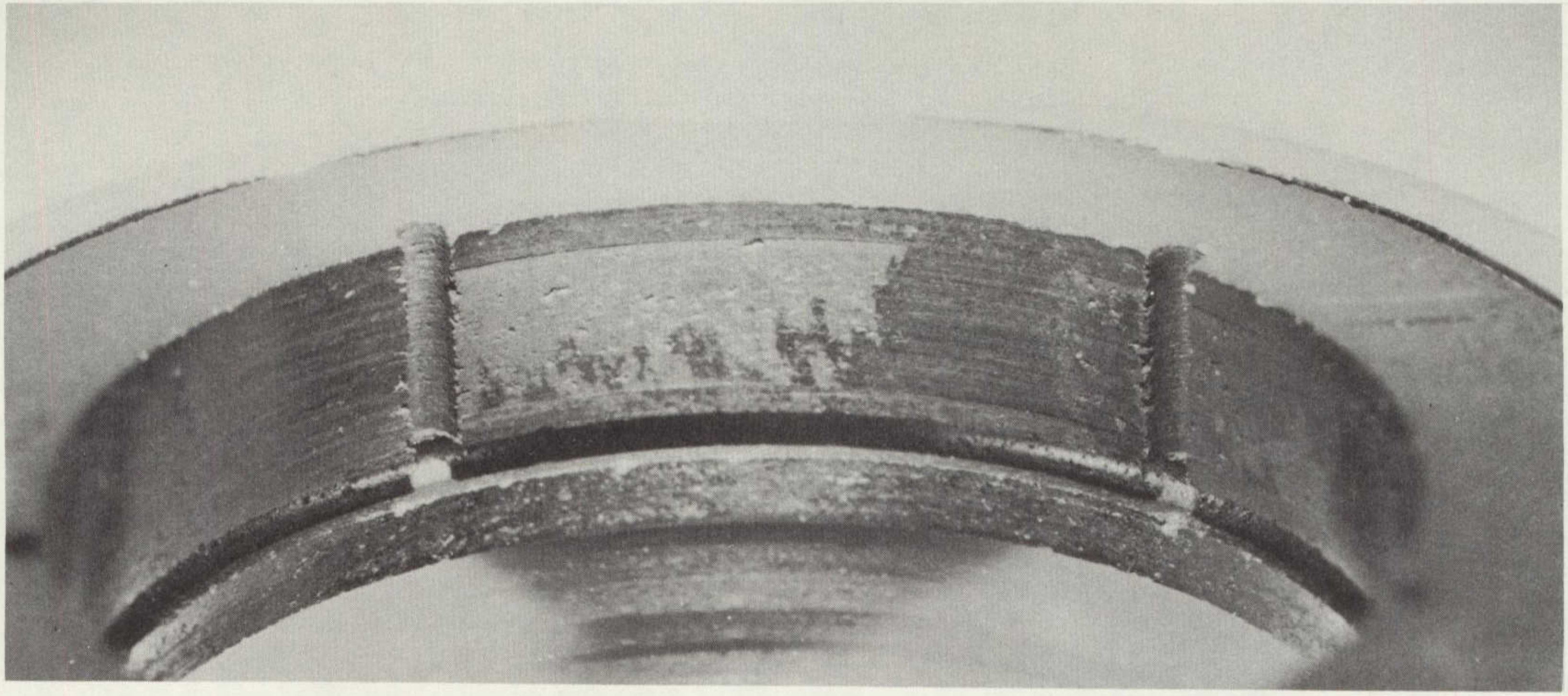
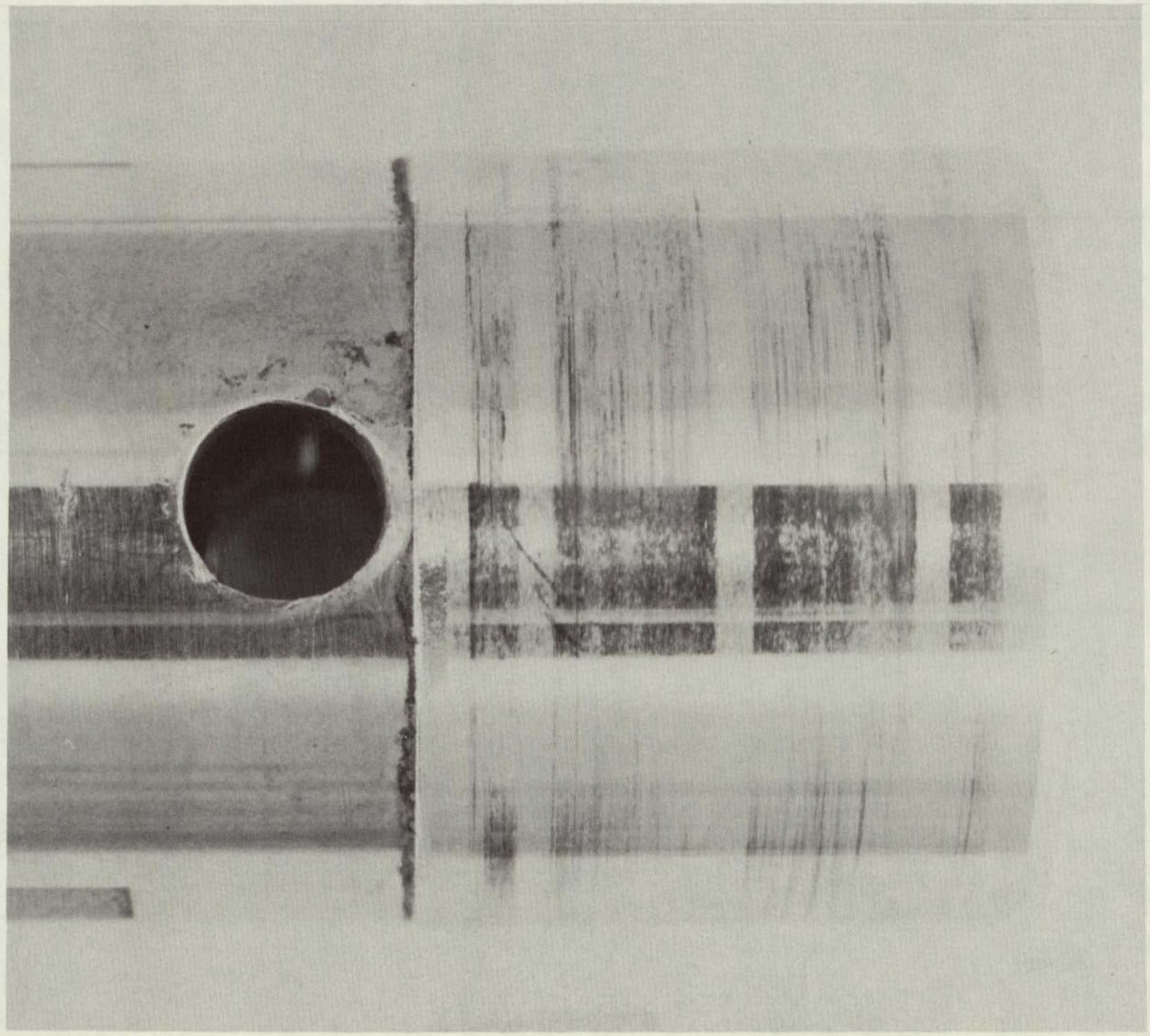


Figure 125. Helium Seal Turbine Side Seal Ring (RS009690X, S/N 05, Build 14, Posttest 749)



LOX SIDE　　　　　　　　　　　　　　　　　　　　TURBINE SIDE

Figure 126. Helium Seal Mating Ring (RS009667X, S/N 001-1, Build 14, Posttest 749)

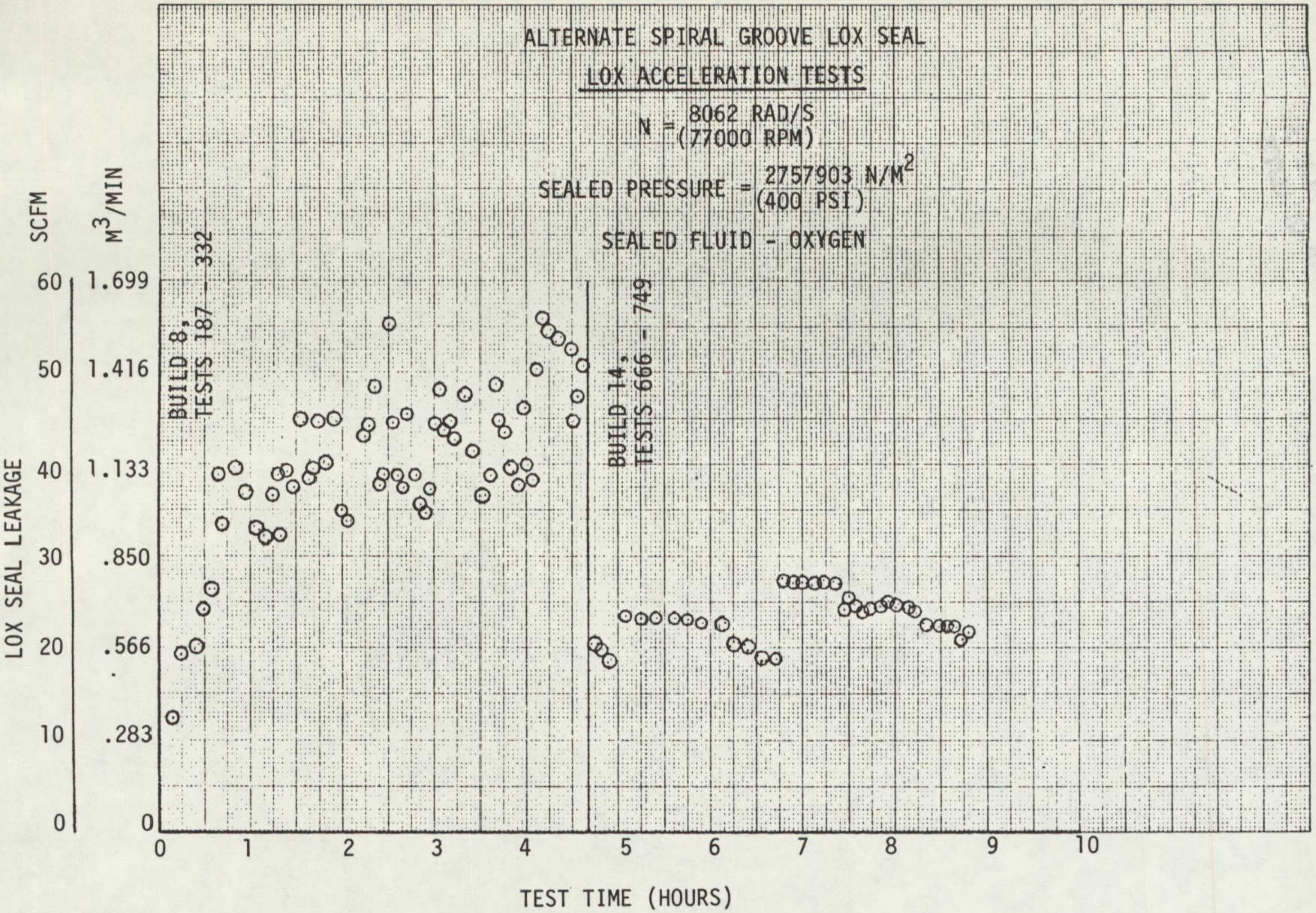


Figure 127. LOX Seal Leakage

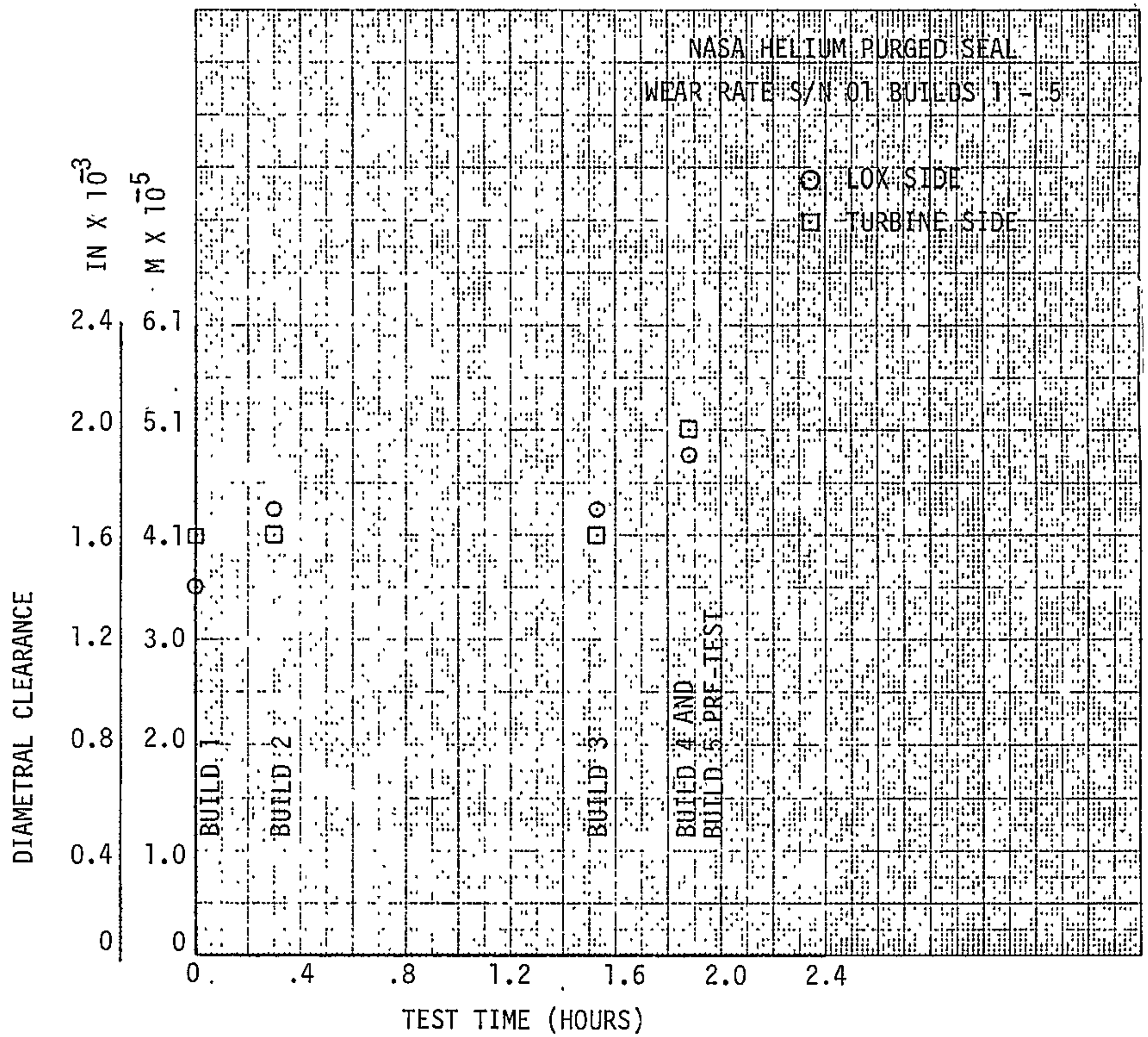


Figure 129. Helium Seal Wear Rate (S/N 01, Builds 1-5)

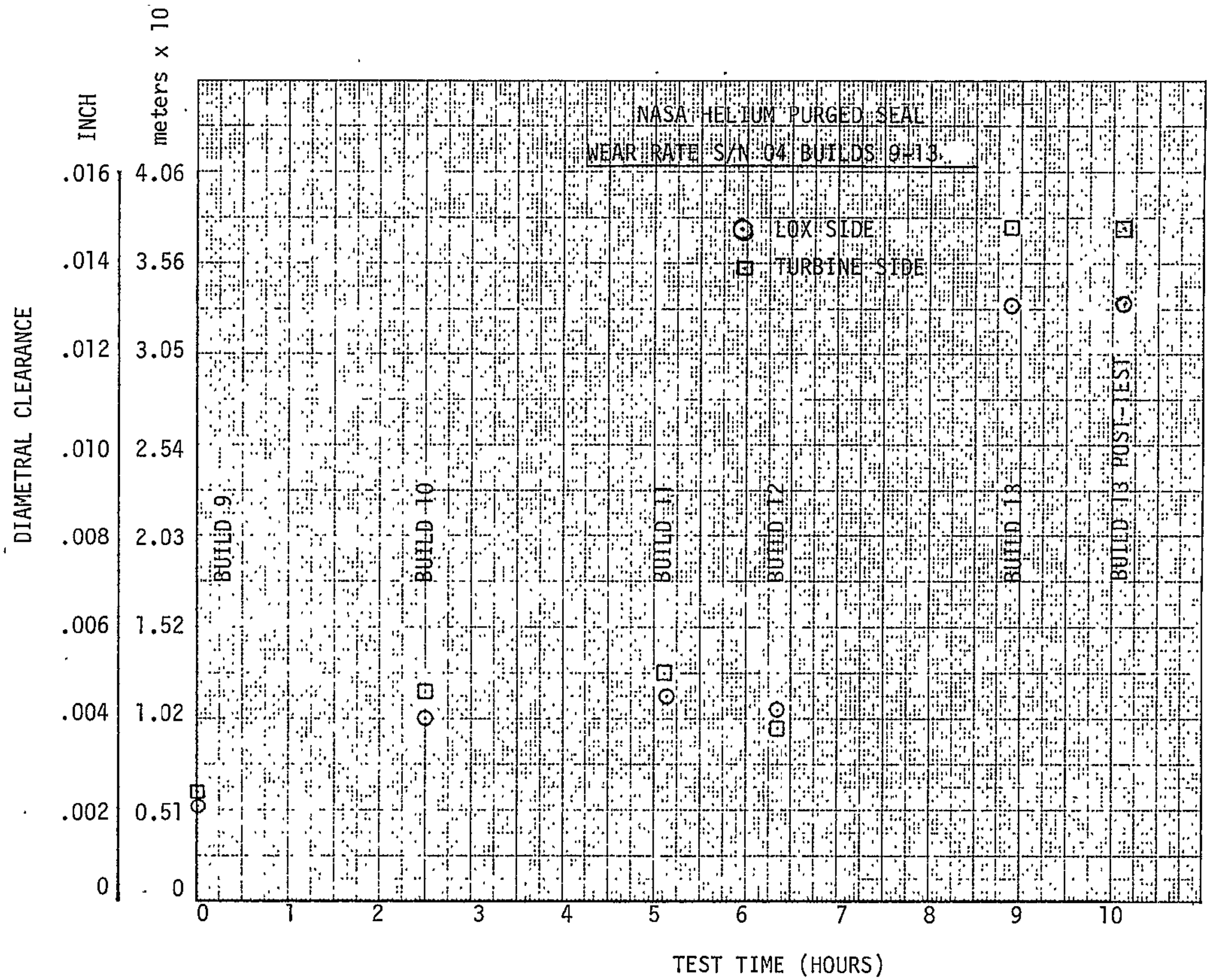
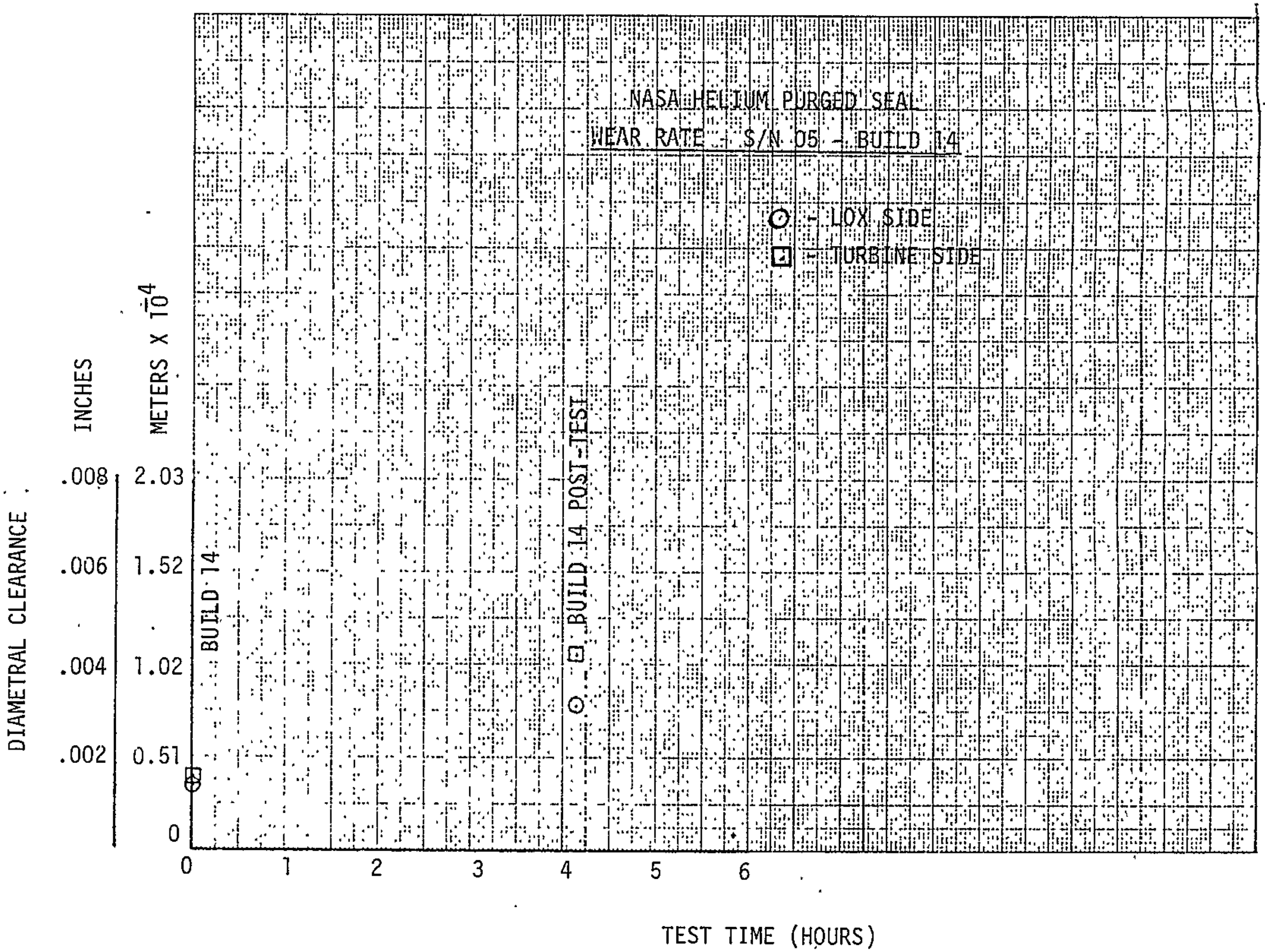


Figure 130. Helium Seal Wear Rate (S/N 04, Builds 9-13)



gure 131. Helium Seal Wear Rate (S/N 05, Build 14)

CONCLUSIONS

1. The shrouded Rayleigh step hydrodynamic lift pad LOX seal is feasible for advanced, small, high-speed oxygen turbopumps.

Total testing time	11 hours, 40 minutes
Total starts	376
Average leakage for 2,413,165 to 2,771,692 N/m^2g (350 to 402 psig)	0.762 m^3/minute (26.9 scfm-O_2)
LOX seal pressure	
Wear during 10-hour testing	Not measurable

2. The machined metal bellows secondary LOX seal is not feasible due to carbon wear and difficulty of manufacture.

3. The piston ring secondary LOX seal is feasible.

Total testing time	11 hours, 27 minutes
Total starts	365
Condition post testing	Excellent

4. The spiral groove hydrodynamic LOX face seal is feasible.

Total testing time	11 hours, 43 minutes
Total starts	339

During build 8, of 2,757,903 N/m^2g (400 psig) LOX fast-start tests:

Total time	4 hours, 28 minutes
Total starts	146
Leakage range	0.544 to 1.580 m^3/minute (19.2 to 55.8 scfm) oxygen with gradual increase with testing

During build 14, of 2,757,903 N/m^2g (400 psig) LOX fast-start tests:

Total time	4 hours, 10 minutes
Total starts	84
Average leakage	0.657 m^3/minute (23.2 scfm) oxygen for 64 tests more than 1-minute duration

5. The helium purge intermediate floating ring seal with shrouded Rayleigh step hydrodynamic lift pads on the carbon ring inside diameter is feasible.

Total testing time	23 hours, 23 minutes
Total starts	749
Leakage range	0.088 to 0.654 m^3/minute (3.1 to 23.1 scfm) helium

6. The small, high-speed seal tester adequately met seal testing requirements. Primary limitation on testing duration was the tester bearing which required inspection after 2.5 hours testing.

7. LOX seal Rayleigh step lift pad spring loads were less than the design values for satisfactory testing.

8. The reverse pumping element upstream of the LOX face seal was not consistent in dropping the pressure at the seal as a function of speed. Data in Table 13 indicated that the seal upstream cavity pressure was reduced by 1.6% to 50.9%, at 8062 rad/s (77,000 rpm). The range was probably due to the variation of seal upstream cavity through flow leaking past the slave seal to the bearing cavity. A higher pressure drop could be achieved by closer spacing of the rotating and stationary elements or adding radial vanes to the rotating element.

REFERENCES

1. Zuk, J., P. Ludwig, and R. L. Johnson: Design Study of Shaft Face Seal with Self-Acting Lift Augmentation, I - Self-Acting Pad Geometry, NASA TN D-5744, 1970.

2. Zuk, J., P. Ludwig, and R. L. Johnson: Quasi-One-Dimensional Compressible Flow Across Face Seals and Narrow Slots, I - Analysis, NASA TN D-6668, 1972.