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FINAL REPORT

HIGH-SPEED CRYOGENIC SELF-ACTING SHAFT SEALS FOR LIQUID ROCKET TURBOPUMPS

by

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Prepared For

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16. Abstract

Design analysis, detail design, fabrication and experimental evaluation were performed on three self-acting lift pad liquid oxygen face seals and two self-acting gaseous helium circumferential seals for high speed liquid oxygen turbopumps.

The Rayleigh Step LOX seal demonstrated satisfactory performance for a total of 559 tests and 48.5 hours.

The inward pumping spiral groove LOX seal requires additional development due to excessive leakage and wear.

The outward pumping pressure balanced spiral groove LOX seal demonstrated feasibility during 71 tests for 1.4 hours.

The Rayleigh Step segmented carbon helium seal demonstrated satisfactory performance for a total of 401 tests and 26.1 hours.

The Rayleigh Step floating ring helium seal demonstrated satisfactory performance for a total of 168 tests and 25.3 hours.

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FOREWORD

This program was sponsored by the National Aeronautics and Space Administration, Lewis Research Center, Structures and Mechanical Technology Division, under Contract NAS3-20807. The period of performance was June 1972 to September 1982.

The NASA Project Manager wss Mr. W. F. Hady from start to March 1977, Mr. L. P. Ludwig from March 1977 to January 1980 and Mr. E. DiRusso from January 1980 to completion. The Contracting Officers were Mr. Leonard Schopen and Mr. David Thomas. Design support and technical consultation was provided by Mr. W. F. Hady, Mr. L. P. Ludwig, Dr. John Zuk and Mr. E. DiRusso.

The Rocketdyne Program Manager was Mr. D. L. Fulton. The Project Engineer was Mr. R. E. Burcham. Technical assistance was provided by Mr. W. A. Diamond, Mr. J. L. Boynton and other members of the technical staff.

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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 two self-acting lift pad gaseous helium circumferential seals. The objective of the program was to develop technology for reliable, 10-hour life, multiple-start seals for use in high speed liquid oxygen turbopumps. The seals were designed to operate at 32,000 rpm on a 7.62 cm (3.00 in.) nominal diameter shaft with 1034 to 3447 kPa (150 to 500 psia) LOX pressure and 345 to 689 kPa (50 to 100 psia) helium pressure.

The following seals were evaluated:

1. <u>Rayleigh Step LOX Seal</u>: Tested for 559 starts and 48.5 hours total.

   a. Phase I seal 1 was tested for 68 starts and 2.4 hours in gaseous nitrogen and 90 starts for 9.8 hours in liquid oxygen. The seal was damaged by a tester explosion. The wear and leakage was satisfactory prior to the damage.

   b. Phase I seal 2 was tested for 73 starts and 10.1 hours in liquid oxygen. The seal was in good condition with no wear. The leakage was satisfactory.

   c. Phase III seal was tested for 195 starts and 15.3 hours in liquid oxygen. The seal was in good condition with slight wear 0.00025 cm (0.0001 in.). The leakage was satisfactory 0.042 to 0.061 m^3/s (90 to 130 SCFM).

   d. Phase IV seal was tested for 133 starts and 10.9 hours in liquid oxygen. The seal was in good condition with no significant wear. The leakage was satisfactory.

2. <u>Inward pumping spiral groove LOX seal</u>: Tested for 43 starts and 1.5 hours total in liquid oxygen.

   a. The Phase IV basic seal was tested for 9 starts and 630 seconds. The leakage was excessive. The mating ring was worn 0.028 to 0.063 cm (0.011 to 0.025 in.). The carbon was worn 0.102 to 0.152 cm (0.040 to 0.060 in.).

   b. The Mod I seal was tested for 3 starts and 20 seconds. the leakage was excessive. The mating ring was worn 0.0005 cm (0.0002 in.). The carbon was worn 0.0010 to 0.0056 cm (0.0004 to 0.0022 in.).

   c. The Mod II seal was tested for 24 starts and 2058 seconds. The leakage suddenly increased excessively. The mating ring was worn 0.0013 cm (0.0005 in.). The carbon was worn 0.030 to 0.048 cm (0.012 to 0.019 in.).

   d. The Mod III seal was tested for 7 starts and 2724 seconds. An explosion and fire was caused by rubbing at the seal face.

3. Outward pumping pressure balanced spiral groove LOX seal: Tested for 71 starts and 1.4 hours total in liquid nitrogen.

   a. Phase V seal 1 was tested for 31 starts and 24.3 minutes. Heavy rubbing and wear 0.0025 cm (0.001 in.) occurred due to a tester malfunction. The seal performance was satisfactory prior to the damage.

   b. Phase V seal 2 was tested for 40 starts and 59.5 minutes. The seal was in satisfactory condition with negligible rubbing and wear. The leakage was satisfactory 0.023 to 0.047 m^3/s (50 to 100 SCFM).

4. Rayleigh Step segmented carbon helium seal: Tested for 401 starts and 26.1 hours total with gaseous helium.

   a. Phase I three-segment seals 1 through 4 were tested for 12 starts and 0.7 hours total. The carbon segments were broken due to excessive tester shaft deflections.

   b. Phase I six-segment seal 1 was tested for 57 starts and 1.7 hours. The segments were worn uneven due to mating ring distortion.

   c. Phase I six-segment seal 2 was tested for 20 starts and 2.6 hours. The segments were worn uneven.

   d. Phase I six-segment seal 3 was tested for 65 starts and 7.2 hours. The seal was damaged by a tester explosion. The leakage was satisfactory prior to the explosion.

   e. Phase IV seal 1 was tested for 133 starts and 10.9 hours. The seal was in good condition with slight wear 0.00076 cm (0.0003 in.). The leakage was acceptable 0.0014 to 0.0037 m^3/s (3 to 8 SCFM).

   f. Phase IV seals numbers 2 and 3 were tested for 71 starts and 1.4 hours. The segments were damaged by a tester malfunction. The leakage was satisfactory prior to the damage.

   g. Phase V seals 1 through 3 were tested for 71 starts and 1.4 hours. The segments were damaged by a tester malfunction. The leakage was satisfactory prior to the damage.

5. Rayleigh Step floating ring helium seal: Tested for 168 starts and 25.3 hours total with gaseous helium.

   a. Phase III basic seals 1 and 2 were tested for 62 starts and 4.4 hours. Both seals seized and wore a groove in the mating ring.

   b. Mod I seal 1 was tested for 63 starts and 9.6 hours. The seal was in good condition with negligible wear. The leakage was satisfactory 0.019 to 0.023 m^3/s (40 to 50 SCFM).

   c. Mod I seal 2 was tested for 143 starts and 11.3 hours. The seal was in good condition with negligible wear. The leakage was satisfactory 0.019 to 0.023 m^3/s (40 to 50 SCFM).

INTRODUCTION

Rotating shaft seals used for high-speed, high-pressure liquid oxygen turbopumps will require significant advances in sealing technology for effective sealing and reliable operation. The conventional rubbing contact face seals provide effective sealing for pressures up to 2068 kPa (300 psia) at speeds up to 61 m/s (200 ft/sec) with a life of 2 hours. Higher speeds and pressures or longer life require either labyrinth or floating ring type clearance seals with significantly higher leakage. The objective of this program is to develop technology for self-acting hydrodynamic seals which will provide effective sealing and reliable operation for 10 hours life at speeds of 137 m/s (450 ft/sec) and pressures up to 3447 kPa (500 psia).

The self-acting hydrodynamic seals develop a fluid film at the sealing interface to support the seal ring without rubbing contact. The fluid film thickness is controlled by the hydrodynamic lift 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. Effective sealing without rubbing contact is accomplished by operating at small 0.00025 to 0.0010 cm (0.0001 to 0.0004 in.) clearances.

The following liquid oxygen seals were evaluated:

1. Shrouded Rayleigh Step hydrodynamic lift pad face seal with a piston ring secondary seal and with a segmented Vespel secondary seal.

2. Spiral groove inward pumping hydrostatic/hydrodynamic face seal with a piston ring secondary seal.

3. Spiral groove outward pumping pressure balanced hydrostatic/hydrodynamic face seal with a segmented Vespel secondary seal.

The following helium seals were evaluated:

1. Shrouded Rayleigh Step segmented carbon hydrodynamic circumferential seal.

2. Shrouded Rayleigh Step floating ring hydrodynamic circumferential seal.

The evaluation included analysis, detail design, hardware fabrication, and experimental testing with actual propellants at the required operating conditions. An existing tester was modified to simulate the turbopump environment. Hydrodynamic analysis of the Rayleigh Step and outward pumping spiral groove geometry was performed by NASA Lewis. Hydrodynamic analysis of the inward pumping spiral groove geometry was performed by Crane Packing Company. The seal hardware was fabricated by Stein Seal Company, Koppers Company and Crane Packing Company. The experimental testing was performed at Rocketdyne and Wyle Laboratories.

SEAL DESIGN

A design analysis and detailed design of the self-acting lift pad seal designs furnished by NASA was conducted to ensure satisfactory operation in gaseous nitrogen and liquid oxygen. The hydrodynamic analysis of the Rayleigh Step and outward pumping spiral groove designs was performed by NASA. The hydrodynamic analysis of the inward pumping spiral groove LOX seal design was performed by Crane Packing Company.

The LOX seals were designed to the following specifications:

Fluid:	Liquid and/or gaseous oxygen Gaseous nitrogen
Temperature:	Liquid oxygen 90 K (-297 F) Gaseous oxygen 132 K (-220 F) Gaseous nitrogen 294 K (70 F)
Pressure:	2413 to 3447 kPa (350 to 500 psia)
Speed:	32,000 rpm
Start Time:	3.5 seconds
Shutdown Time:	2.5 seconds
Shaft Axial Movement:	±0.051 cm (0.020 in.)
Operating Life:	10 hours
Number of Starts:	130

The helium seals were designed to the following specifications:

Fluid:	Gaseous helium
Temperature:	294 to 163 K (70 to -297 F)
Pressure:	345 to 689 kPa (50 to 100 psia)
Speed:	32,000 rpm
Start Time:	3.5 seconds
Shutdown Time:	2.5 seconds
Mating Ring Radial Runout:	0.0076 cm (0.003 in.) TIR
Mating Ring Diameters:	
Phase I-IV:	10,000 cm (3.9370 in.)
Phase V:	6.768 cm (2.6648 in.)
Operating Life:	10 hours
Number of Starts:	130

PHASE I RAYLEIGH STEP LOX SEAL

The Phase I LOX seal (Fig. 1) consists of a face type carbon seal ring with Rayleigh Step hydrodynamic lift pads on the outside of the sealing dam to provide fluid film support. The carbon seal ring (Fig. 2) is retained by interference fit with an Invar 36 metal band. The retainer band has two anti-rotation tangs engaging slots in the housing to provide full axial movement without rotation. The seal ring assembly is loaded against the rotating mating ring through an Invar 36 pilot ring with compression springs. The seal ring has a lapped sealing dam on the back side to provide a static seal to the pilot ring. The pilot ring is sealed to the housing with a carbon piston ring (Fig. 3). The sealing surfaces of the pilot ring are hard chrome plated.

	PART	PHASE I	PHASE III
1	HOUSING	INCONEL 600	SAME
2	PILOT RING	INVAR 36	SAME
3	RETAINER	INVAR 36	SAME
4	SEAL RING	CARBON P03N	CARBON P692
5	PISTON RING	CARBON P5NR2	VESPEL SP211
6	SPRING	INCONEL X750	SAME
7	STATIC SEAL	INCONEL X750	SAME
8	MATING RING	K-MONEL	SAME
9	KEY	303 SS	SAME

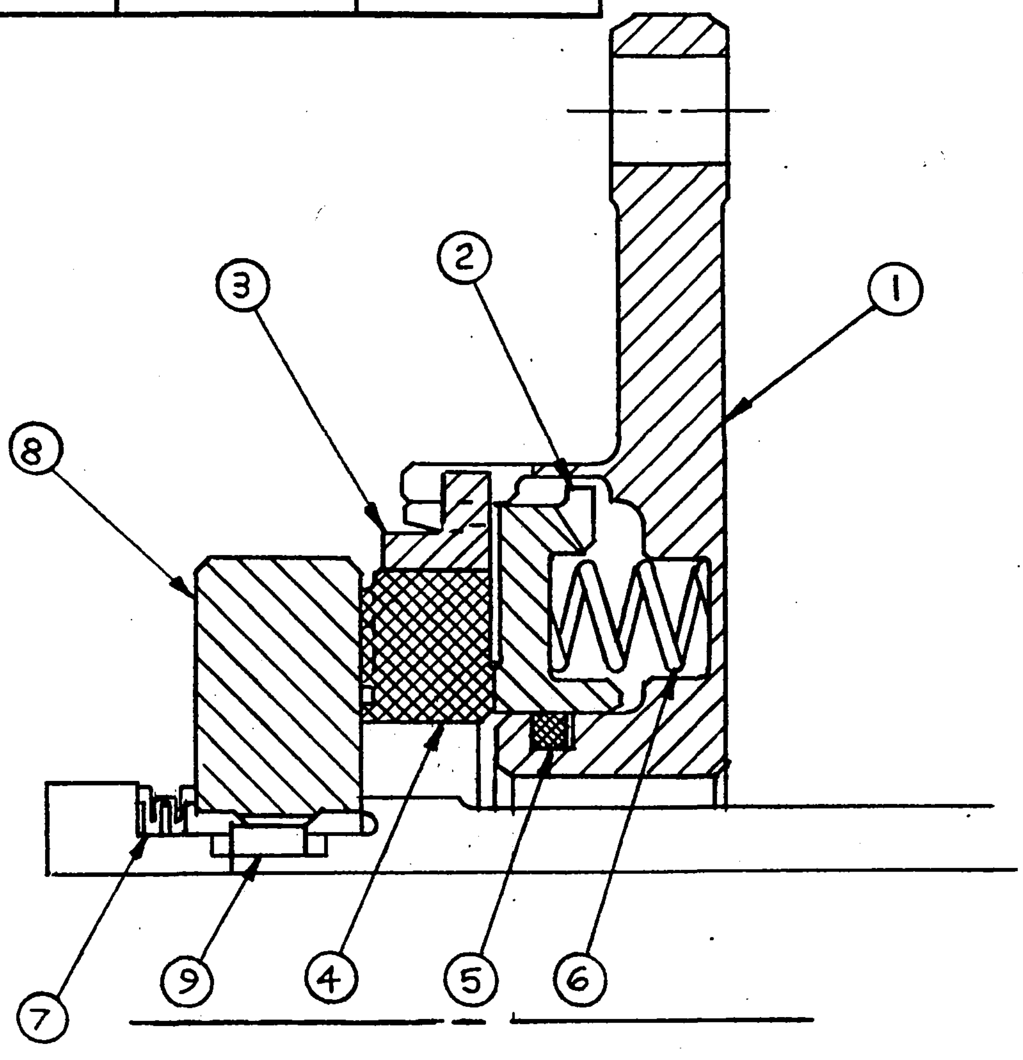

Figure 1. Phase I and III Rayleigh Step LOX Seal

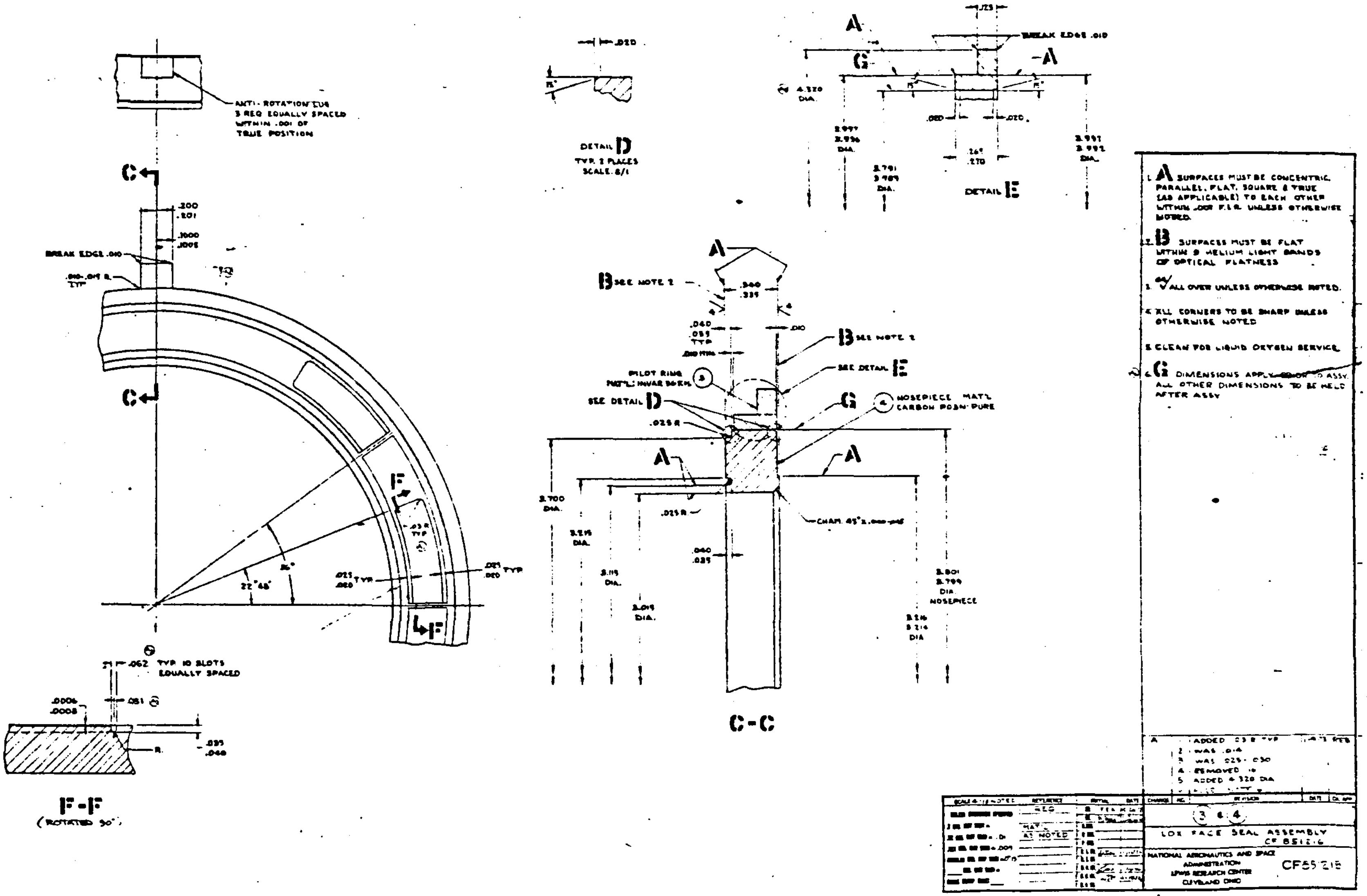

Figure 2. Phase I LOX Seal Ring (CF 851218)

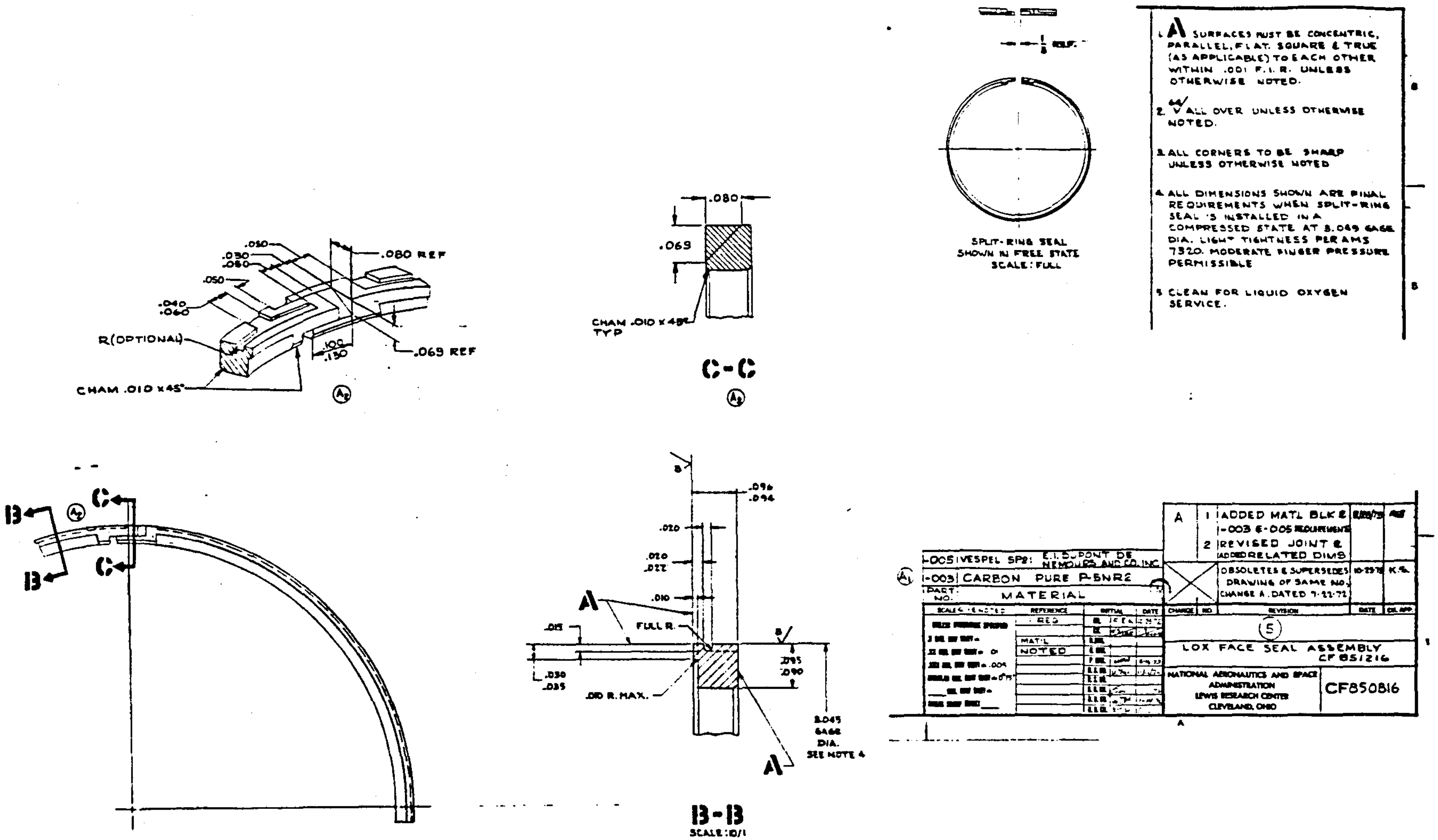

Figure 3. Phase I Piston Ring (CF 850816)

Rayleigh Step Lift Pads

The Rayleigh Step lift pads (Fig. 4) 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 hydrodynanic lifting force at the seal face. The lift force decreases for the 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 Seal-Acting Lift Pad Design Program for Gas Film Seals (Ref. 1). The generated lift force as a function of the operating environment, lift pad geometry and operating film thickness is shown in Fig. 5.

The lift pad geometry was optimized for gaseous oxygen at 133 K (-220 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 0.00025 cm (0.0001 in.) for liquid pad geometry decreases from 560 N (126 lb) to 49 N (11 lb) when the environment changes from turbulent liquid oxygen to gaseous oxygen. The lift force at 0.00025 cm (0.0001 in.) for gas pad geometry decreased from 338 N (76 lb) to 253 N (57 lb) if the environment changes from liquid to gas. 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 gas mixture will operate with a larger film thickness and increased leakage. The increased leakage is more acceptable than rubbing contact.

Force Balance

The sealing dam opening force and the closing force due to the pressure acting on the secondary seal diameter were approximately equal 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. The predicted average opening pressure profile factor at the sealing dam is 63 to 70% of the pressure differential, depending on the assumed loss coefficient and the pressure ratio (Fig. 6).

The sealing dam dimensions were selected to provide a 70% balance factor (closing area/dam area). The seal is force balanced when the balance factor is equal to the sealing dam pressure profile factor. The design provides a slightly positive closing force to allow for variations in fluid condition and sealing surface geometry.

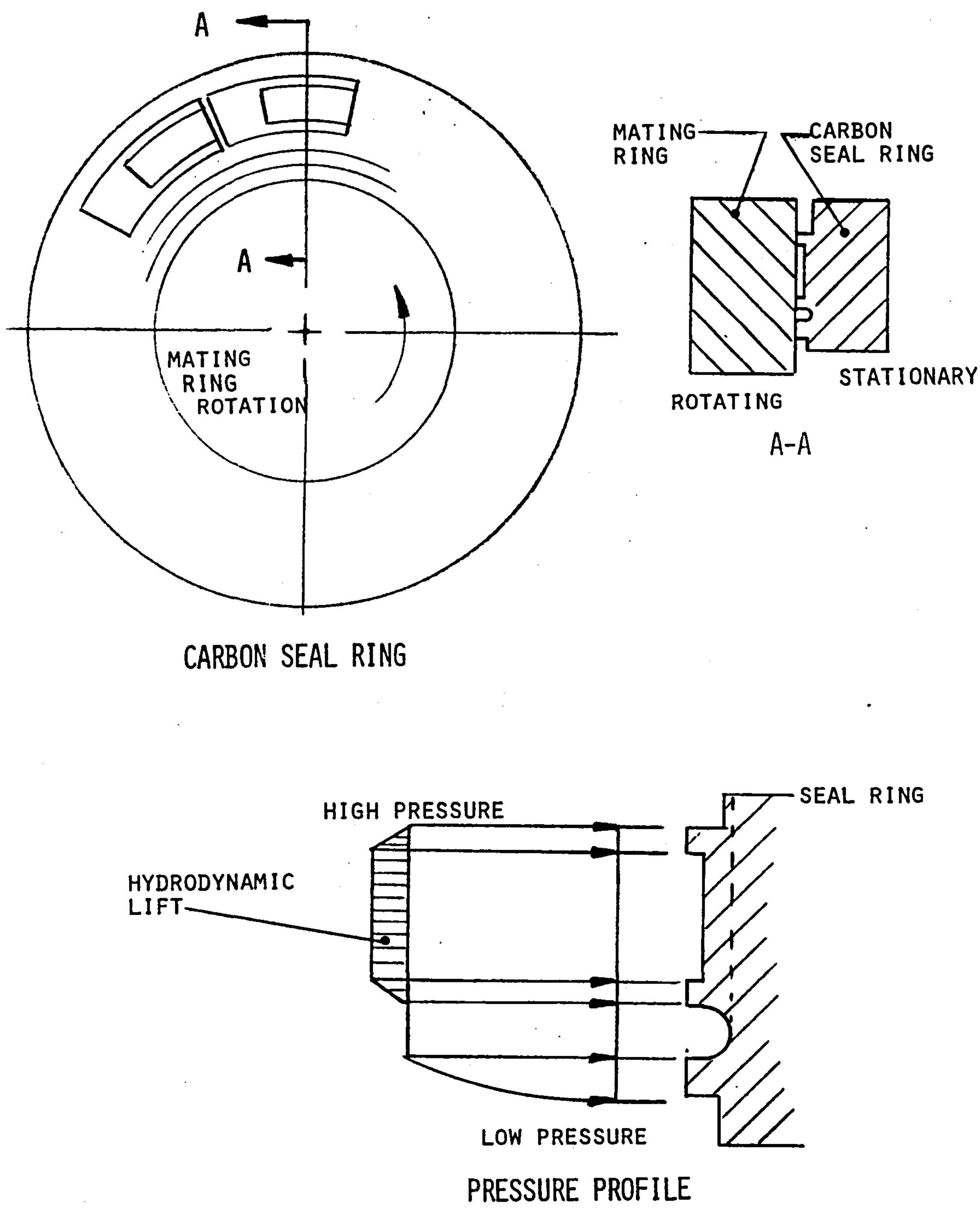

Figure 4. Rayleigh Step Hydrodynamic Face Seal

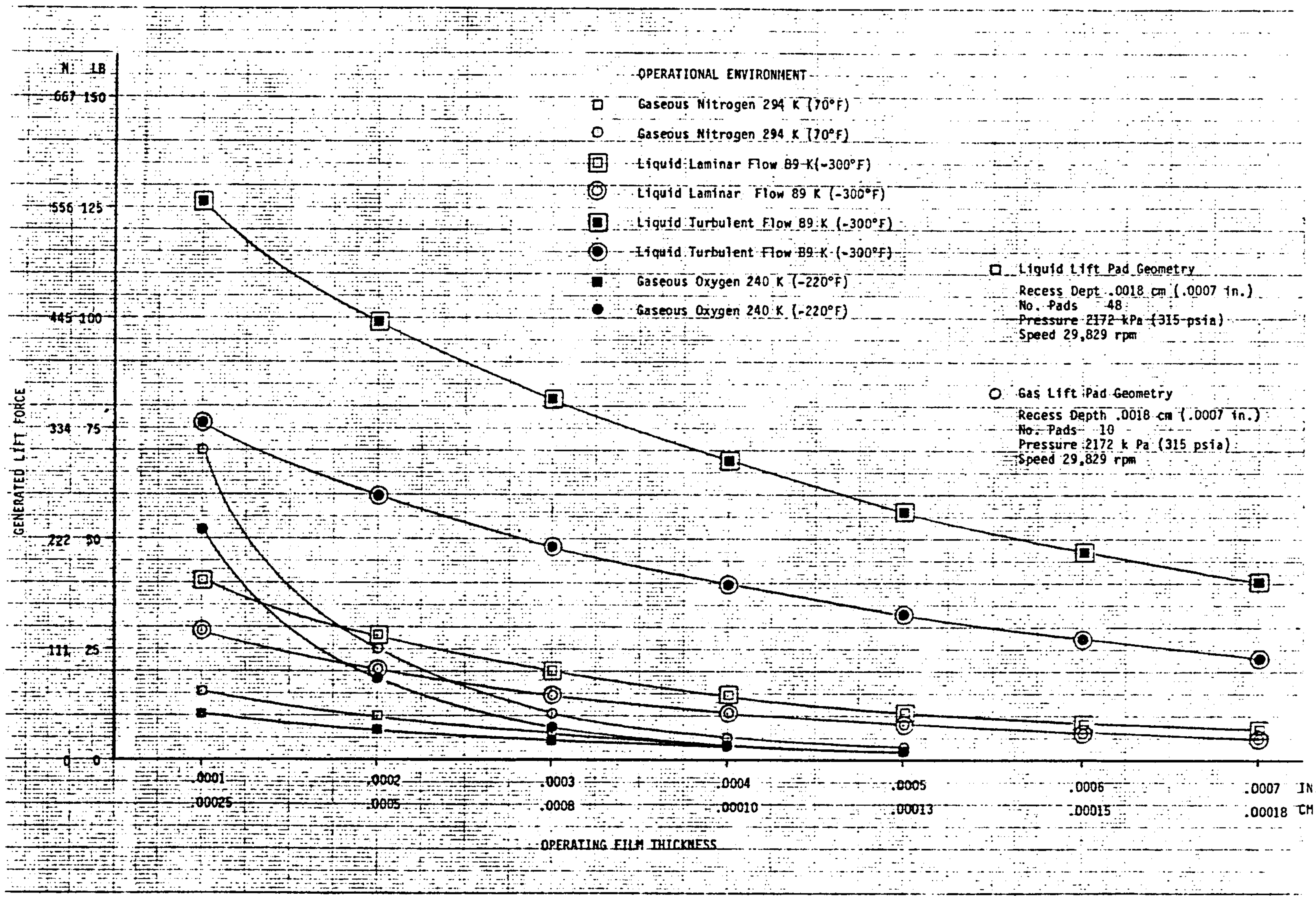

Figure 5. Rayleigh Step LOX Seal Lift Force

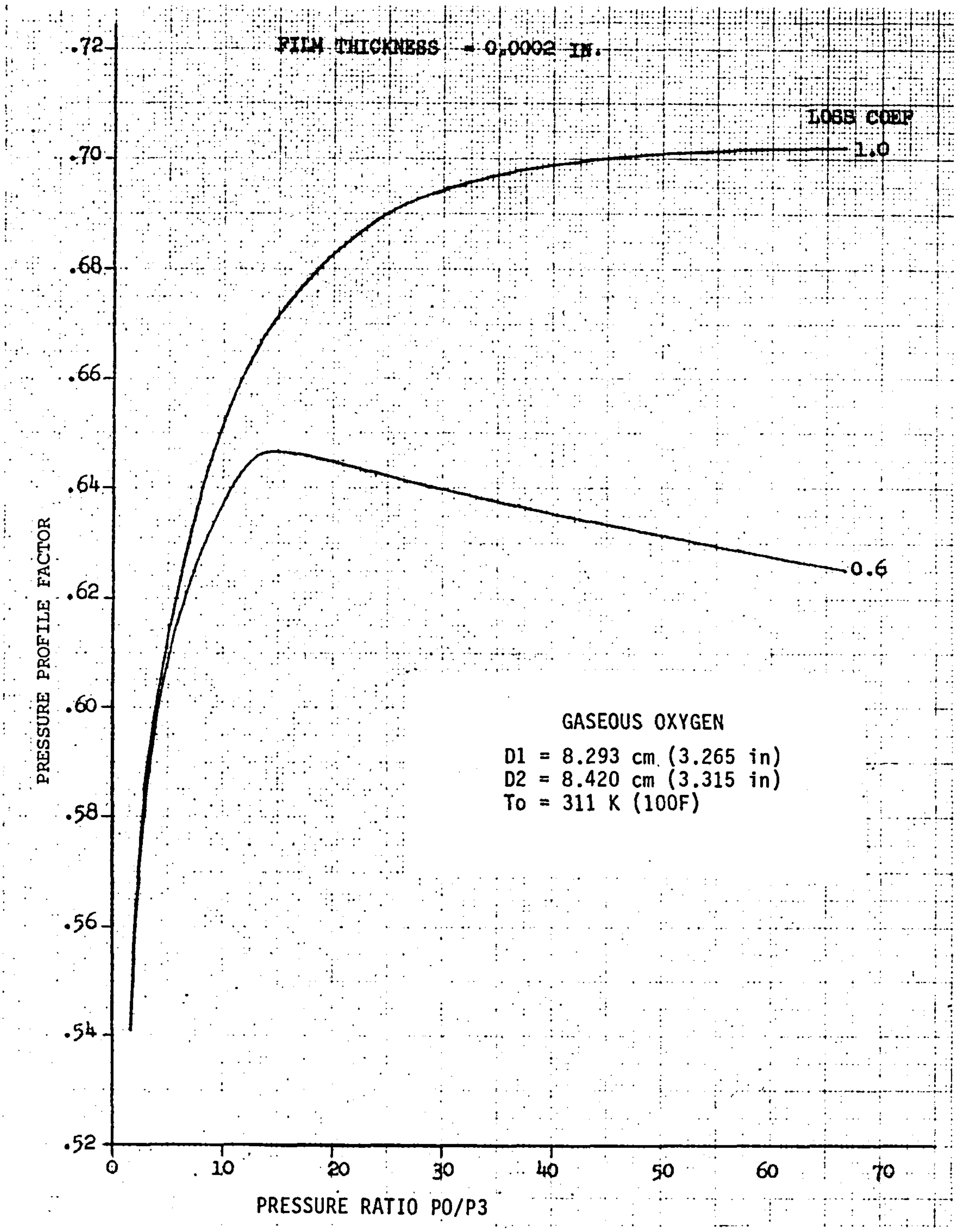

Figure 6. Rayleigh Step LOX Seal Sealing Dam Pressure Profile Factor

Leakage

The predicted sealing dam liquid oxygen leakage rate as a function of operating film thickness at 2068 kPa (300 psia) and 30,000 rpm is shown in Fig. 7. The nominal leakage at the sealing dam is 0.010 m^3/s (22 SCFM) for 0.0005 cm (0.0002 in.) film thickness. The leakage at the secondary piston ring is expected to be approximately equal to the nominal sealing dam leakage. The leakage at the lapped joint static sealing dam between the seal ring and pilot ring is not included and is expected to be negligible.

Seal Ring Stress and Deflection

The carbon seal ring and Invar retainer band assembly was analyzed to establish the interference fit for positive retention and to determine the radial deflection caused by thermal contraction and pressure induced forces. The results are shown in Table 1 for a pressure of 2413 kPa (350 psia) and temperature of 90 K (-297 F).

TABLE 1. RAYLEIGH STEP LOX SEAL RING STRESS AND DEFLECTIONS

INITIAL DIA INTERFERENCE, cm (IN.)	0.028	(0.011)
TEMPERATURE DIA DEFLECTION, cm (IN.)	-0.0038	(-0.0015)
PRESSURE DIA DEFLECTION, cm (IN.)	-0.0023	(-0.0009)
TOTAL DIA DEFLECTION, cm (IN.)	-0.0061	(-0.0024)
CARBON RING STRESS, kPa (PSI)	-35033	(-5081)
INVAR BAND STRESS, kPa (PSI)	128998	(18709)

Mating Ring

The LOX seal mating ring is K-monel, hard chrome plated on the sealing surface and lapped flat within three helium light bands. The ring is free mounted (Fig. 1) on the shaft sleeve and spring loaded for clamping to prevent distortions caused by shaft sleeve deflections. The shoulder on the shaft sleeve is flat within three helium light bands. The spring load and static sealing are provided by a standard machined metal bellows type static seal. The ring is keyed to the sleeve at one location to prevent rotation. A narrow pilot land is used on the mating ring bore to minimize bending moments caused by sleeve distortion.

PHASE II RAYLEIGH STEP LOX SEAL

The Phase II LOX seal (Fig. 8) is the same as Phase I, except the seal ring is solid carbon. The carbon seal ring is piloted with a separate Invar 36 retainer ring which is attached to the Invar 36 pilot ring. The Rayleigh Step geometry is the same as Phase I.

The PHASE II LOX seal was fabricated but not tested due to insufficient funding.

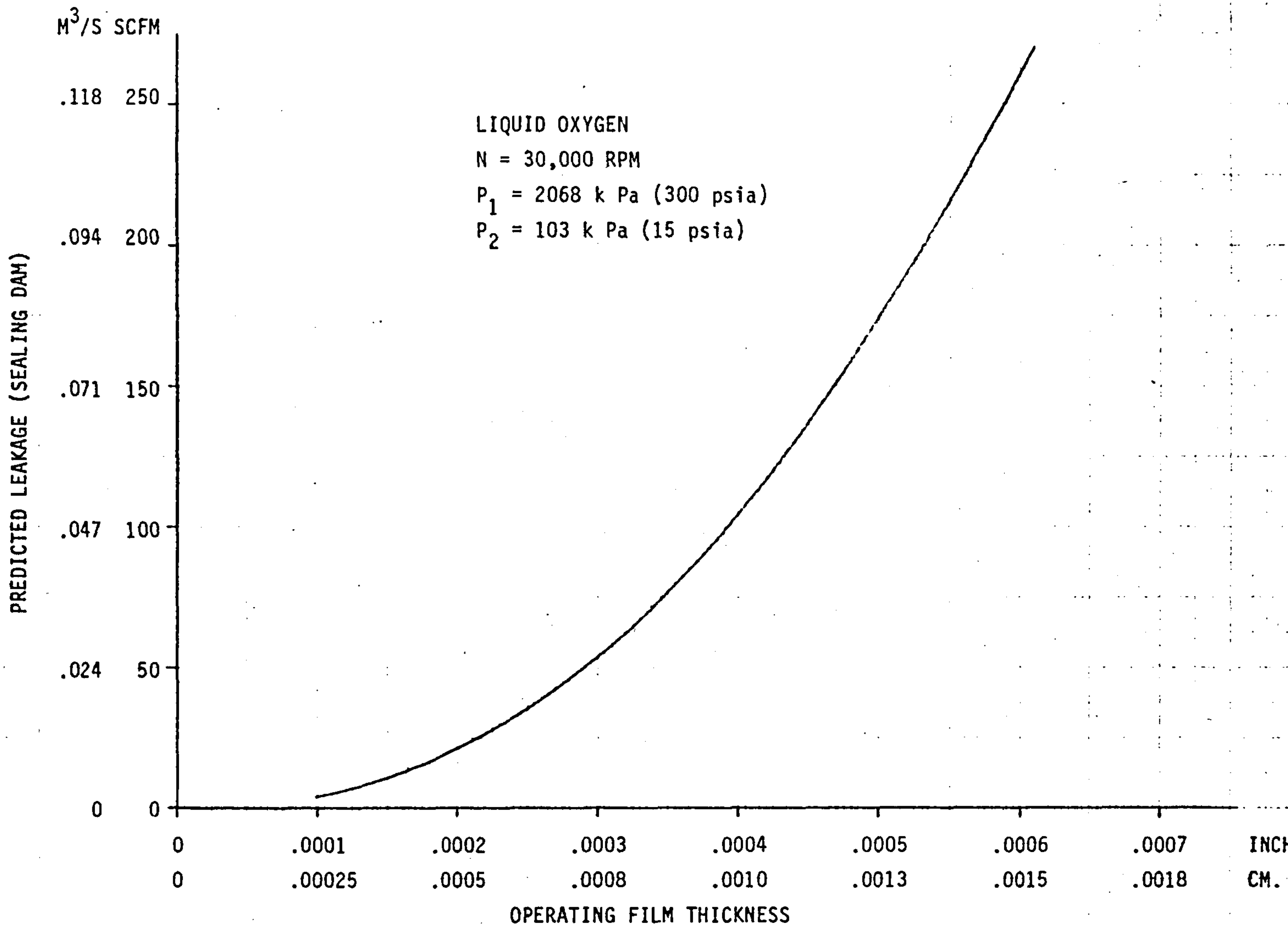

Figure 7. Rayleigh Step LOX Seal Predicted Leakage at Sealing Dam

	LOX FACE SEAL ASSY II	CC851360
1	RETAINER RING	CD851361
2	PILOT RING	CD851362
3	SEAL RING	CD851363

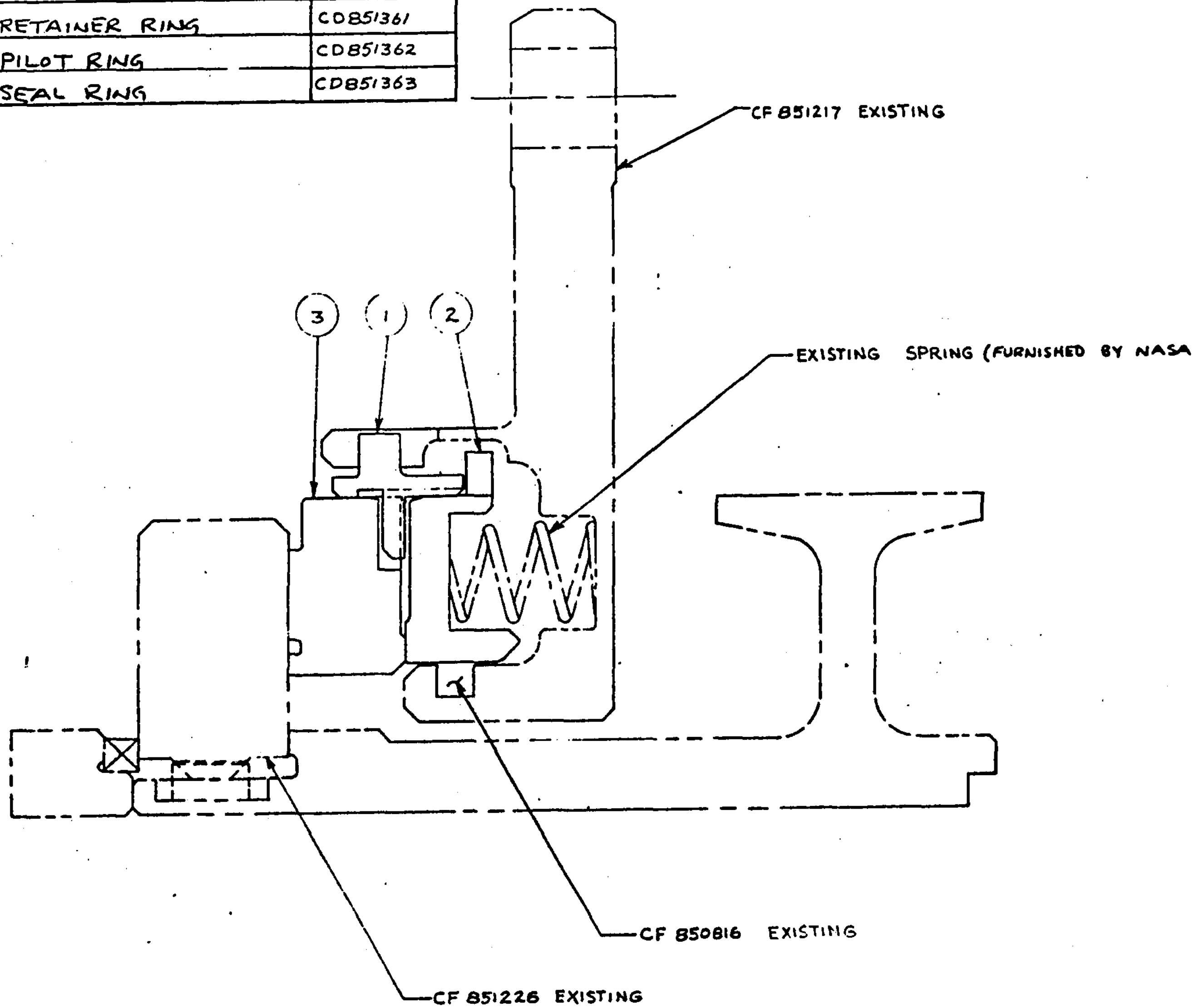

Figure 8. Phase II Rayleigh Step LOX Seal (CC 851360)

PHASE III RAYLEIGH STEP LOX SEAL

The Phase III LOX seal (Fig. 1) is the same as Phase I except the carbon seal ring material was changed from P03N to P692 to reduce chipping and the piston ring material was changed from carbon P5NR2 to Vespel SP211 for improved sealing.

PHASE IV RAYLEIGH STEP LOX SEAL

The Phase IV Rayleigh Step LOX seal (Fig. 9) uses the same seal ring assembly with the same geometry and materials as the Phase III seal. The pilot ring and housing are revised to allow the use of a segmented Vespel SP211 secondary seal (Fig. 10) in place of the piston ring seal used for Phase III. The segmented seal provides more effective sealing between the pilot ring and housing.

PHASE IV SPIRAL GROOVE LOX SEAL

The Phase IV inward pumping spiral groove LOX seal (Fig. 11) uses the Phase III housing, pilot ring and piston ring. The seal ring (Fig. 12) is the same except the carbon face is a plain flat surface. The spiral groove geometry (Fig. 13 and 14) is etched into the hard chrome plated surface of the rotating mating ring.

The spiral grooves develop both hydrostatic and hydrodynamic lift (Fig. 15) 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 varies inversely with gap to the face clearance gap, decreasing as the gap increases. Therefore, the gap is self-adjusting to equalize the lift force and closing force.

<u>Basic Design</u>

Analysis was performed on the spiral groove LOX seal to establish the carbon seal ring inside diameter for pressure balance. The design conditions were as follows:

Speed:	32,000 rpm
Pressure:	1724 and 4137 kPa (250 and 600 psia)
Temperature:	235 K (-225 F) at 1724 kPa (250 psia) GOX 270 K (-190 F) at 4137 kPa (600 psia) GOX 170 K (-290 F) LOX
Fluid:	Liquid and/or gaseous oxygen
Spring Load:	62.3 N (14 lb)

	PART	MATERIAL
1	HOUSING	INCONEL 600
2	PILOT RING	INVAR 36
3	RETAINER	INVAR 36
4	SEAL RING	CARBON P692
5	SECONDARY SEAL	VESPEL SP211
6	SPRING	INCONEL X750
7	STATIC SEAL	INCONEL X750
8	MATING RING	K-MONEL
9	KEY	303 SS

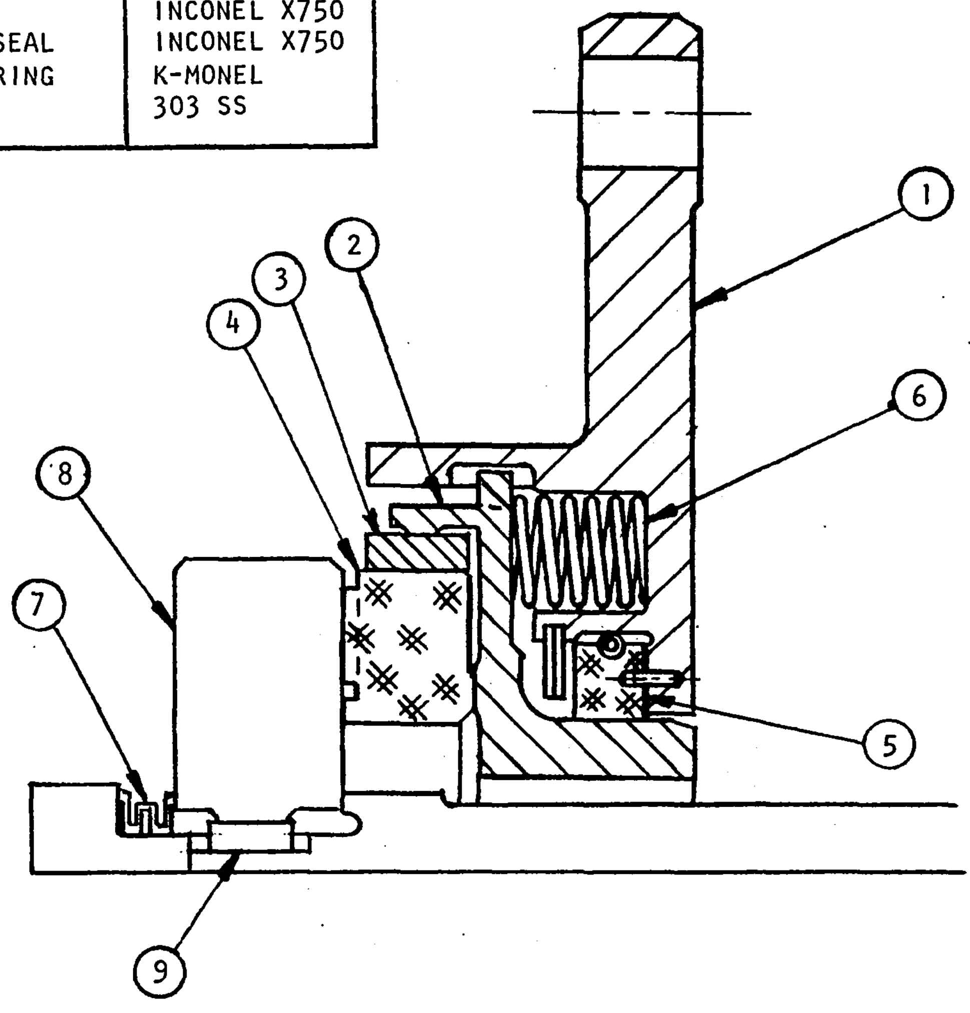

Figure 9. Phase IV Rayleigh Step LOX Seal

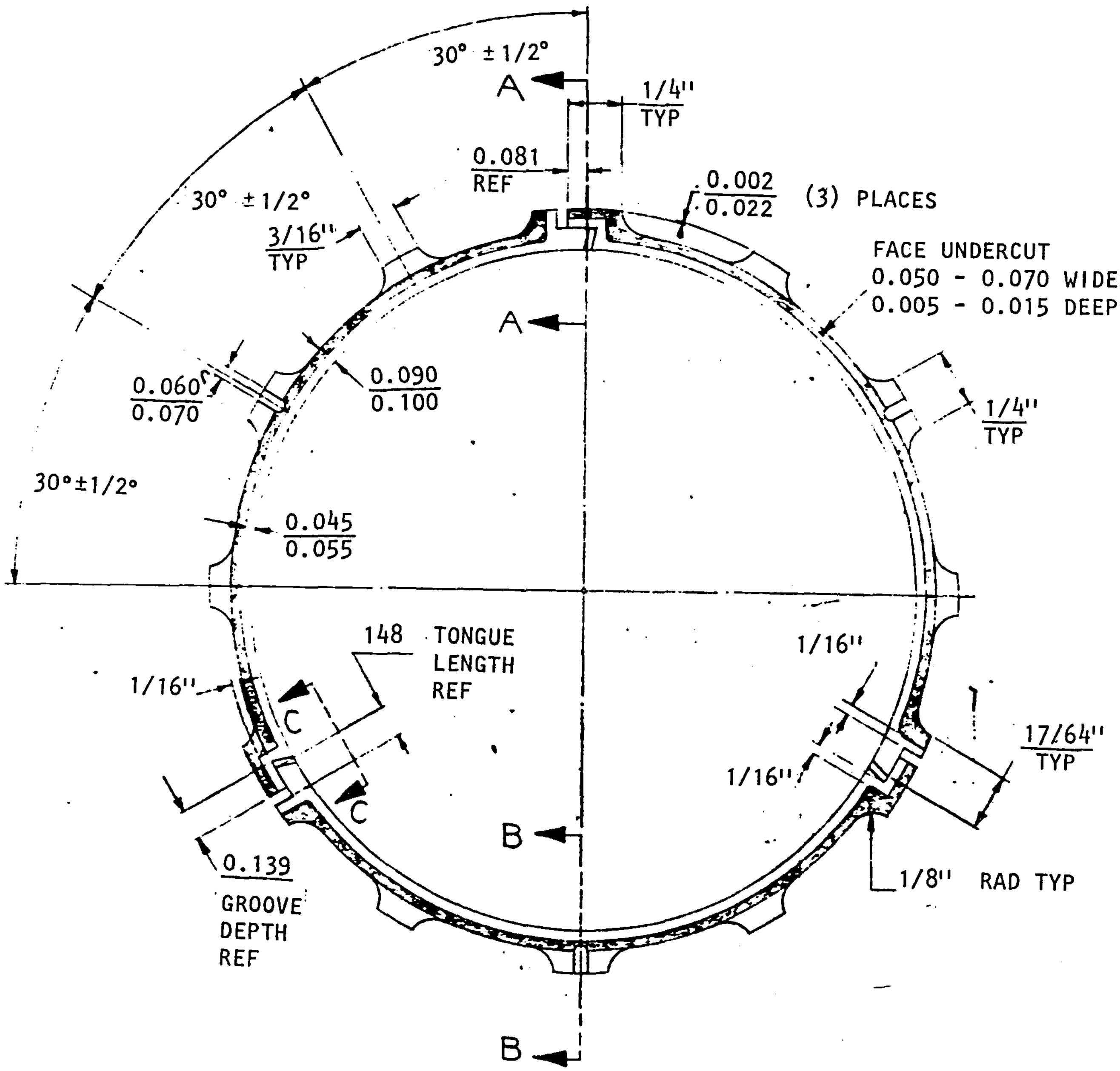

Figure 10. Phase IV Rayleigh Step LOX Seal Segmented Secondary Seal

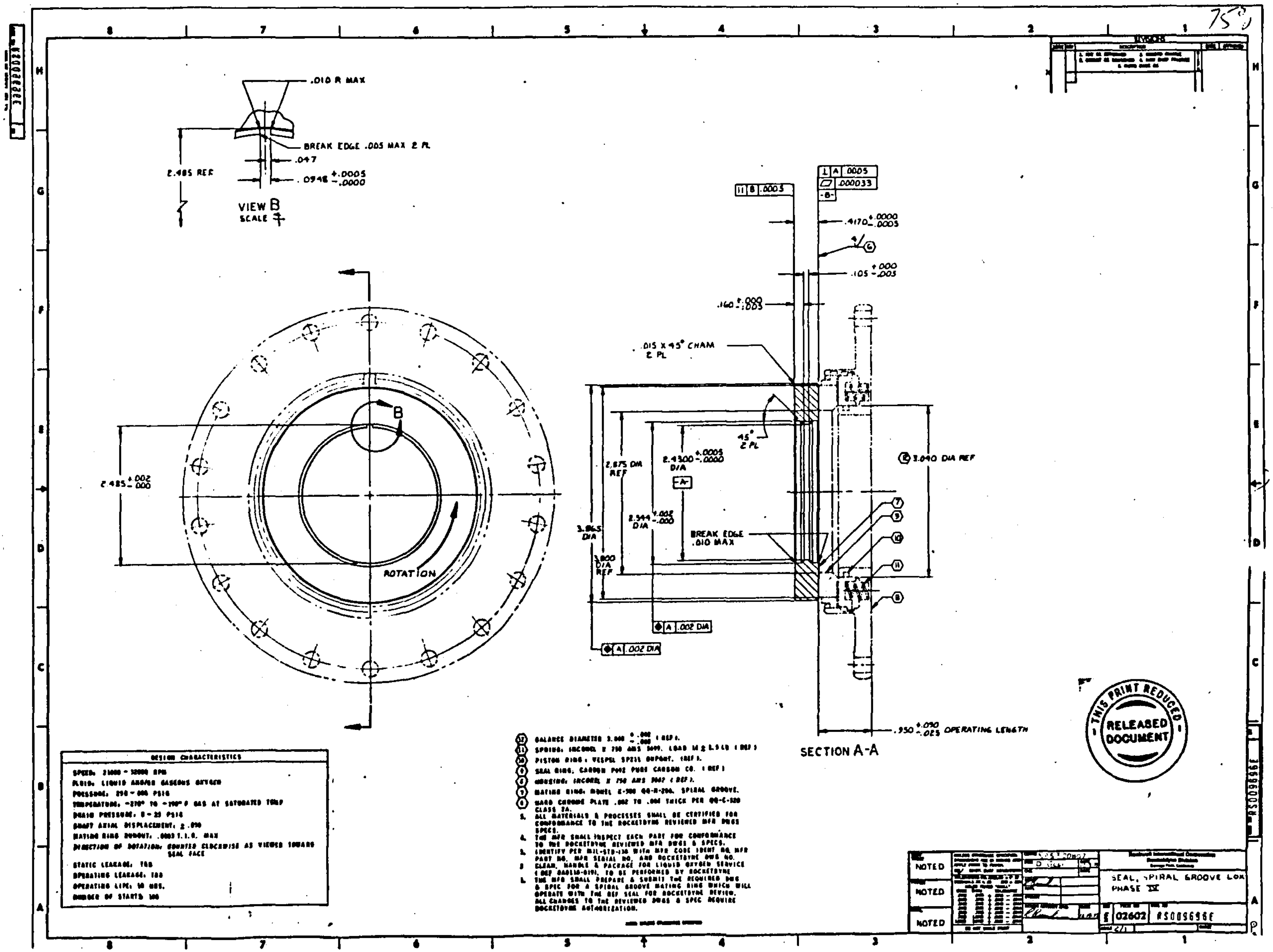

Figure 11. Phase IV Spiral Groove LOX Seal

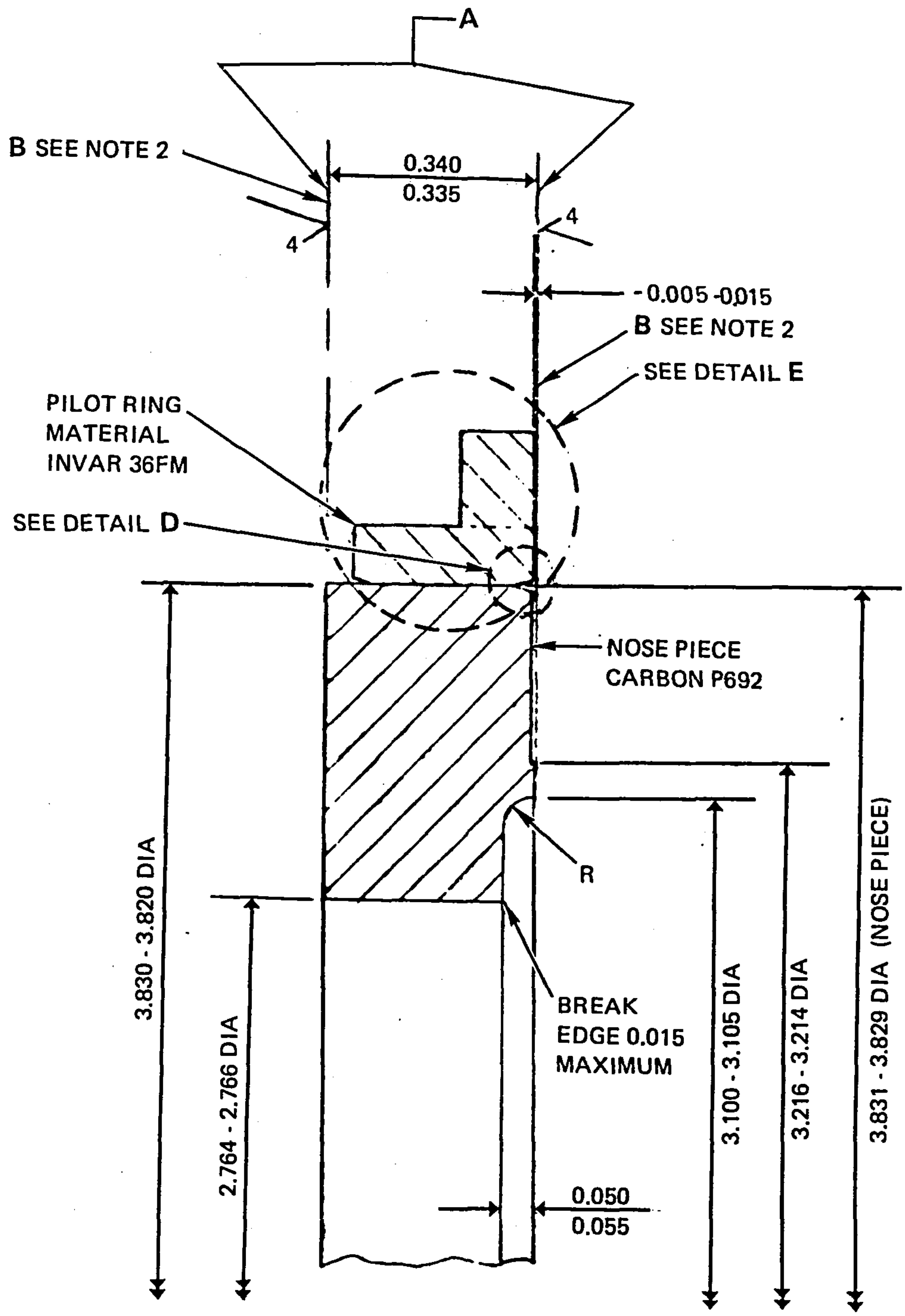

Figure 12. Phase IV Spiral Groove LOX Seal Ring

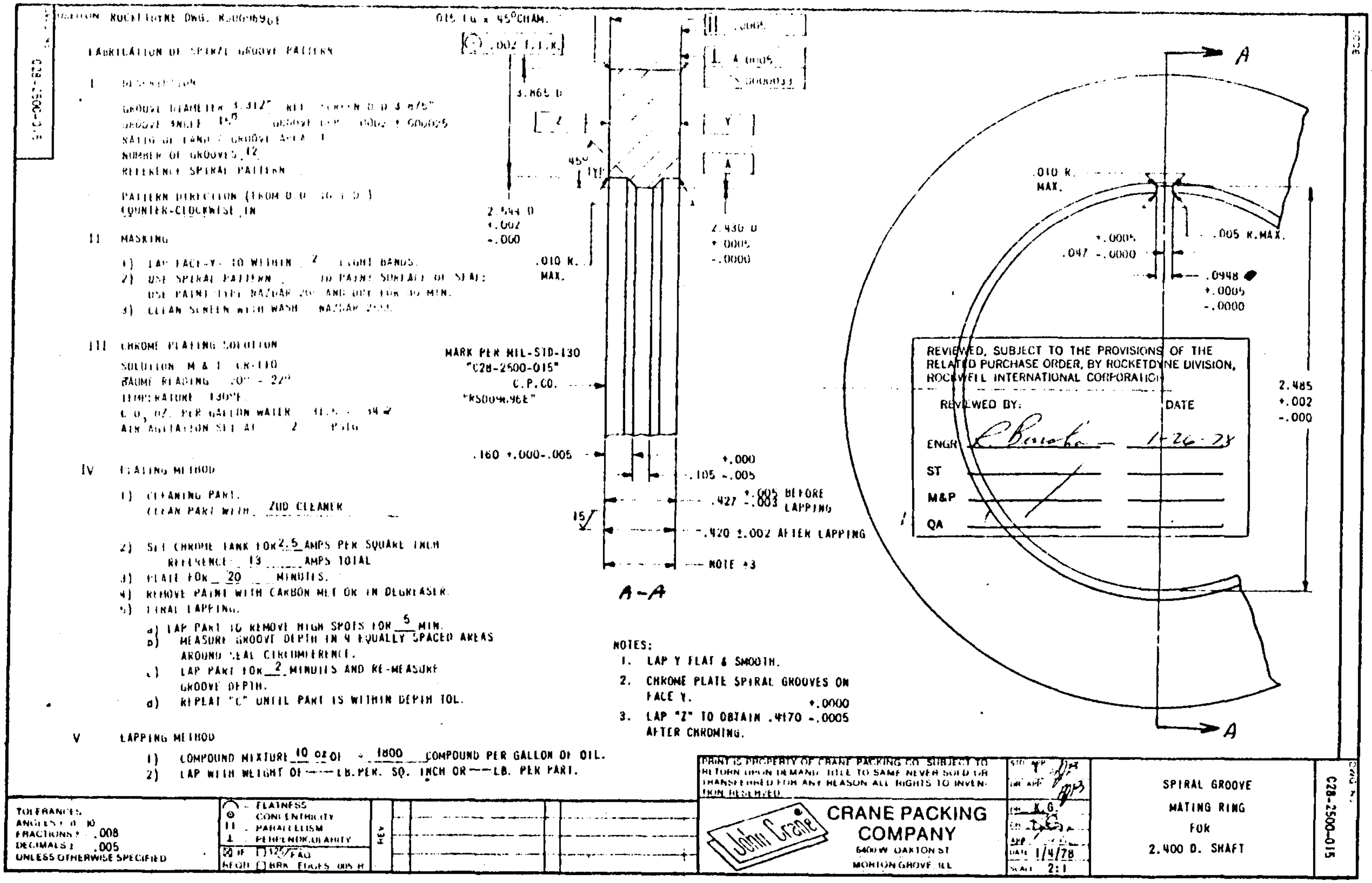

Figure 13. Phase IV Basic Inward Pumping Spiral Groove LOX Seal Mating Ring (Crane Packing Company)

Figure 14. Phase IV Basic Inward Pumping Spiral Groove LOX Seal Mating Ring

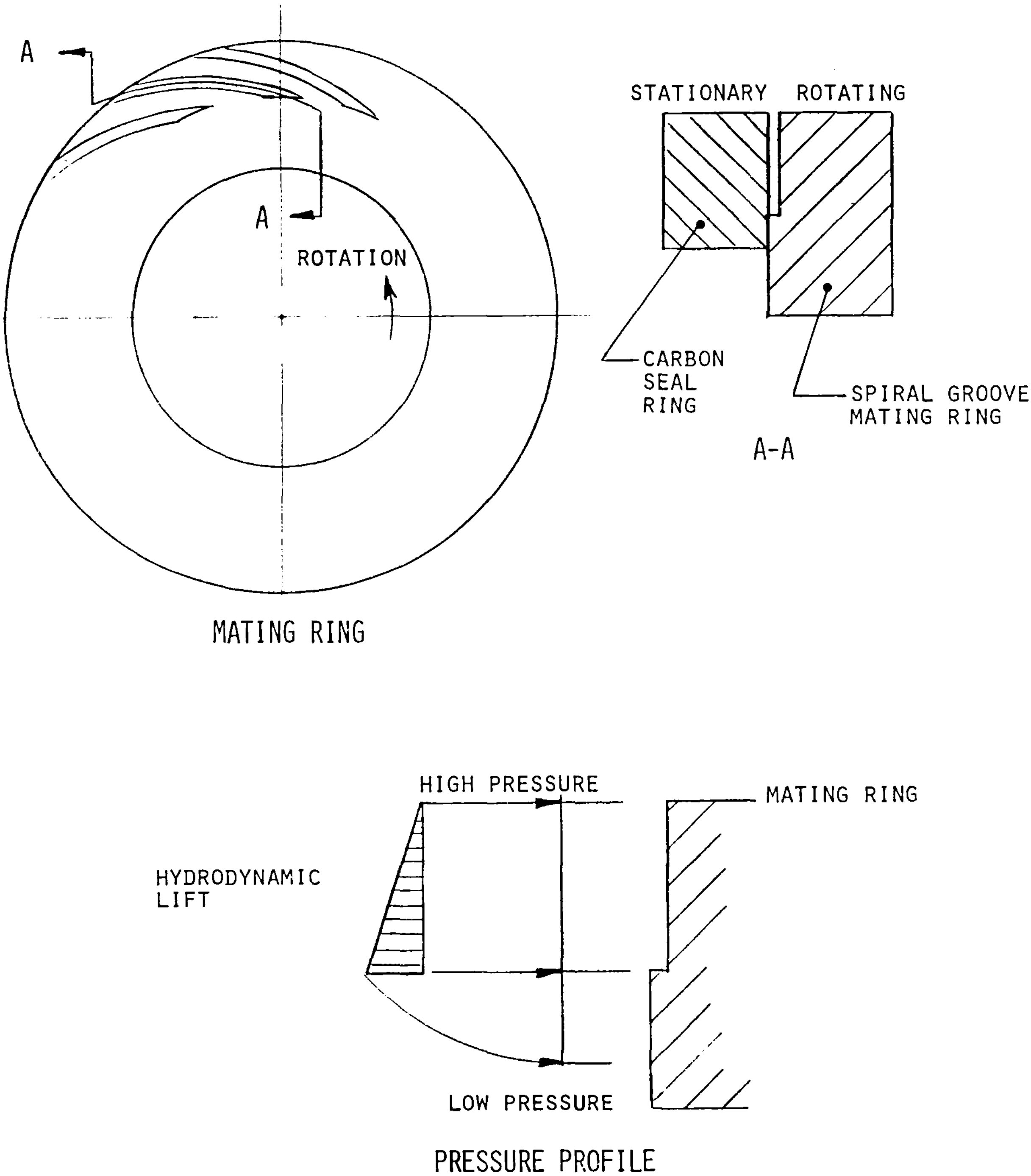

Figure 15. Inward Pumping Spiral Groove Hydrostatic/ Hydrodynamic Face Seal

The results of a computer analysis made by Crane Packing Company are given below:

FLUID	PRESSURE	OPENING FORCE	STIFFNESS, (10^6)	GAP	LEAKAGE
GOX	1724 kPa (250) PSIA	4919 N (1106) LB	4.660 N/CM (2.663) LB/IN.	0.00035 CM (0.00014) IN.	0.0007 M^3/S (1.5) SCFM
LOX	1724 kPa (250) kPa	4919 N (1106) LB	3.243 N/CM (1.853) LB/IN.	0.00063 CM (0.00025) IN.	0.0006 M^3/S (1.25) SCFM
GOX	4137 kPa (600) PSIA	11267 N (2533) LB	10.412 N/CM (5.590) LB/IN.	0.00038 CM (0.00015) IN.	0.0016 M^3/S (3.5) SCFM
LOX	4137 kPa (600) PSIA	11267 N (2533) LB	8.592 N/CM (4.910) LB/IN.	0.00043 CM (0.00017) IN.	0.0015 M^3/S (3.2) SCFM

Analysis indicates that the carbon seal face inside diameter should be 7.302 cm (2.875 in.) for the desired force balance. The sealing dam width will be 0.556 cm (0.219 in.). The seal will lift off (opening force will equal closing force) at 345 kPa (50 psia) and 200 rpm. The basic design was biased toward the minimum operating gap to minimize leakage.

Mod I Design

The basic design was changed due to heavy face rubbing. The force balance was revised by reducing the inside diameter of the carbon sealing face from 7.302 cm (2.877 in.) to 7.023 cm (2.765 in.) (Fig. 16). The smaller face diameter will increase the opening force and allow the seal to operate at a larger face gap to minimize rubbing contact.

Mod II Design

Revision was required due to leakage and rubbing at the seal face. Analysis indicated that the wide sealing dam concept used by Crane on the more recent spiral groove designs may not be satisfactory for cryogenic fluids due to excessive force variation caused by vaporization of the fluid across the sealing interface. The spiral groove design was revised (Fig. 17) to be similar to the narrow dam concept used on the successful small high speed LOX seal program.

The spiral groove inside diameter was changed from 8.412 cm (3.312 in.) to 7.671 cm (3.020 in). The spiral groove depth was changed from 0.0005 cm (0.0002 in.) to 0.0010 cm (0.0004 in.) for improved lift at the larger operating gap. The carbon seal ring with 7.023 cm (2.765 in.) inside diameter is used with the revised spiral groove mating ring.

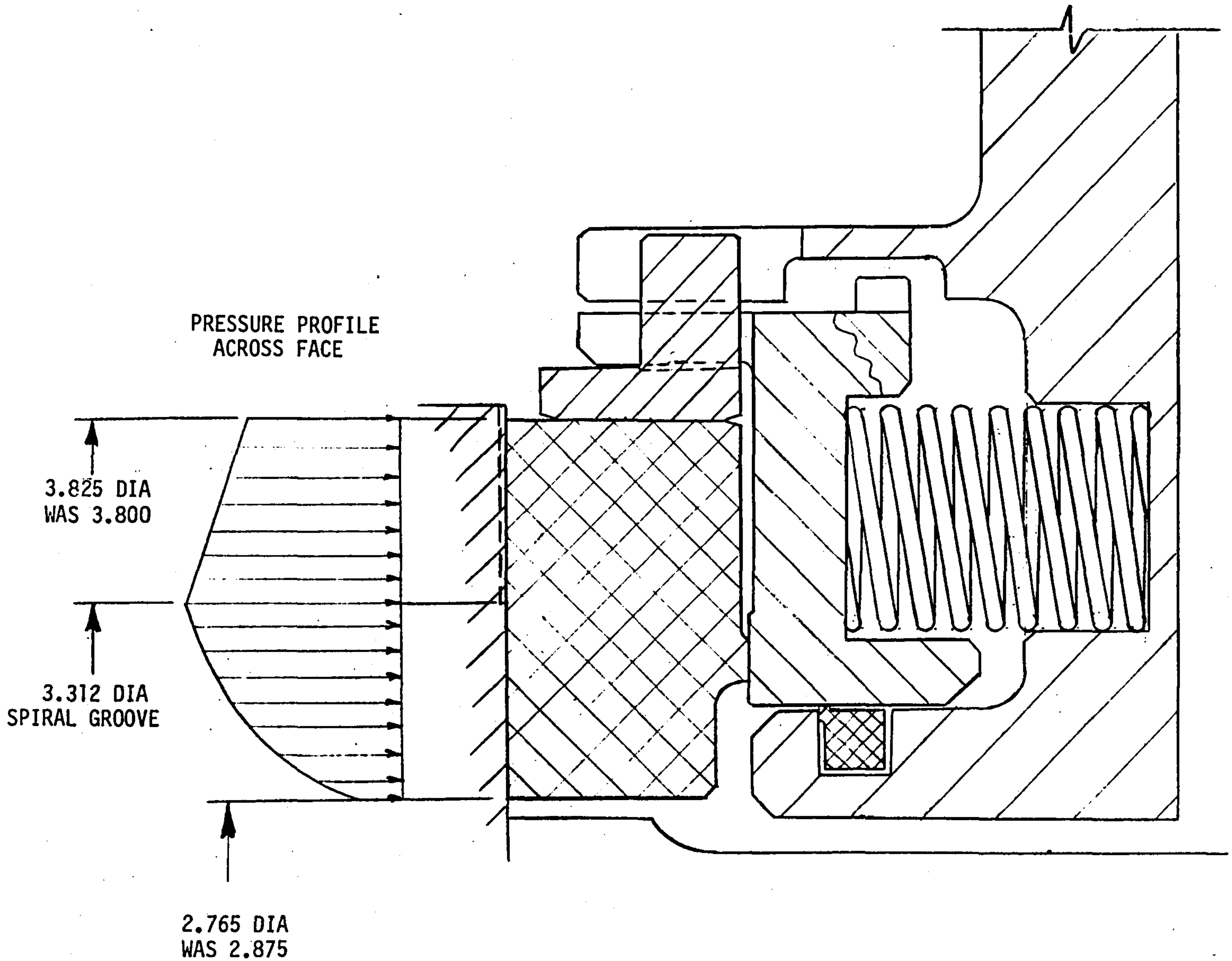

Figure 16. Phase IV Spiral Groove LOX Seal, MOD I

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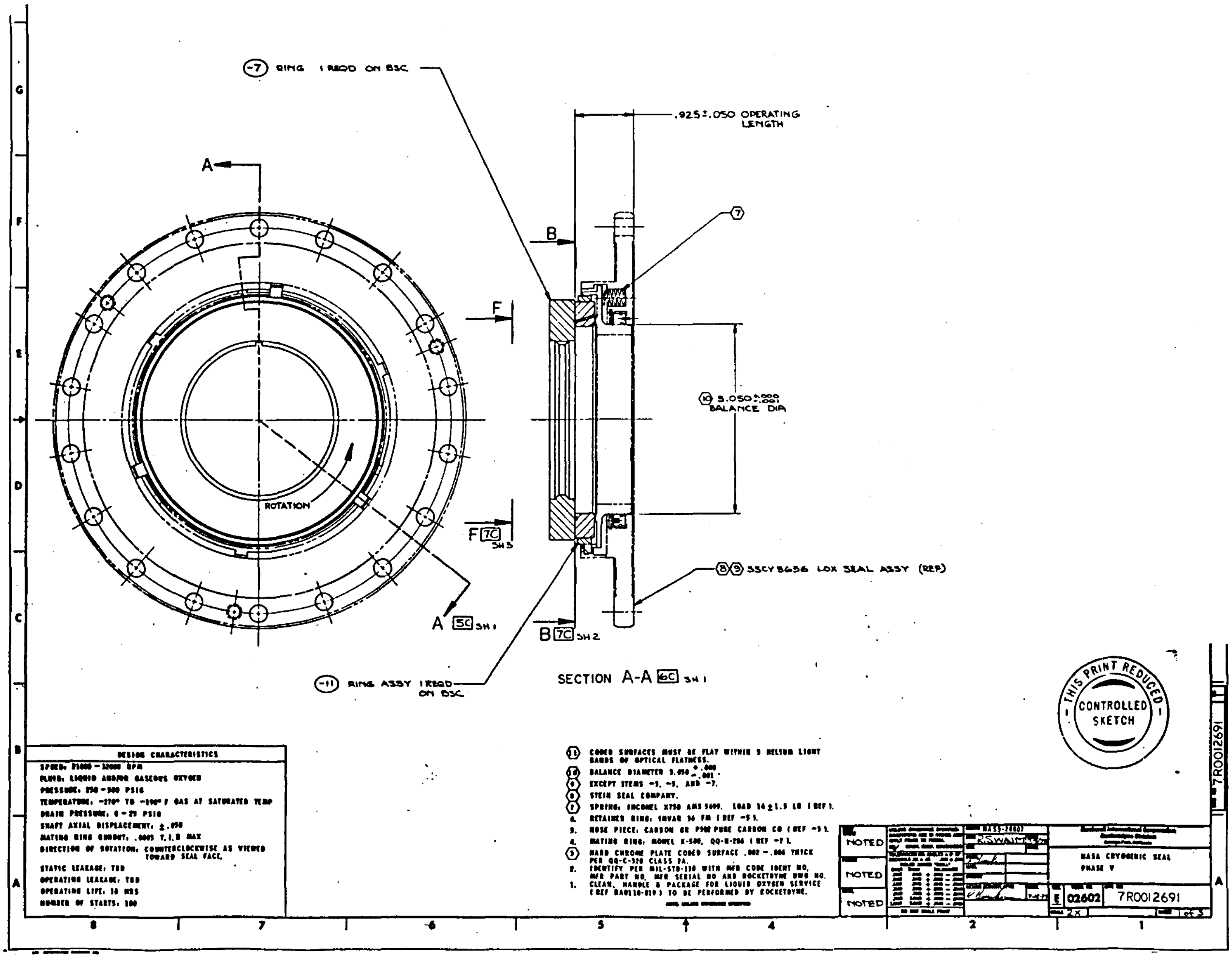


Figure 18. Phase V Outward Pumping (Pressure Balanced) Spiral Groove LOX Seal Assembly

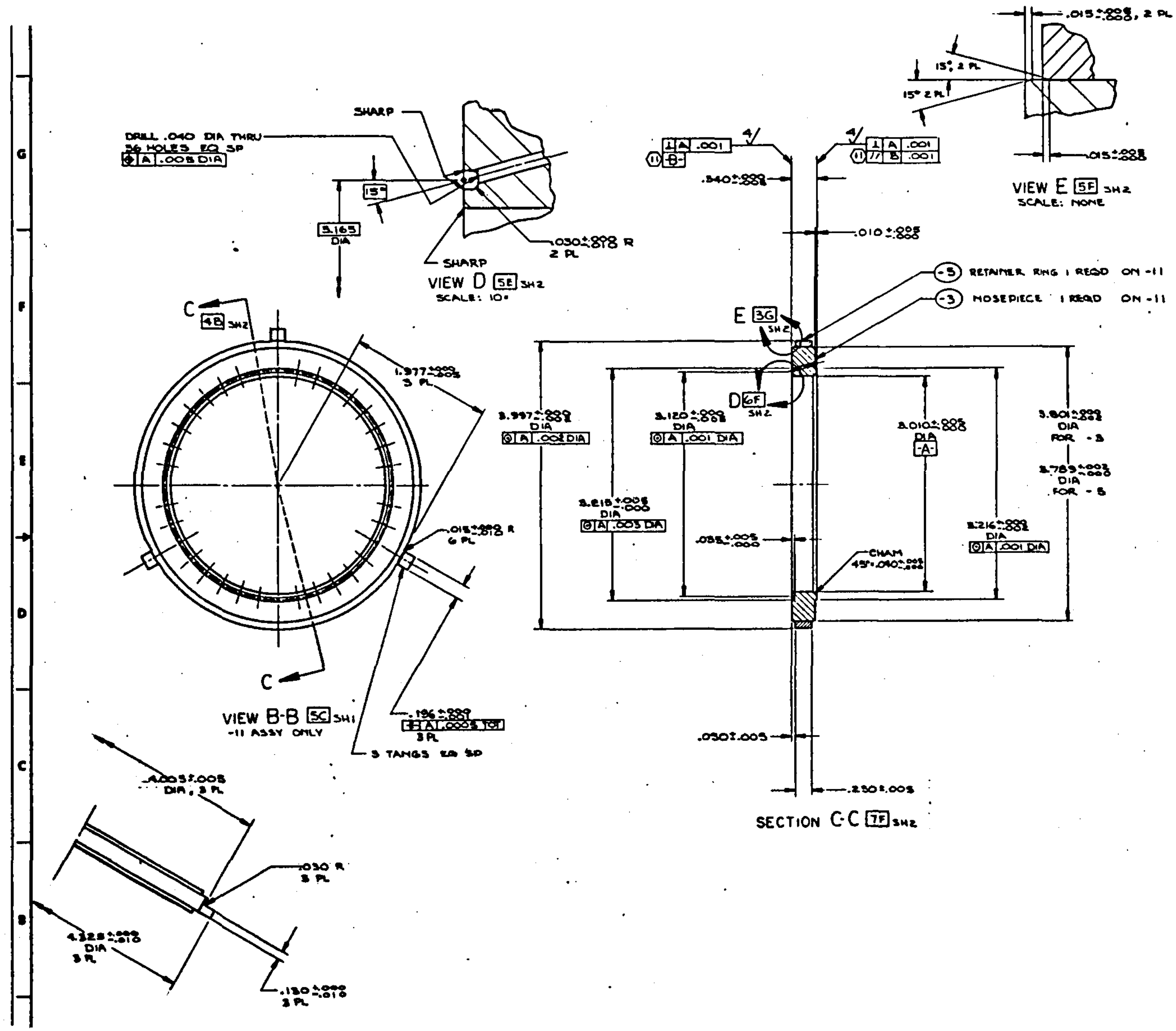


Figure 19. Phase V Outward Pumping (Pressure Balanced) Spiral Groove LOX Seal Ring

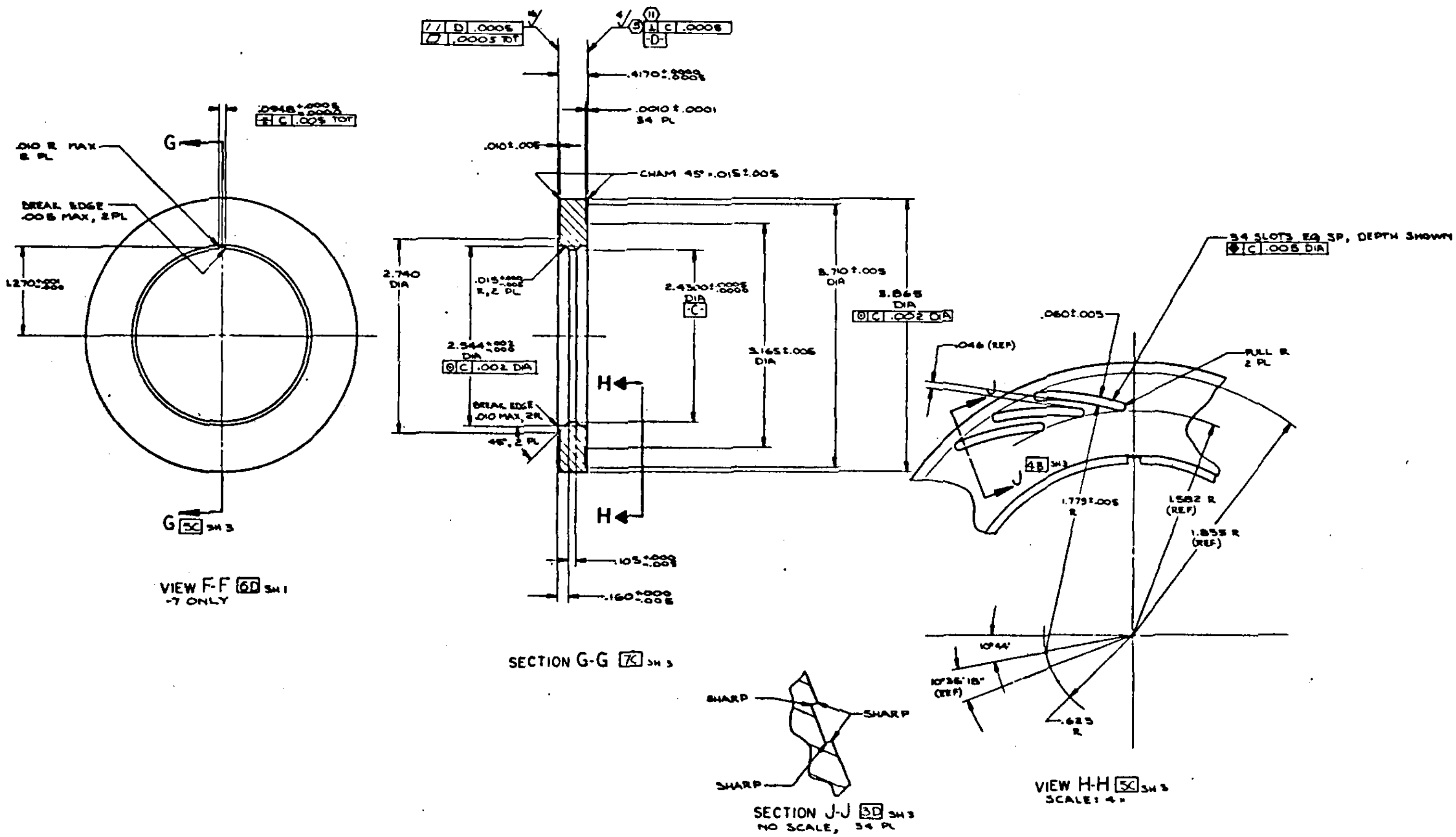


Figure 20. Phase V Outward Pumping (Pressure Balanced) Spiral Groove LOX Seal Mating Ring

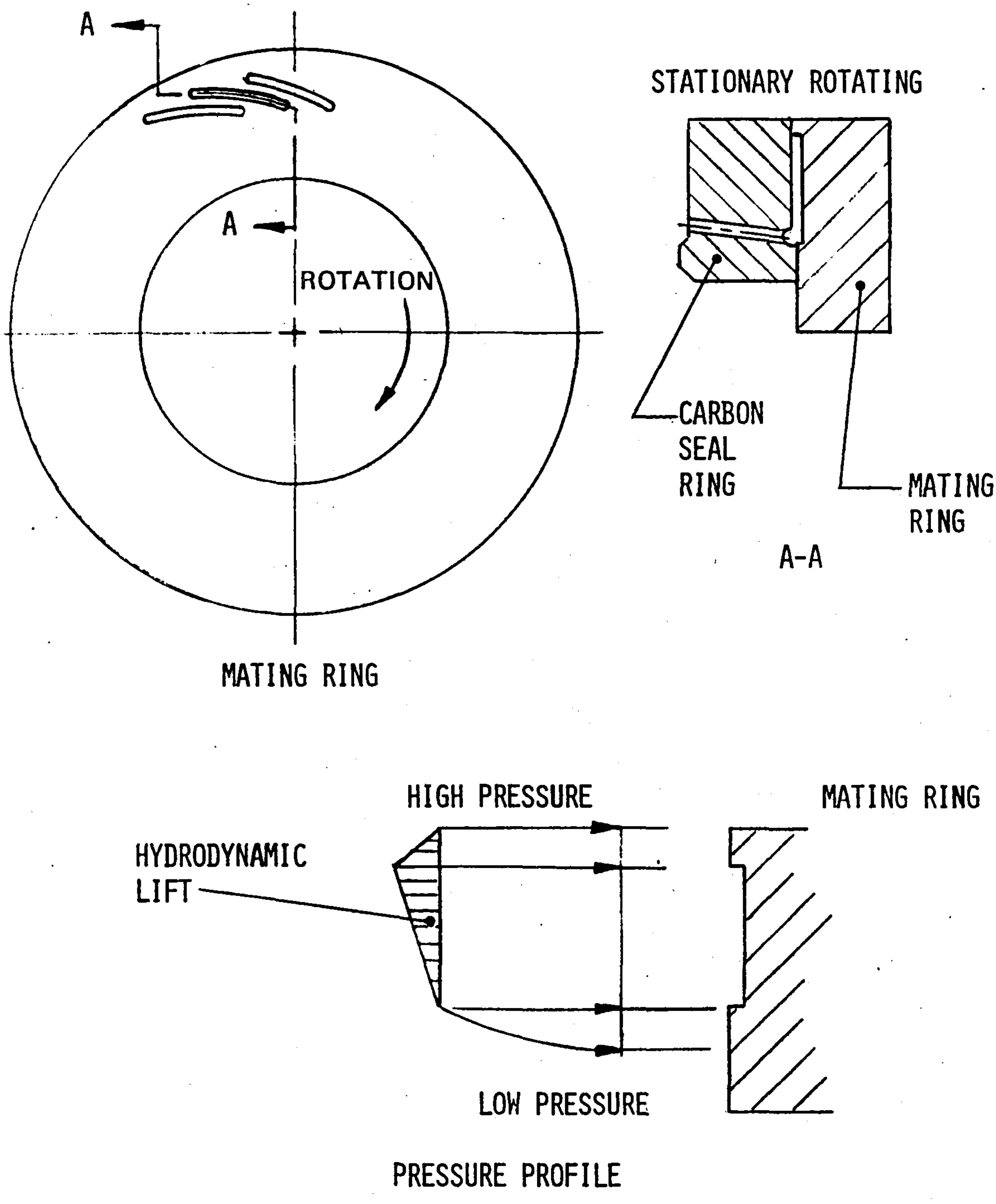


Figure 21. Outward Pumping Pressure Balanced Hydrodynamic Face Seal

Lift Force

The spiral groove lift force as a function of film thickness for liquid and gaseous oxygen is shown on Fig. 22. The sealing dam opening force at 3447 kPa (500 psia) is constant for liquid oxygen at 565 N (127 lb) and varies for a gaseous oxygen from 725 N (163 lb) to 765 N (172 lb) as the film thickness decreases. The pressure closing force at the same pressure is 754 N (169 lb); The spring force is 62N (14 lb). The resultant closing force is the sum of the pressure closing force and spring force minus the sealing dam opening force.

The resultant closing force is shown with the spiral groove lift force on Fig. 22. The seal will seek an operating film thickness where the closing force is equal to the lift force. The analysis indicates that the seal will operate with a film thickness of 0.00074 cm (0.00029 in.) with gaseous oxygen and 0.00068 cm (0.00027 in.) with liquid oxygen (Fig. 22).

PHASE I SEGMENTED RAYLEIGH STEP HELIUM SEAL

The initial Phase I helium seal (Fig. 23) consisted of double three-segment carbon G84 circumferential rings. The helium purge pressure is supplied between the rings. to provide a pressure barrier for separation of the drain cavities. The segments are loaded radially inward against the mating ring with extension garter springs and the unbalanced radial pressure force. The segments use Rayleigh Step lift pads (Fig. 24) to provide hydrodynamic lift force for fluid separation of the segments and rotating mating ring. The lift force varies with fluid film thickness, increasing for smaller gaps and decreasing for larger gaps. The segments will seek an equilibrium position where the closing force is equal to the lift force and sealing dam opening force. The radial pressure profile for a segmented Rayleigh Step seal is shown in Fig. 25.

The three-segment design was changed to a six-segment design (Fig. 26) during the Phase I test program due to breakage of the carbon segments. The six-segment design provided increased flexibility of the ring assembly and stronger segments. The carbon material was also changed from G84 to P5N for increased strength.

Lift Force

The lift force and closing force per segment, as a function of the film thickness, for the three-segment and six-segment designs is shown on Fig. 27. The resultant closing force is the sum of the unbalanced radial pressure force and the spring force minus the sealing dam opening force and friction force. The unbalanced radial pressure force for the three-segment design is 18.3 N (4.12 lb) per segment. The spring force is 0.93 N (0.21 lb) per segment. The dam opening force is 9.52 N (2.14 lb) per segment. The resultant closing force is 9.74 N (2.19 lb). The data indicate the segments will operate with 0.00066 cm (0.00026 in.) film thickness. The six-segment design is nearly the same with 0.00074 cm (0.00029 in.) operating gap.

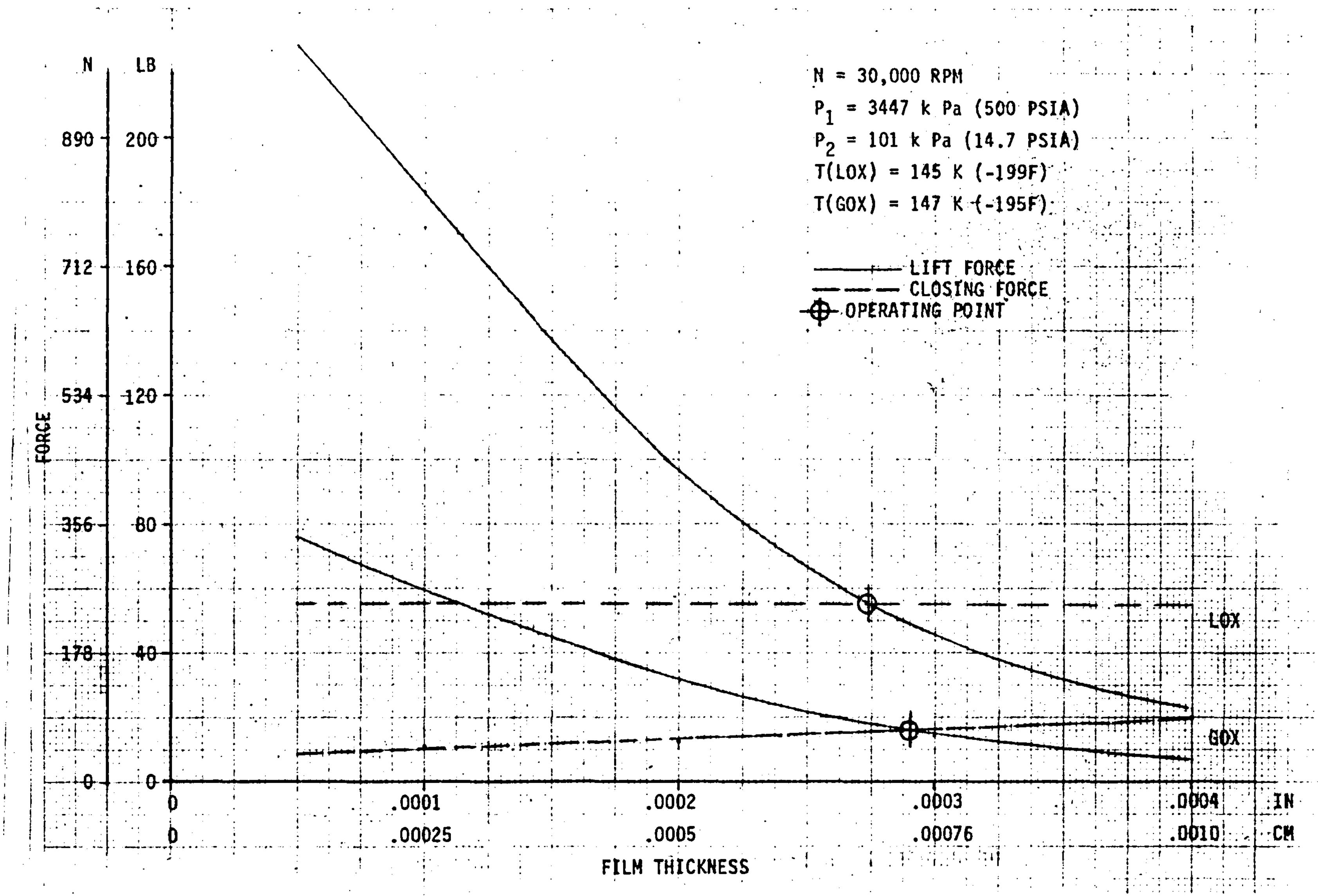


Figure 22. Phase V Outward Pumping Spiral Groove LOX Seal Lift Force

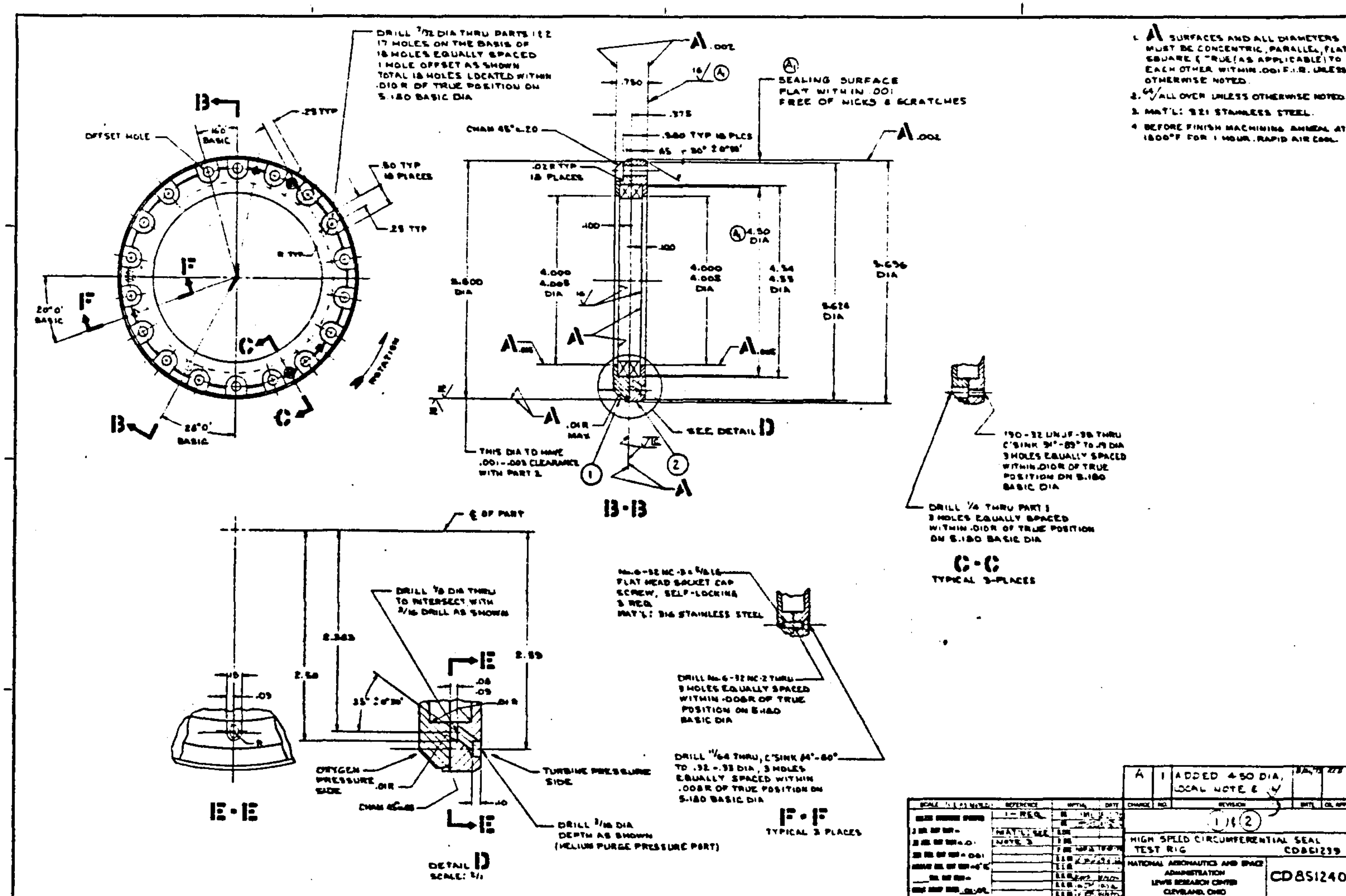


Figure 23. Phase I Rayleigh Step Helium Seal (CD 851240)

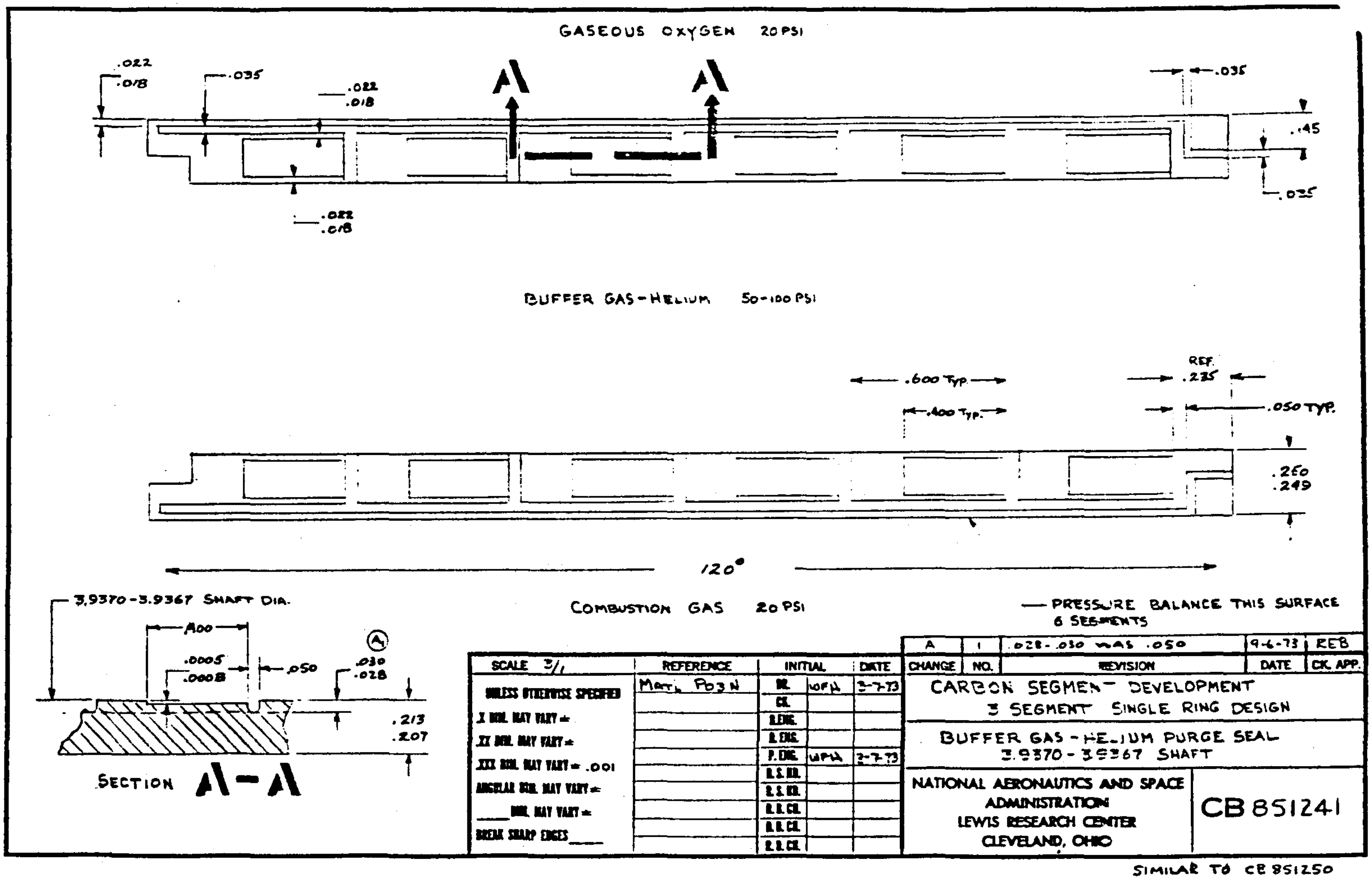


Figure 24. Phase I Three-Segment Rayleigh Step Geometry (CD 851241)

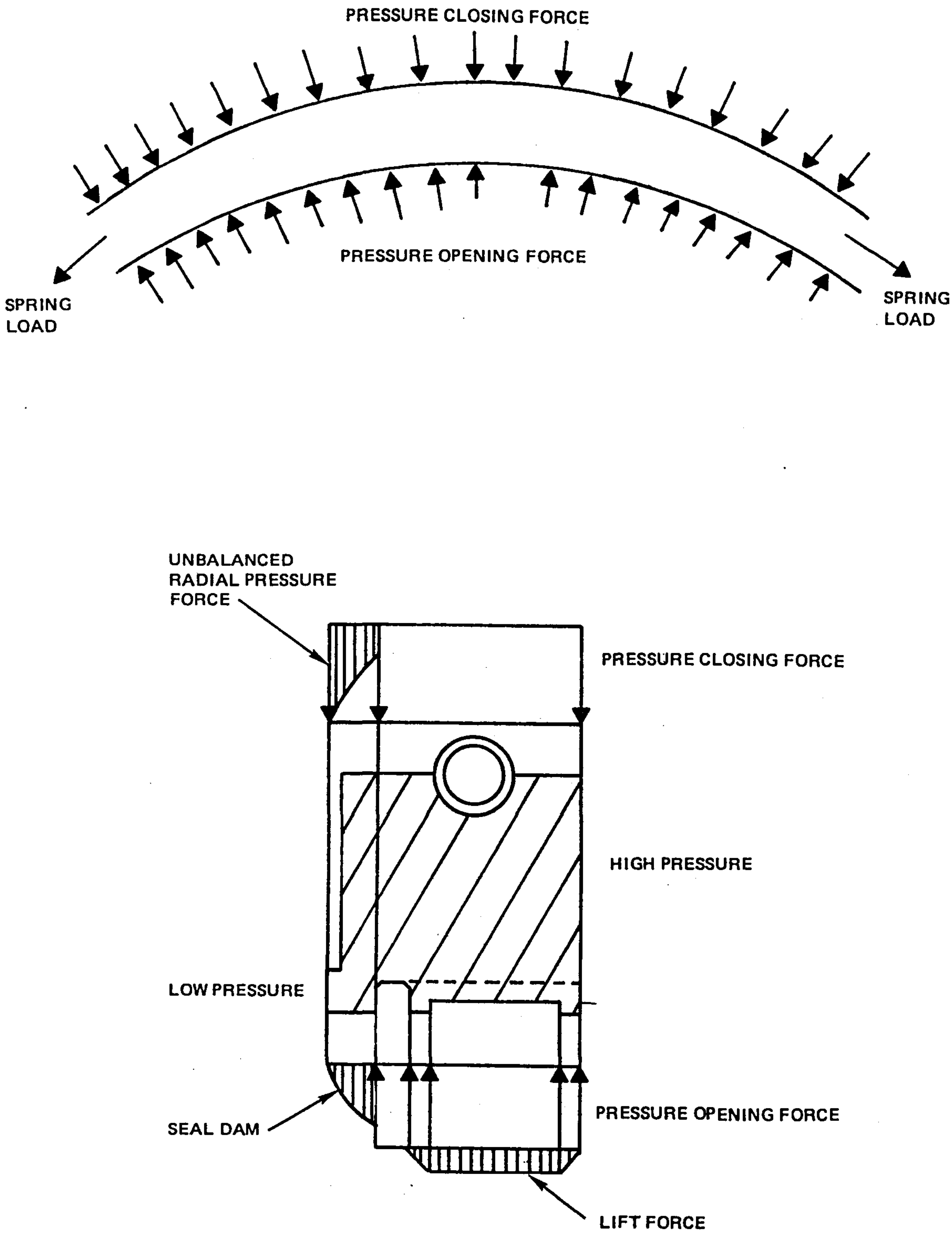


Figure 25. Segmented Rayleigh Step Helium Seal Radial Pressure Profile

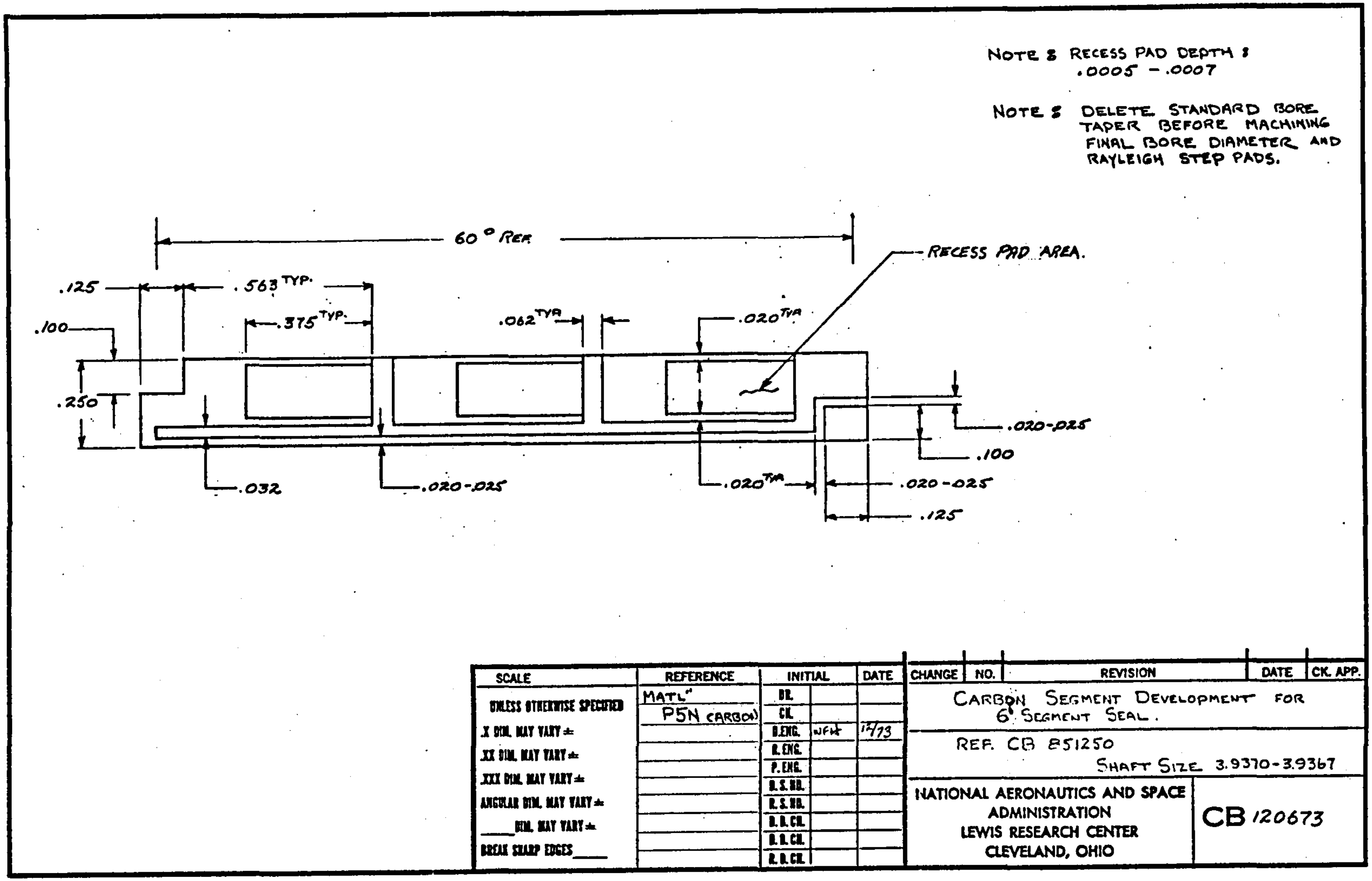


Figure 26. Phase I Six-Segment Rayleigh Step Geometry

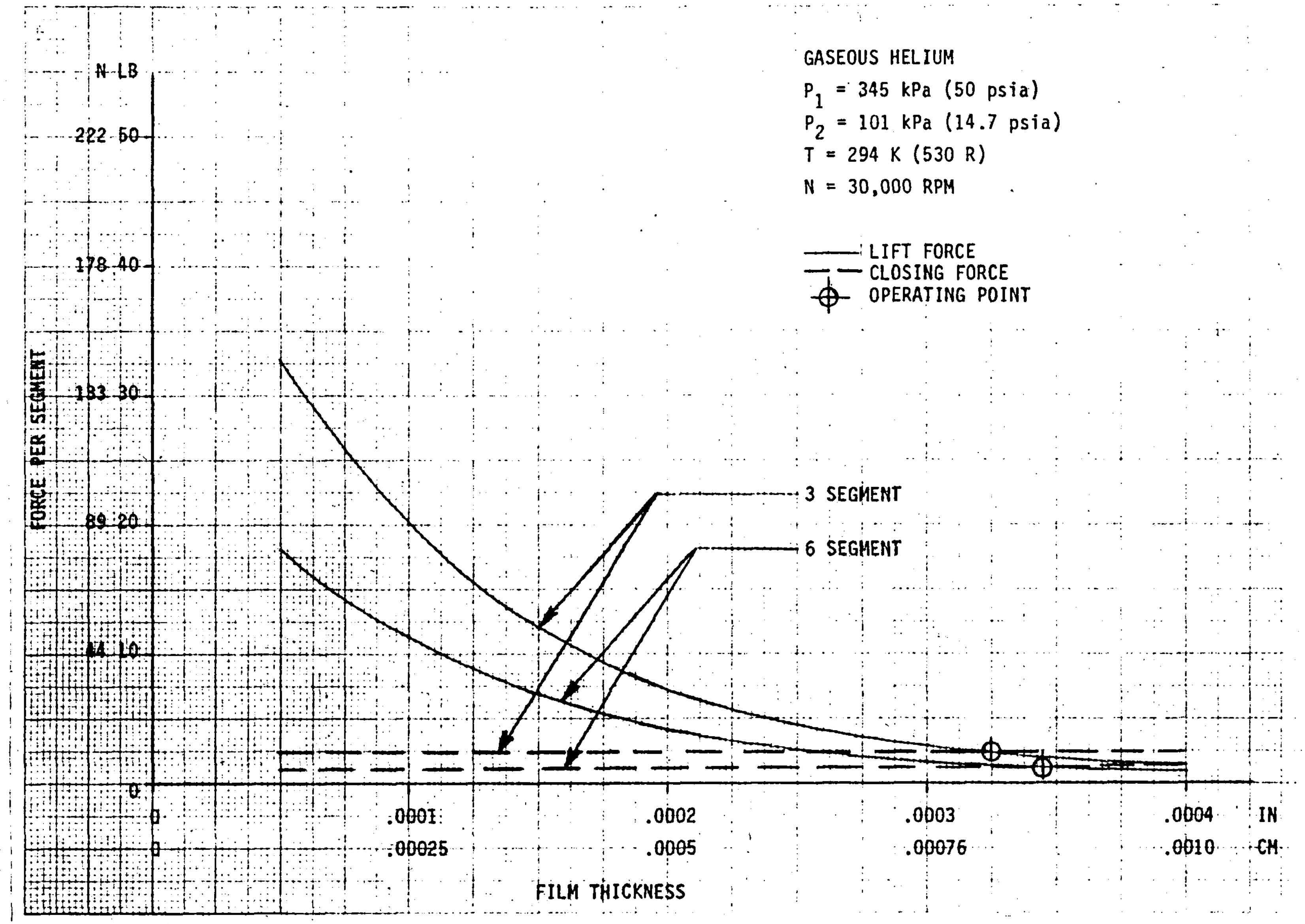


Figure 27. Phase I Rayleigh Step Segmented Carbon Helium Seal Lift Force

Mating Ring

The Phase I mating ring design was changed from a symmetrical T-shape to an offset thin web design (Fig. 28) to minimize the thermal distortion caused by the liquid oxygen side being colder. The offset web design uses the centrifugal force deflection to compensate for the thermal contraction.

PHASE III FLOATING RING RAYLEIGH STEP HELIUM SEAL

The Phase III floating ring Rayleigh Step helium seal (Fig. 29) consists of double metal banded carbon G84 circumferential seal rings pressurized between with gaseous helium. The rings are free to float in the radial direction and are restrained from rotation with anti-rotation tangs. The unbalanced radial pressure load is supported by the rings in compressive hoop stress. Rayleigh Step lift pads are utilized upstream of the sealing dam to provide hydrodynamic lift. The seal ring inside diameter is grooved around the Rayleigh pads to vent the pressure up to the sealing dam to reduce the unbalanced pressure load. The side surface is also relieved for pressure balance. The seal ring pressure profile is shown in Fig. 30.

Lift Force

The Rayleigh Step lift pads provide hydrodynamic lift for noncontact operation except during the start and stop transients. A fluid film is developed in the recessed pads by viscous pumping to assist in support of the seal ring in order to minimize rubbing contact. The fluid film thickness is controlled by the hydrodynamic lifting force in the pad. The lift force decreases for a larger gap and increases for a smaller gap. The floating seal ring seeks an equilibrium position where the gap is constant around the shaft. When the shaft moves off center, the unbalanced radial load tends to recenter the seal ring.

The lift pad geometry was optimized for gaseous helium at 294 K (530 R). The calculated maximum lift force at 0.00013 cm (0.00005 in.) is 22.2N (4.99 lb) per pad. The lift force decreases to 0.93N (0.21 lb) at 0.00010 cm (0.0004 in.) and is not effective for larger gaps. The lift force per pad as a function of film thickness is shown in Fig. 31.

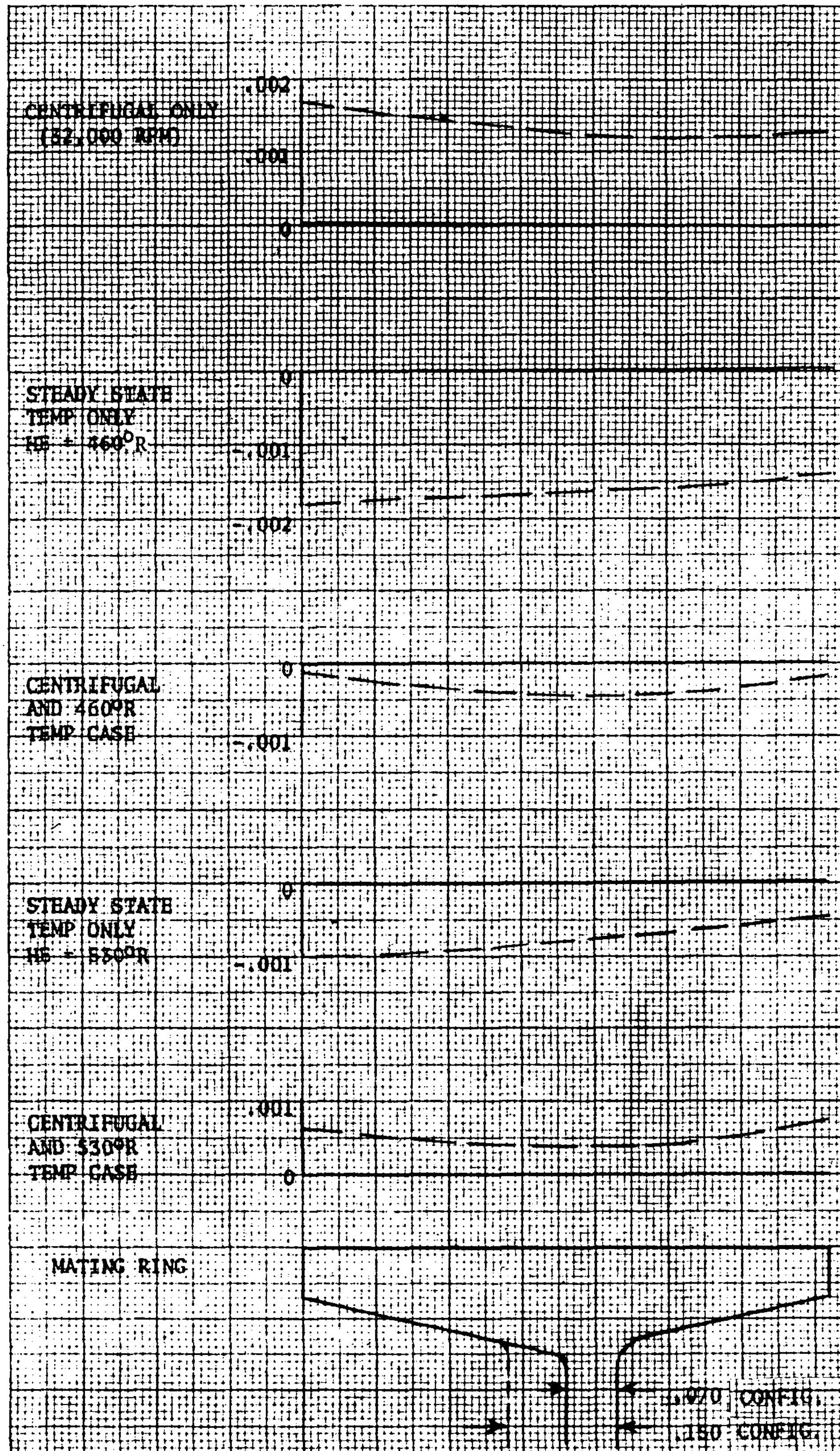


Figure 28. Phase III Helium Seal Mating Ring Operation Deflections

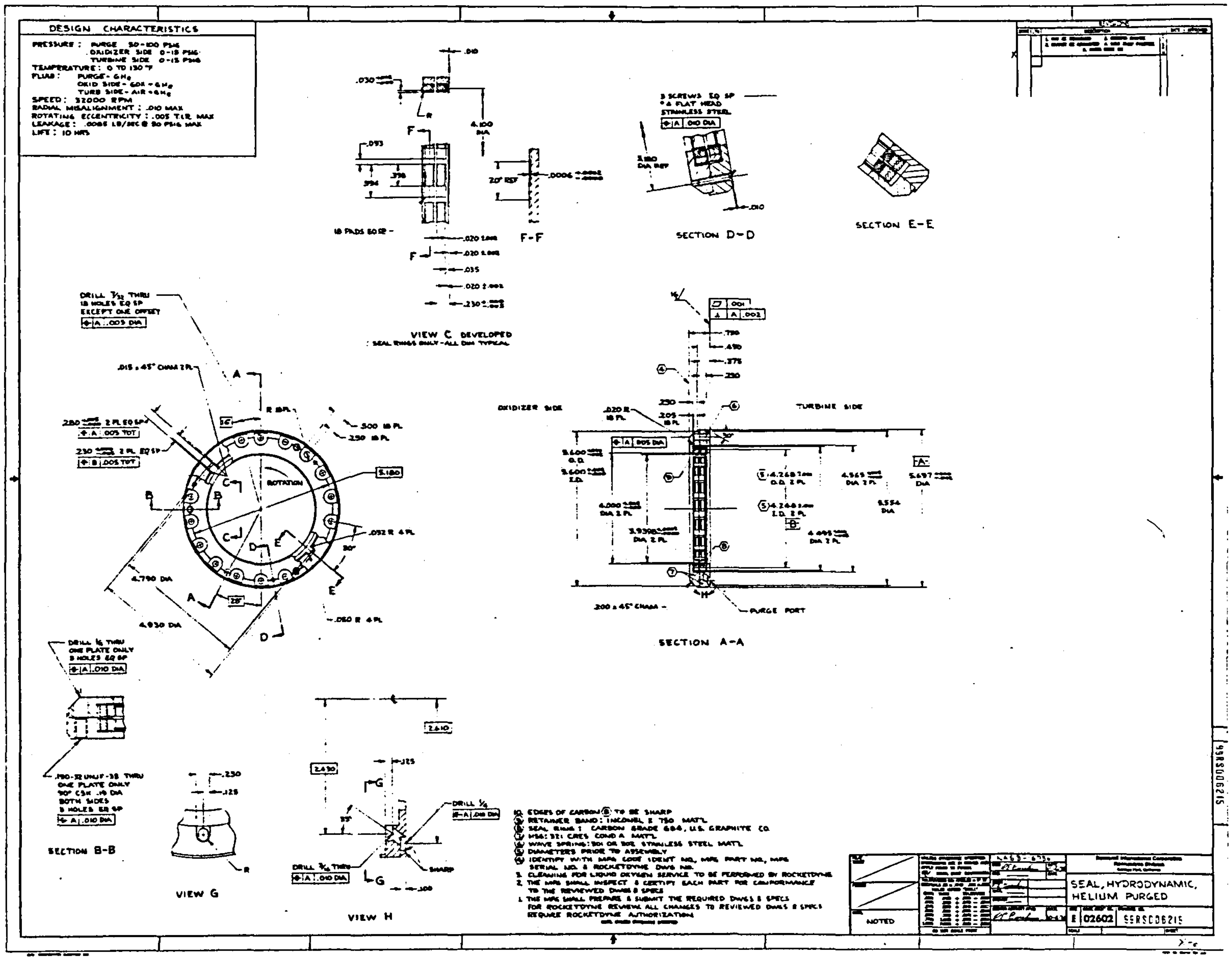


Figure 29. Phase III Floating Ring Rayleigh Step Helium Seal

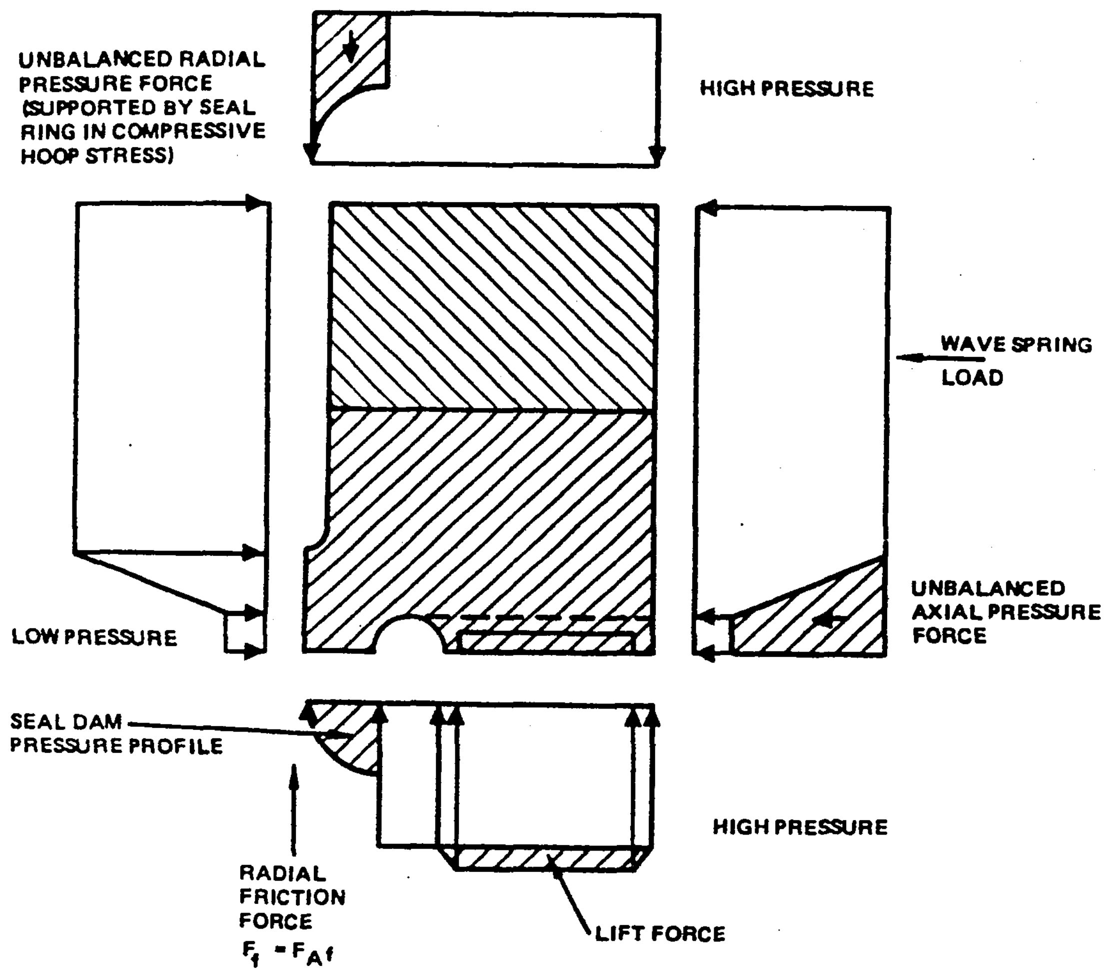


Figure 30. Phase III Floating Ring Rayleigh Step Seal Pressure Profile

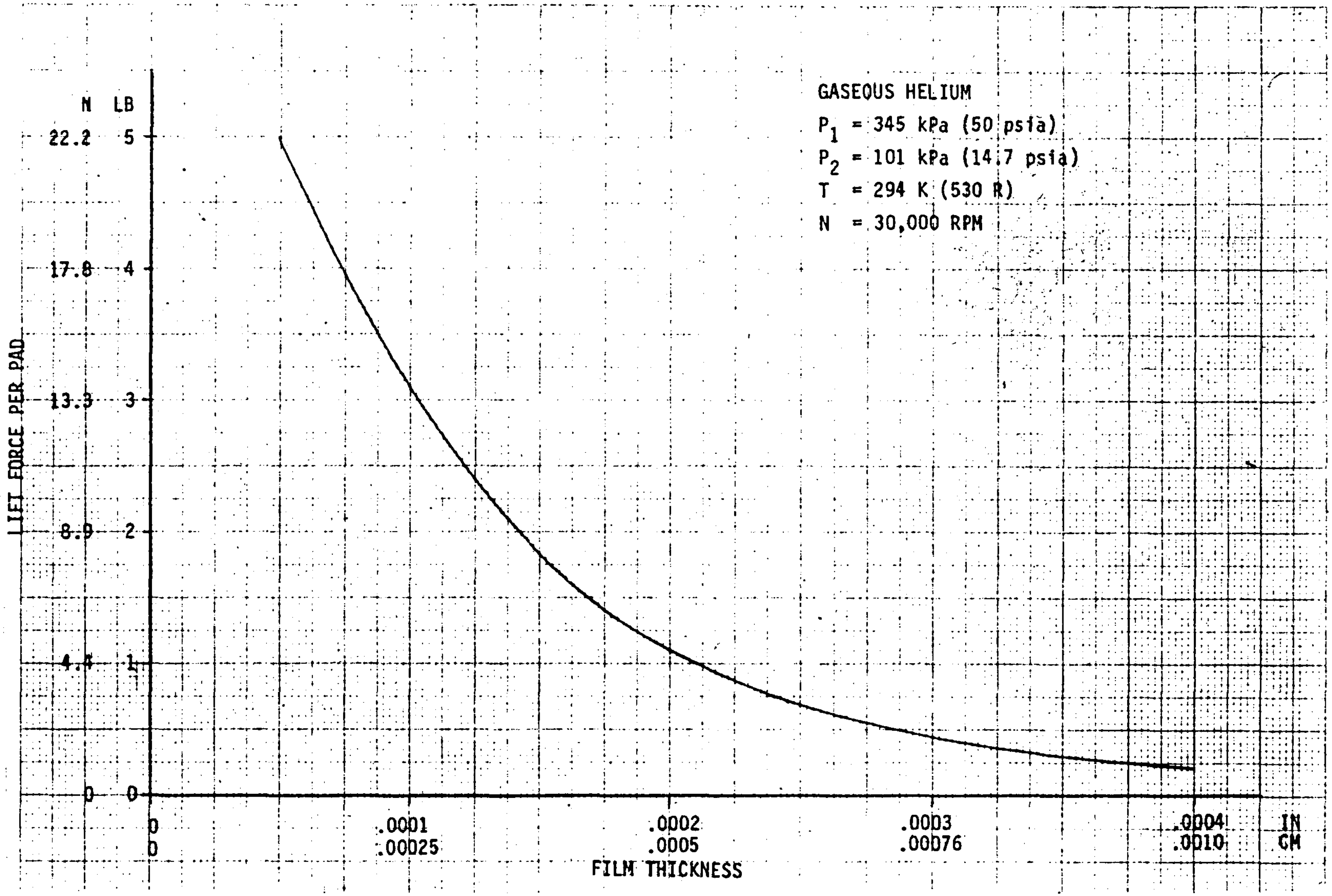
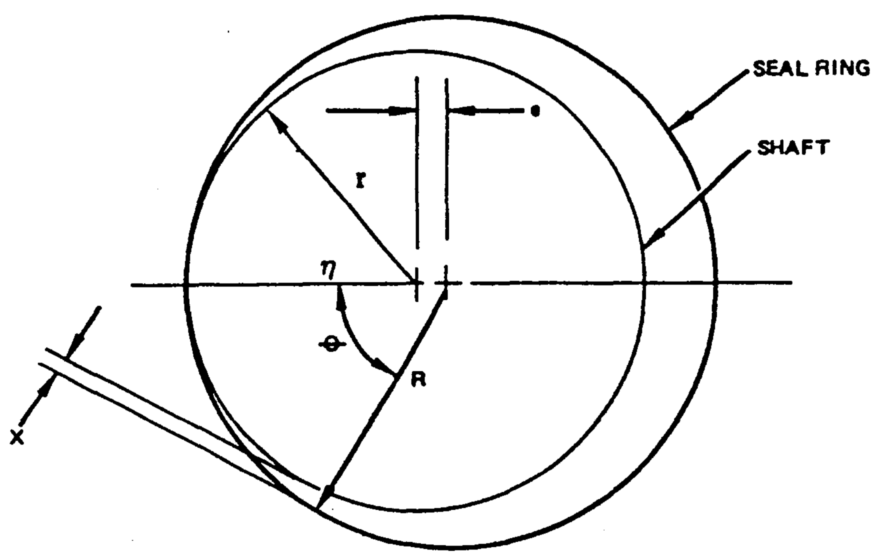


Figure 31. Phase III Rayleigh Step Floating Ring Helium Seal Lift Force

The lift pad film thickness varies around the circumferential seal ring from zero at the contact point to the diametral clearance opposite the contact as shown in the following equation:

$$x = [R^2 + e^2 - 2Re \cos \theta]^{1/2} - r$$

x = film thickness
R = seal ring inside radius
r = shaft outside radius
θ = angle from contact
e = eccentricity of seal ring and shaft



A comparison of the lift force and film thickness to the angle from contact, indicates that only two pads provide significant lift force to assist in centering the seal ring. The maximum lift force is 27.04 N (6.08 lb).

The ability of the seal ring to center on the shaft without rubbing contact depends on the lift force to exceed the radial friction force and dynamic inertia forces. The radial friction force is a function of the unbalanced axial forces and the coefficient of friction. The radial friction force for the seal ring is 7.6N (1.7 lb). The analysis indicates that the lift force is sufficient to center the seal ring without rubbing contact.

Seal Ring Stress and Deflection

The carbon G84 seal ring and Inconel x 750 retainer band assembly was analyzed to establish the interference fit for positive retention and to determine the radial deflection caused by thermal contraction and pressure induced forces. The results are shown in Table 2 for a pressure of 689 kPa (100 psia) and temperature of 255 K (0 F).

TABLE 2. RAYLEIGH STEP FLOATING RING STRESS AND DEFLECTION

INITIAL DIA INTERFERENCE, CM (IN.)	0.051	(0.020)
TEMPERATURE DIA DEFLECTION, CM (IN.)	-0.0058	(-0.0023)
PRESSURE DIA DEFLECTION, CM (IN.)	0	(0)
TOTAL DIA DEFLECTION, CM (IN.)	-0.0058	(-0.0023)
CARBON RING STRESS, kPa (PSI)	-103,425	(-15,000)
INCONEL BAND STRESS, kPa (psi)	123,420	(17,900)

Mating Ring

A Z-shaped helium seal mating ring was designed to maintain a cylindrical sealing surface at the design operating condition. The Phase I T-shape design deflected to a conical sealing surface during operation. The circumferential Rayleigh lift pads will not provide lift on a conical sealing surface and would result in rapid carbon wear. The Z-ring geometry and design temperature distribution is shown in Fig. 32. The Z-design features a 45-degree web conically thinned toward the attachment point at the turbine side of the sealing ring.

Even temperature distribution results on the ring inside diameter from the LOX leakage and on the outside diameter from the helium purge. The design thermal gradient was determined from estimated operating conditions which resulted in the conical deflection of the T-ring as determined from analysis of carbon ring wear after Phase I testing. Sealing surface deflections of the Z-ring at design operating condition were determined using a finite element analysis and are shown in Fig. 33 along with the T-ring characteristic for comparison.

Additional features of the Z-ring design include a press fit shaft pilot to provide position piloting on the shaft at design operating condition and a puller ring added to the web to facilitate ring removal.

PHASE V SEGMENTED RAYLEIGH STEP HELIUM SEAL

The Phase V segmented carbon Rayleigh Step helium seal (Fig. 34) is the same concept as the Phase I seal, except the diameter is reduced from 10,000 cm (3.937 in.), to 6.769 cm (2.665 in.), and the mating ring is a sleeve on the shaft. The Rayleigh Step lift pad geometry is shown in Fig. 35). The lift force per segment as a function of film thickness for a pressure of 345 kPa (50 psia) and temperature of 294 K (530 R) is shown in Fig. 36.

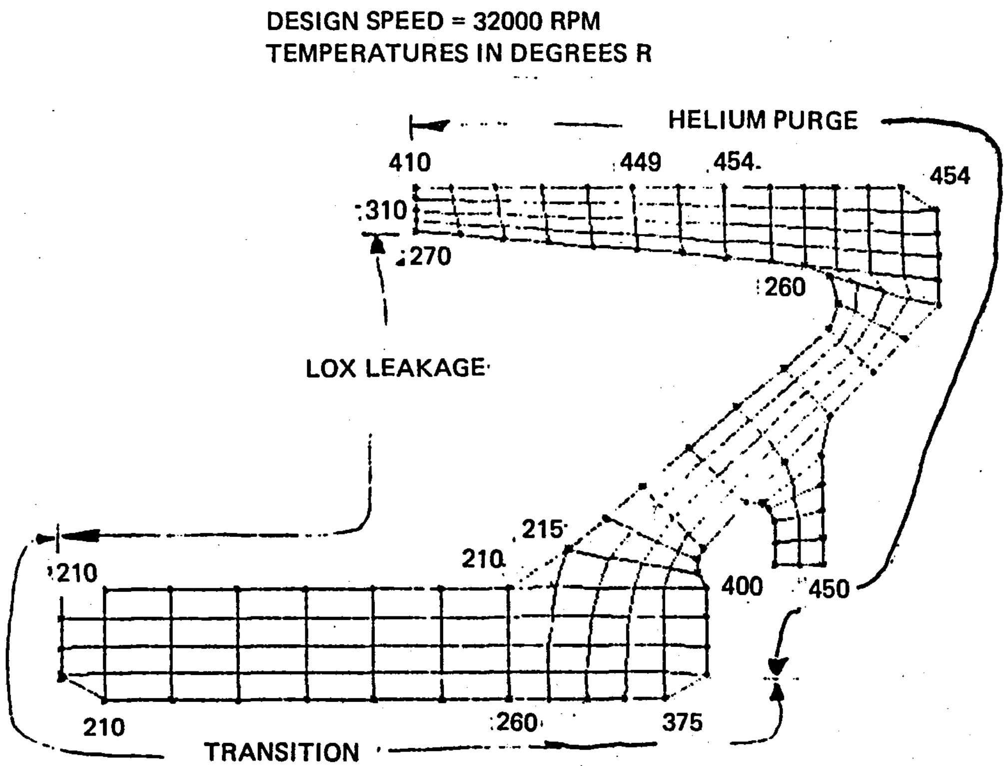


Figure 32. Phase III Helium Mating Ring

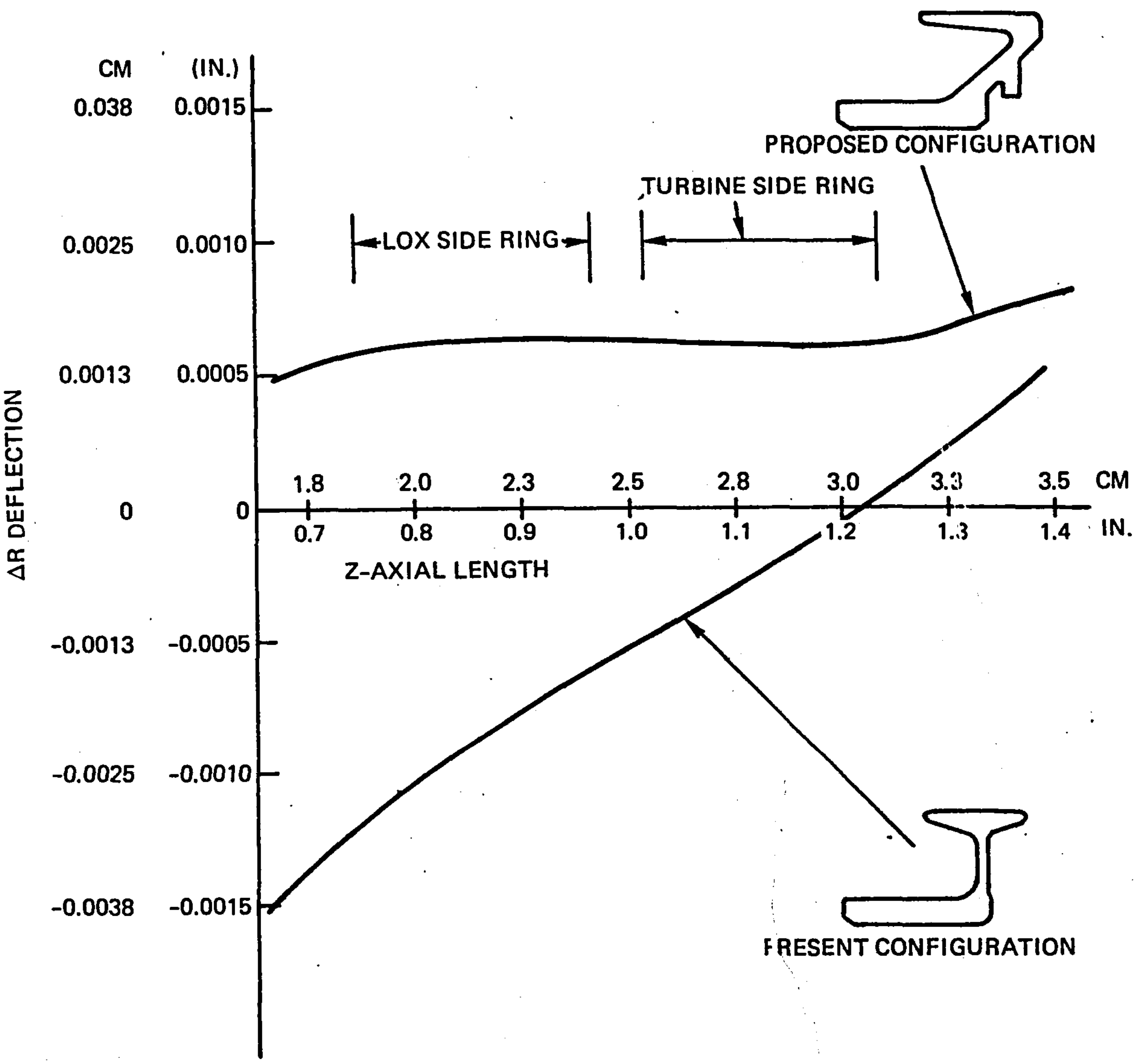


Figure 33. Phase III Helium Mating Ring Sealing Surface Deflections at Design Operation Conditions

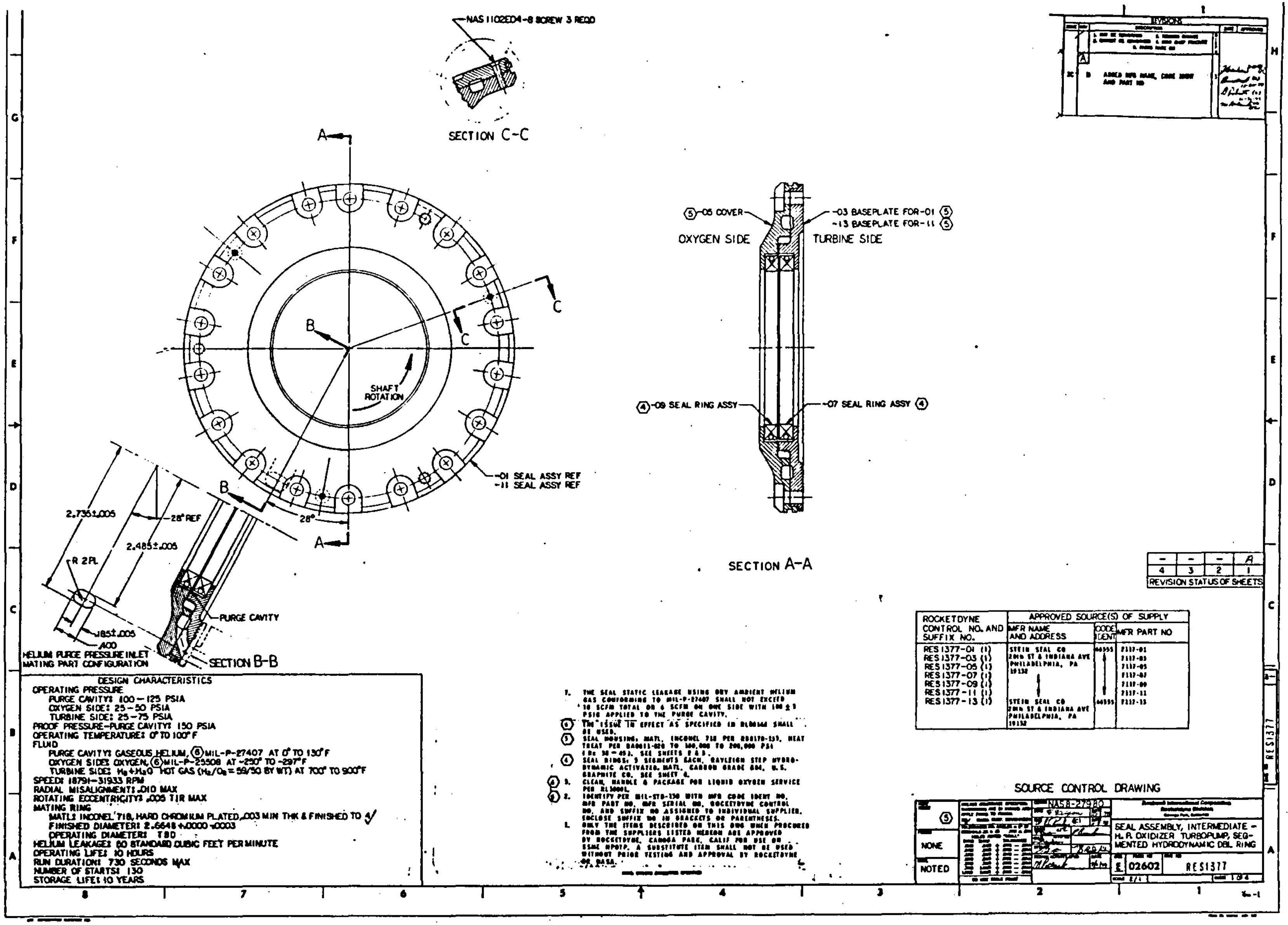


Figure 34. Phase V Segmented Rayleigh Step Helium Seal

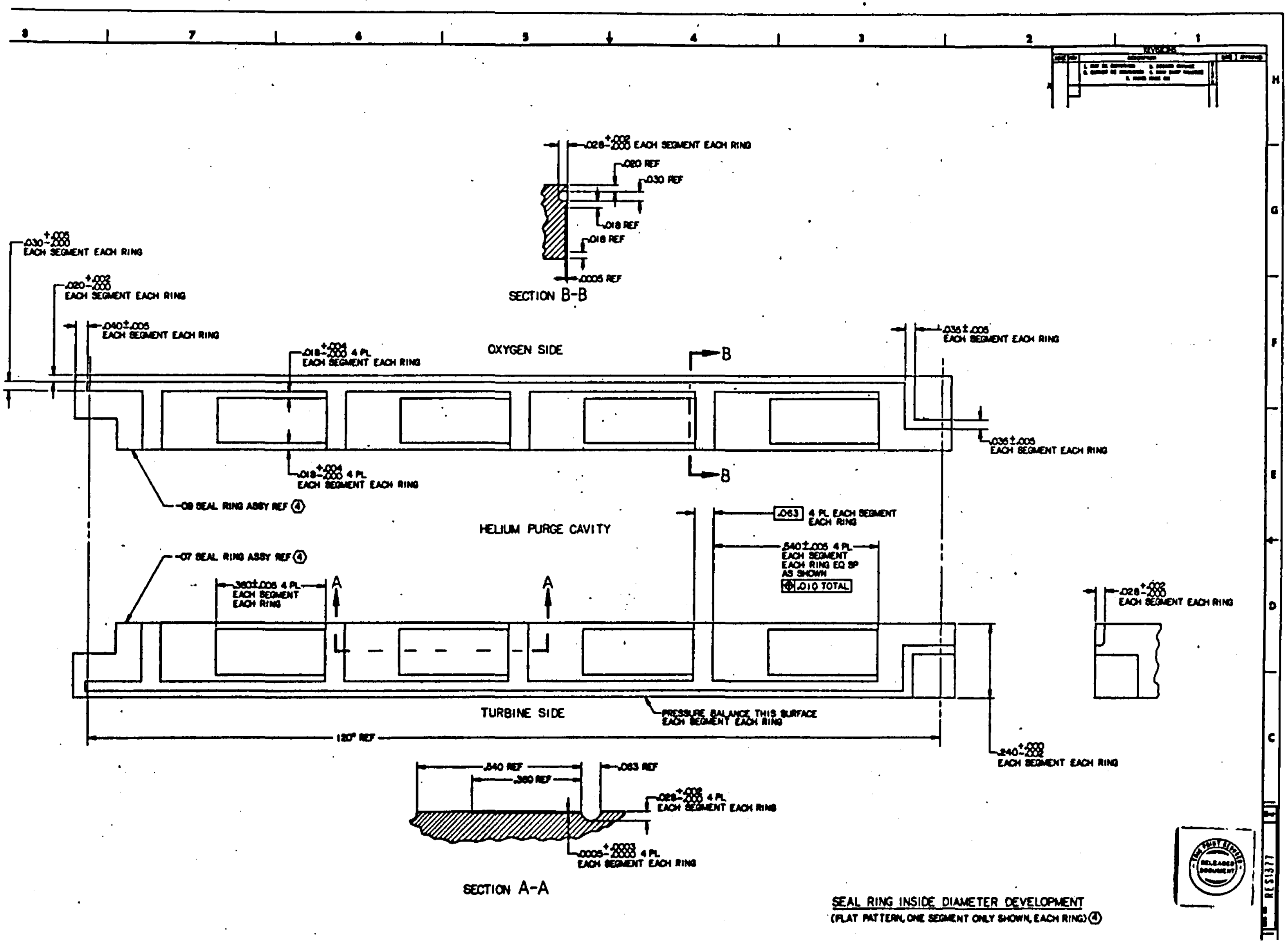


Figure 35. Phase V Rayleigh Step Lift Pad Geometry

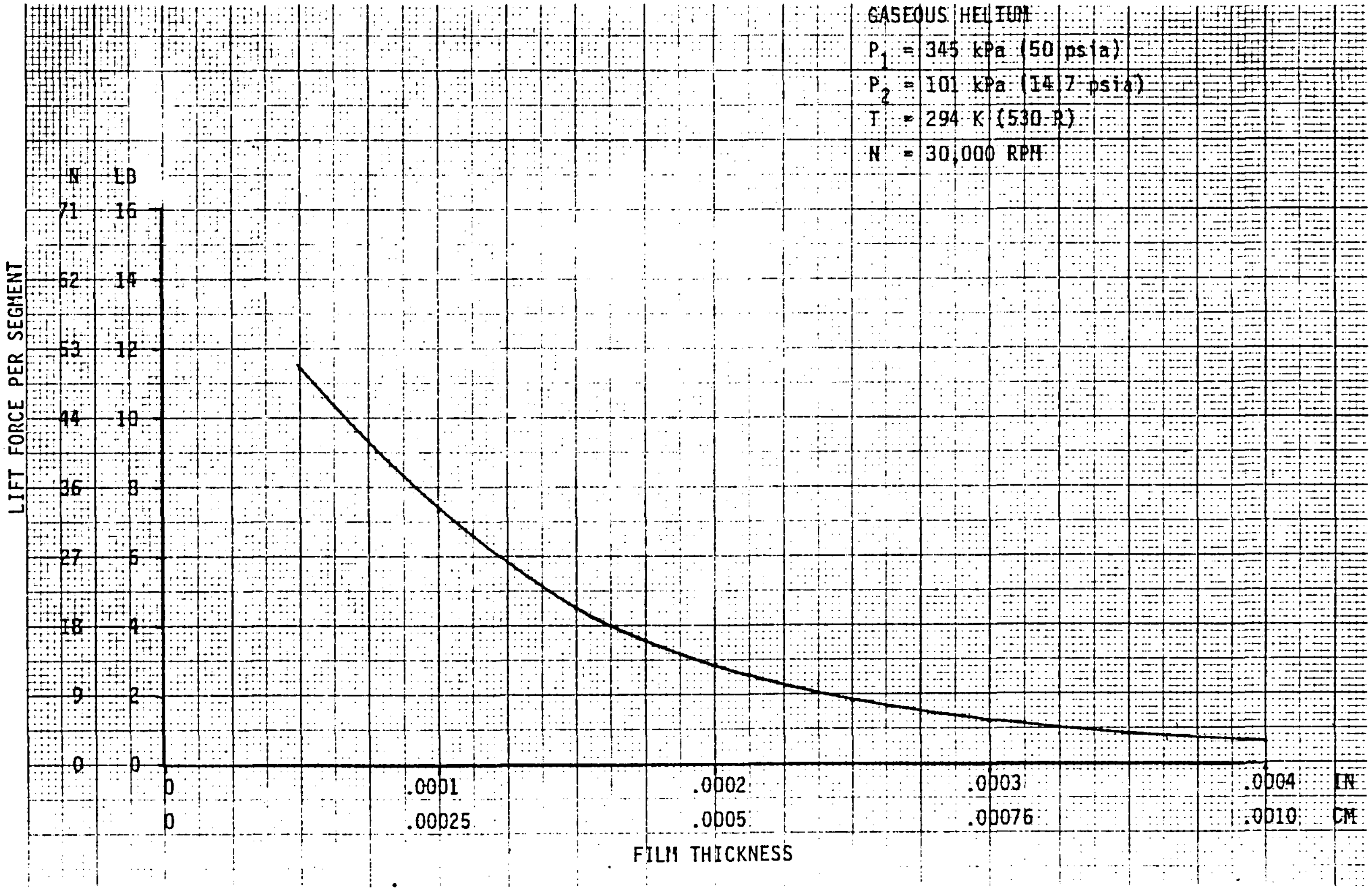


Figure 36. Phase V Rayleigh Step Segmented Carbon Helium Seal Lift Force

TESTER

PHASE I BASIC

The seal tester assembly, as originally used during Phase I of the program, is shown in Fig. 37. This tester is a modification of an existing J-2 liquid hydrogen bearing and seal tester designed to accept the test seals. Additional modifications to the tester were done during later phases of the program based upon the test requirements.

The Phase I tester was designed to provide the test capability for evaluating one cryogenic self-acting lift pad test seal at speeds up to 137 m^3/s (450 ft/sec) and pressures of 2758 kPa (400 psi). The test seal cavity is sealed from the rest of the tester by a face seal on the bearing side and by a helium purge seal and a face seal on the turbine side. A schematic of the tester seal area is shown in Fig. 38. During gaseous nitrogen testing, commercial ball bearings lubricated with an oil-air mist were used. During liquid oxygen testing, the Phase I tester used J-2 turbopump bearings (NA5- 26660) lubricated with liquid oxygen. The bearings in both cases are preloaded using an axial load piston calibrated to give a minimum preload of 889.6 N (200 lb). The tester was mounted on the existing J-2 tester mounting frame.

The Phase I tester was originally designed to be driven by a 373,000 kW (500 hp), variable speed, DC motor capable of up to 120.4 rad/sec (1150 rpm). A 1:30 ratio gearbox was installed into the system so that the required speed of 2931.8 rad/sec (28,000 rpm) could be reached. The tester and drive system are coupled with a splined coupling shaft which extends out of the tester and into the gearbox. This system was designed to be compatible with the existing facility at the Santa Susana Field Laboratory, Component Test Laboratory 1.

During Phase I testing, helium seal failures typical of those created by large shaft deflections spawned an investigation into the tester critical speeds and resulting shaft motions. The tester was instrumented with two Bently transducers 90 degrees apart at the helium seal area of the shaft. Tests were conducted where the tester was gradually spun up to 3351 rad/sec (32,000 rpm) and shaft motions were measured to identify critical speeds. The test results, backed up by theoretical analysis, indicated that the tester was passing through a critical speed and that shaft deflections of as much as 0.0003 m (0.012 in.) were experienced in the helium seal area. For tester bearing spring rates of 1.75×10^8 N/m (1×10^6 lb/in.) the first three critical speeds were calculated to be 1465.9 rad/sec (14,000 rpm), 1989.5 rad/sec (19,000 rpm), and 5235.5 rad/sec (50,000 rpm), respectively. Continued investigation of the problem indicated that additional shaft deflections were caused by loose tester facility mounts and excessive misalignments of the tester shaft and drive motor gearbox output shaft. The facility mounts were promptly modified to replace the spherical bearings and cylindrical adapters with gusset plates to improve stability, and an improved alignment procedure was incorporated into the assembly procedures.

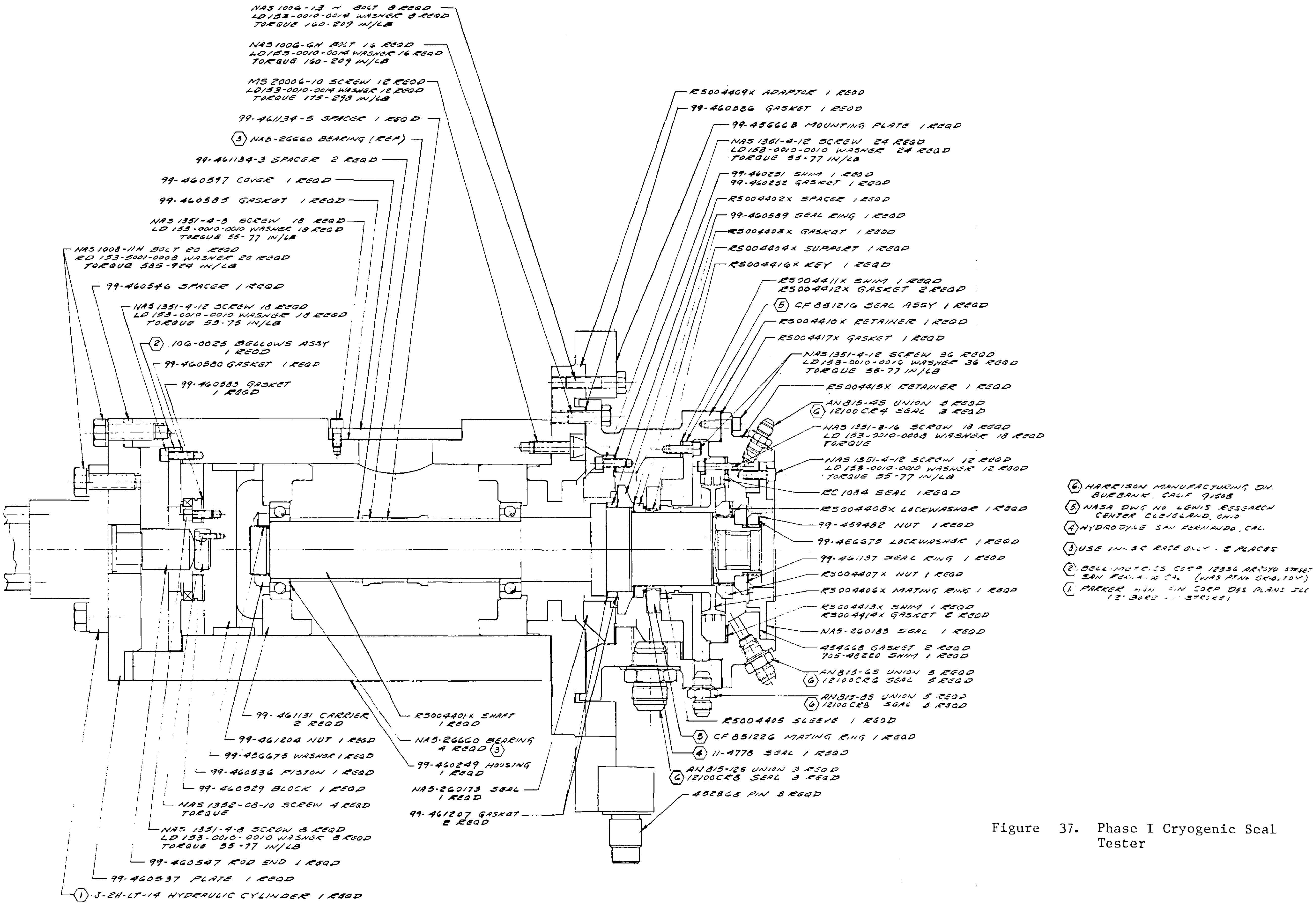


Figure 37. Phase I Cryogenic Seal Tester

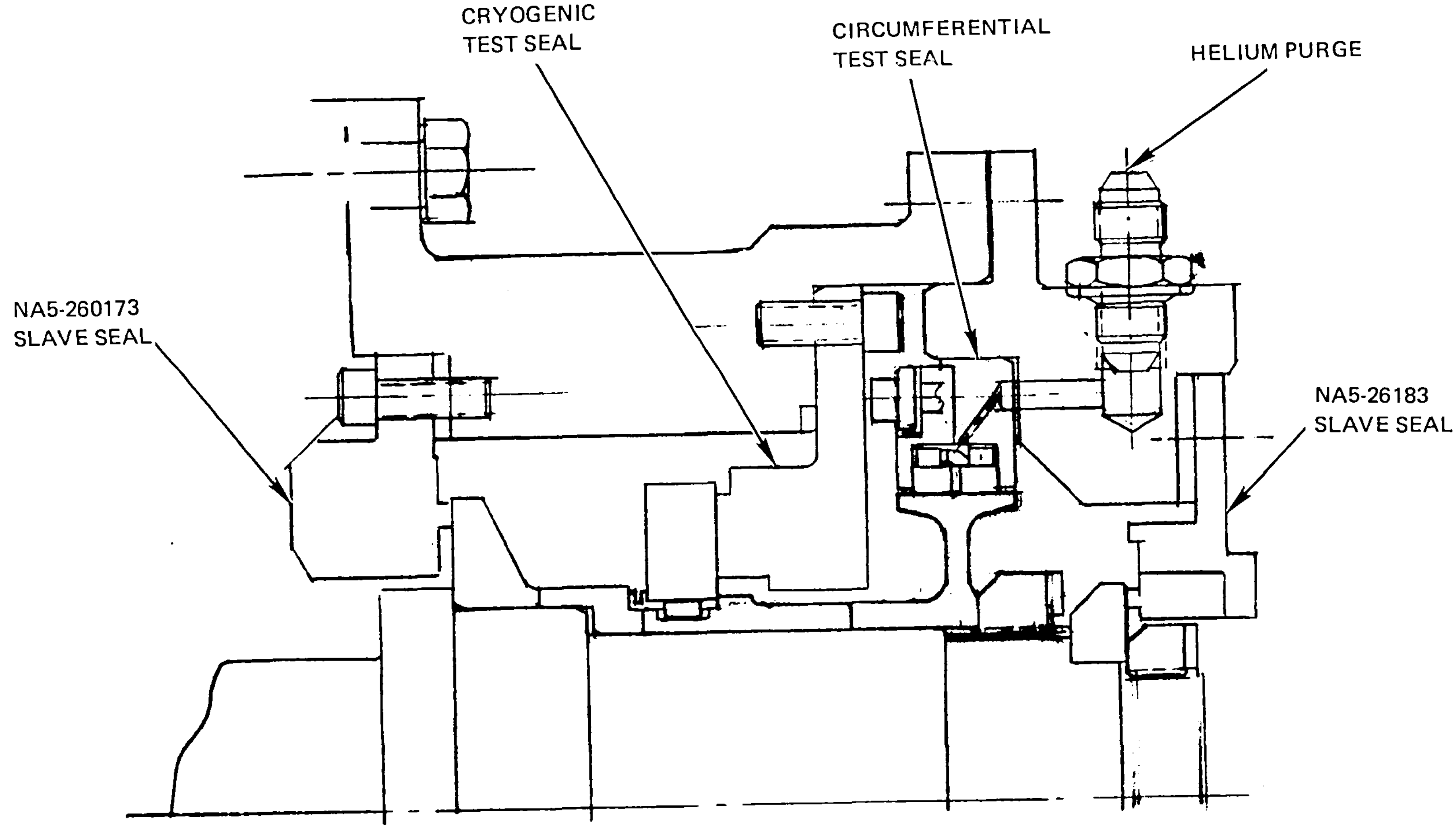


Figure 38. Tester Seal Area

When further checkout tests also resulted in failures, subsequent investigations indicated that the bearings ran in an unloaded position which created additional shaft deflections. A decision was then made to redesign the tester to incorporate a higher bearing preload and to replace the axial load piston with preload springs to ensure that a proper bearing axial load is maintained. In addition, it was decided to change the coupling design to a close-coupled quill shaft between tester and drive and to use a gas-driven turbine instead of an electric motor.

PHASE I INTEGRAL TURBINE

Phase I testing continued with the redesigned tester at Wyle Laboratories in Norco, California. The basic tester configuration was identical to that used previously, except for the changes described above. The first and most important difference, was the fact that the drive system now utilized a gas turbine directly mounted to the system. This was done through the use of a series of adapters designed to pilot directly on the turbine and the tester. The pilots were developed so that precise alignment of the turbine and tester shafts could be easily accomplished. The two systems were connected by a short quill shaft, specially designed to transmit the required torque, but flexible enough to absorb any misalignment that might occur. A layout of the redesigned coupling assembly is shown in Fig. 39.

The second modification to the seal tester involved replacement of the bearing axial load piston with preload springs. The springs were designed to give a minimum axial preload of 1334.4 N (300 lb). A schematic of the bearing preload spring design is shown in Fig. 40.

To prevent recurrence of the shaft deflection and critical speed problem experienced in the first series of tests, a critical speed analysis of the tester and drive system was conducted. For a tester bearing spring rate of 1.75×10^8 N/m (1×10^6 lb/in.) and a turbine bearing spring rate of 3.5×10^7 N/m (0.2×10^6 lb/in.) the first three critical speeds were calculated to be at 2155.8 rad/sec (20,589 rpm), 2552 rad/sec (24,372 rpm), and 7897 rad/sec (75,418 rpm), respectively. Deflection mode shapes also were calculated, indicating that the first critical speed is the only one which results in a deflection of the tester shaft. The test plan was altered so that run time at speeds in the vicinity of these critical speeds was held to a minimum.

Tests also were conducted to determine the actual critical speeds and resulting deflections experienced during tester operation. Results of these tests showed that the tester shaft deflections at the helium seal mating ring were a maximum of 0.0001727 m (0.0068 in.) peak to peak at a critical speed of 1884.78 rad/sec (18,000 rpm) and 0.00009652 m (0.0038 in.) peak to peak at a critical speed of 3455.4 rad/sec (33,000 rpm). The tests also indicated that shaft deflections were acceptable at the planned operating speed of 3351 rad/sec (32,000 rpm).

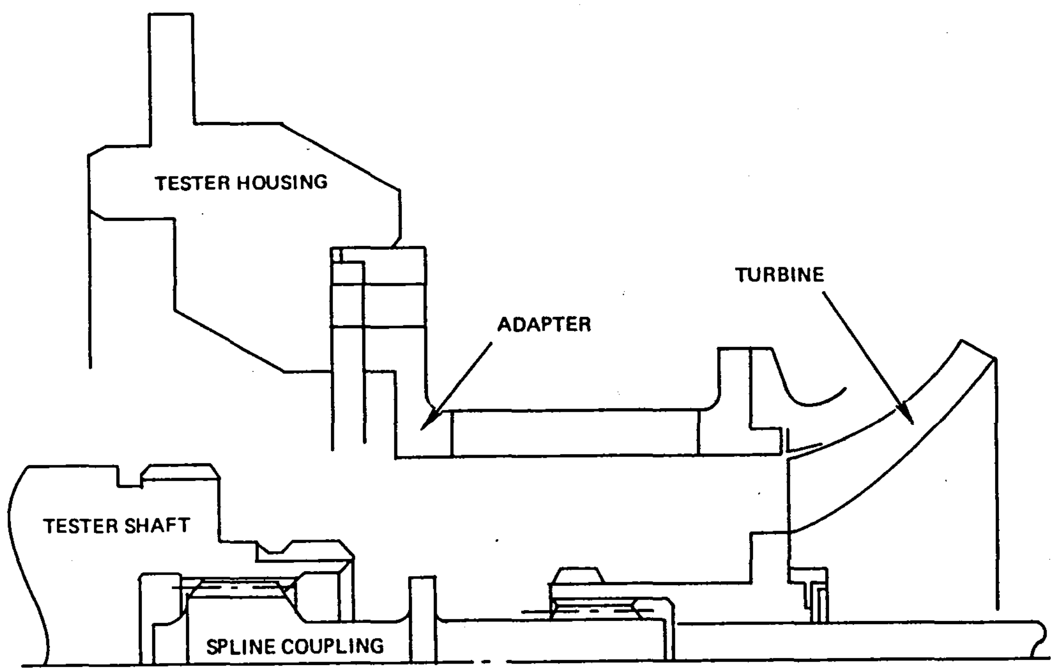


Figure 39. Modified Tester Drive With Close-Coupled Turbine

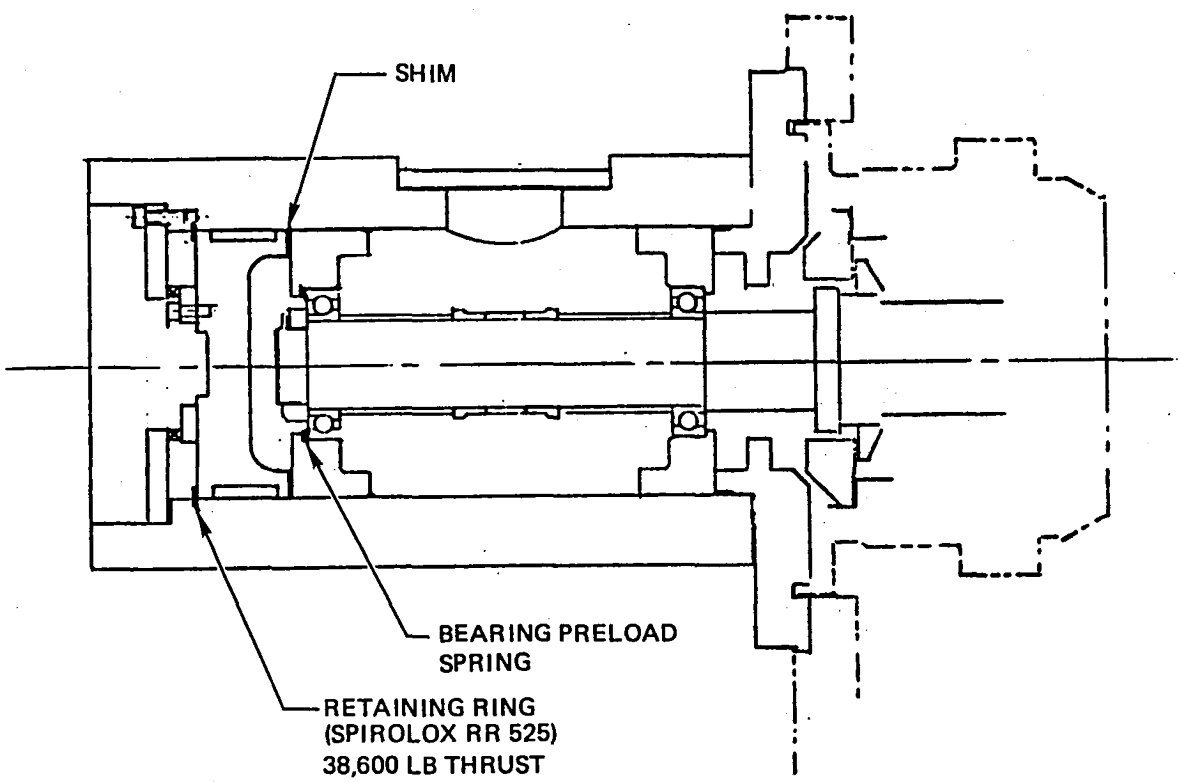


Figure 40. Tester Modification to Replace Bearing Axial Load Piston With Preload Springs

A precision alignment procedure also was adapted to prevent excessive shaft deflections in the tester. This procedure involved measuring the eccentricities of the tester, adapter, and turbine pilot diameters and matching them to produce the best radial alignment possible. This procedure was also utilized in every system assembly rebuild that followed.

PHASE V MODIFICATION

The seal tester Phase I design was used for test phases III and IV; however, a minor alteration to the test seal area was made during Phase V. Specifically, the tester was redesigned to accept a smaller segmented carbon helium seal, which required rework of the seal carrier. A schematic of the Phase V modification is shown in Fig. 41. No further alterations were made to the tester.

DRIVE TURBINE

During Phase I of the program, a gas driven turbine integral with the tester was substituted for an electrical motor as the drive system for testing. The turbine used was a Thompson Products air turbine driven fuel pump assembly, Model No. TT-70300-2, capable of running at 3351 rad/sec (32,000 rpm) for an air inlet pressure of 282.7 kPa (41 psi) and flowrate of 0.2497 kg/sec (0.55 lb/sec). The turbine provided enough torque to accelerate the tester up to the operating speed of 3351 rad/sec (32,000 rpm) in under 10 seconds. The turbine is designed to use either compressed air or gaseous nitrogen as the working fluid, and both were used at various stages of testing to drive the turbine. The principal pumping element of the turbine is a 0.05237 m (2.062 in.) outer diameter impeller. The working fluid flows into the turbine through the impeller and out a nozzle calibrated to produce the desired torque. An exploded view of the turbine assembly is shown in Fig. 42.

Several modifications were performed on the turbine during the course of testing, mainly to increase its power output. The impeller was trimmed twice at various times to a final OD of 0.04826 m (1.90 in.). The nozzle size also was increased approximately 40% in the hopes of raising the turbine power output. Both of these modifications in no way affected the seal performance or test results.

Assembly and disassembly of the turbine onto the tester was chiefly performed by Rocketdyne so that the alignment could be strictly controlled. Wyle Laboratory personnel did, on occasion, remove the turbine from the stand for minor modifications.

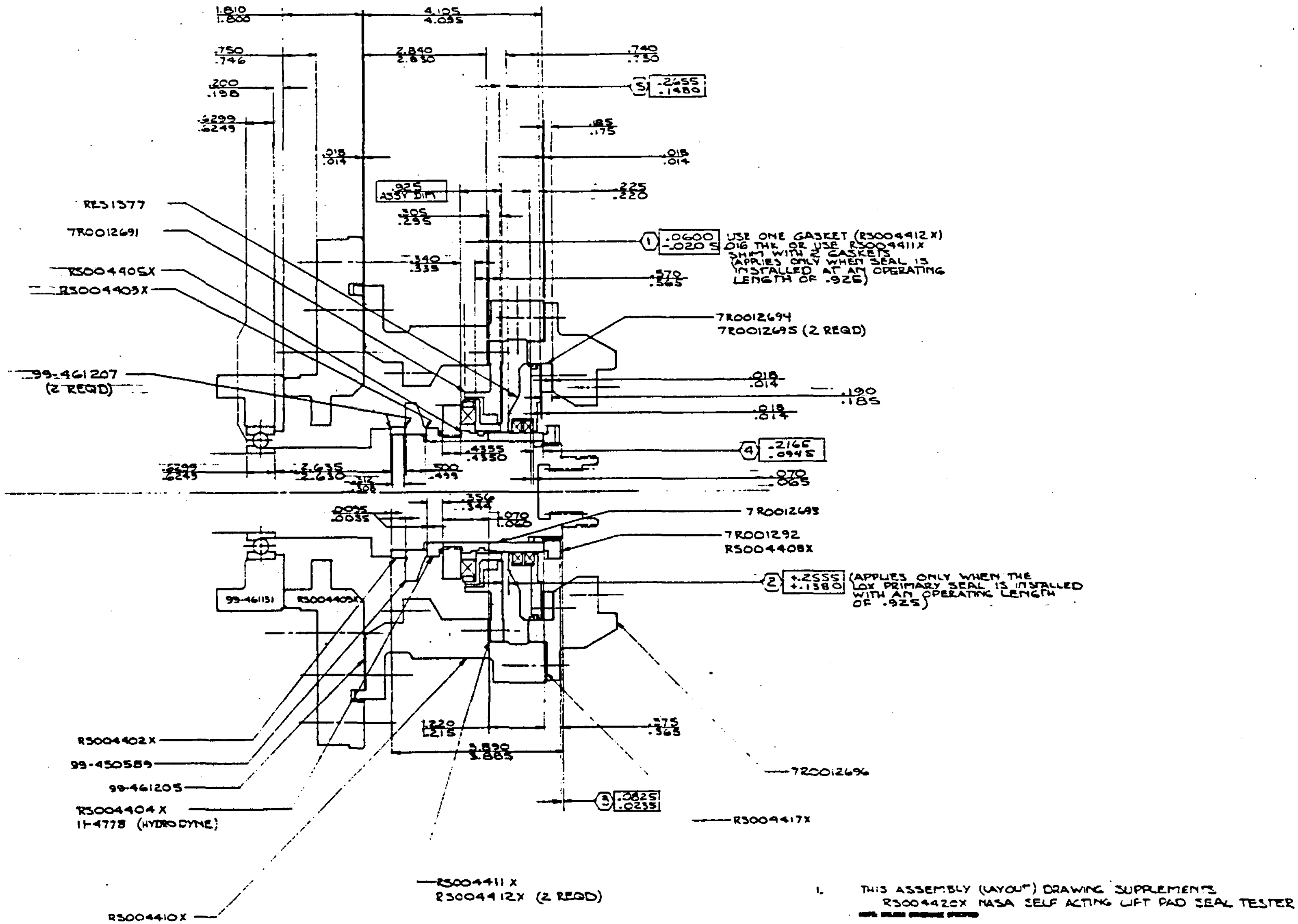


Figure 41. Phase V Tester Modification

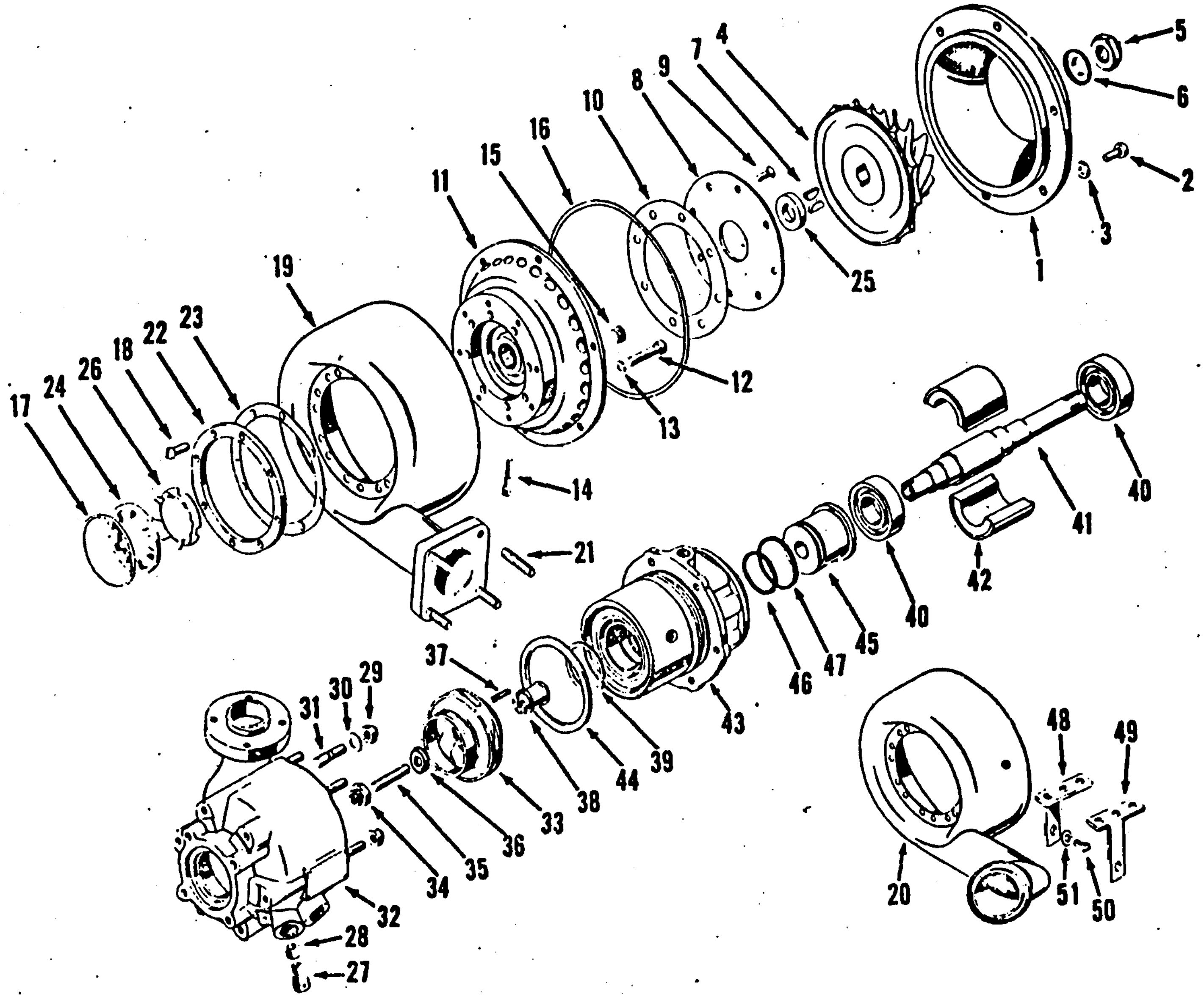


Figure 42. Air Turbine Driven Fuel Pump Subassembly

TEST FACILITY

SANTA SUSANA FIELD LABORATORIES

Phase I seal testing originally began at the Component Test Laboratory 1, Cell 4B at the Santa Susana Field Laboratory in Chatsworth, California. Capabilities include 1.362 m^3 (360 gallon), 13,790 kPa (2000 psi) pressurized liquid oxygen feed tank with 10.59 m^3 (2800 gallon) separate storage tank. The facility also contained gaseous nitrogen flow capability from 13 m^3 (460 ft^3), 20,685 kPa (3000 psi) pressurized tank, and gaseous helium flow capability from 516 m^3 (200 ft^3), 34,475 kPa (5000 psi) pressurized tank. Only nitrogen testing was performed at this facility.

Gaseous nitrogen was supplied to the tester from the feed tank by a pump producing an overall 20,685 kPa (3000 psi) system. All gaseous nitrogen flow was directed to the primary seal cavity. Inlet pressure to the seals was regulated at start by a manually controlled mechanical valve. The maximum pressure of 2758 kPa (400 psi) was achieved at start in under 10 seconds. The nitrogen supply temperature was ambient.

The tester shaft speed was established by a 373,000 kW (500 hp) variable speed DC motor capable of 120.4 rad/sec (1150 rpm). A gearbox ratio of 1:30 was used to obtain tester speeds of 2931.8 to 3351 rad/sec (28,000 to 32,000 rpm). The coupling system consisted of a splined quill shaft specially designed to transmit the required torque. The tester bearings were cooled and lubricated with an oil-air mist centralized lubrication system providing lube oil at 344.7 kPa (50 psi).

WYLE LABORATORIES

The remainder of the test program (Phases I to V) were conducted at Wyle Laboratories in Norco, California. Capabilities include a 7.5 m^3 (2000 gallon) vacuum jacketed LOX storage tank with steady-state flow to 7.5 m^3/min (2000 gpm), a 792.4 m^3 (28,000 ft^3) GN_2 storage tank with steady-state flows to 45.3 kg/sec (100 lb/sec), a 378.4 m^3 (10,000 gallon) vacuum jacketed LN_2 storage tank with steady-state flowrates of 6.8 kg/sec (15 lb/sec). A schematic of the seal test setup is shown in Fig. 43.

Liquid oxygen was supplied to the tester from a 0.946 m^3 (250 gallon) 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 orifices and controlled by motorized valves. LOX seal pressurization also was controlled by an upstream motorized valve. The liquid nitrogen feed system was set up in a similar fashion. Helium purge flow was supplied to the helium purge seal cavity directly from a pressurized tank and regulated to provide 206.8 to 861.9 kPa (30 to 125 psia) at the tester. Gaseous nitrogen for the seals was supplied directly from a pressurized tank through a 150 micron filter.

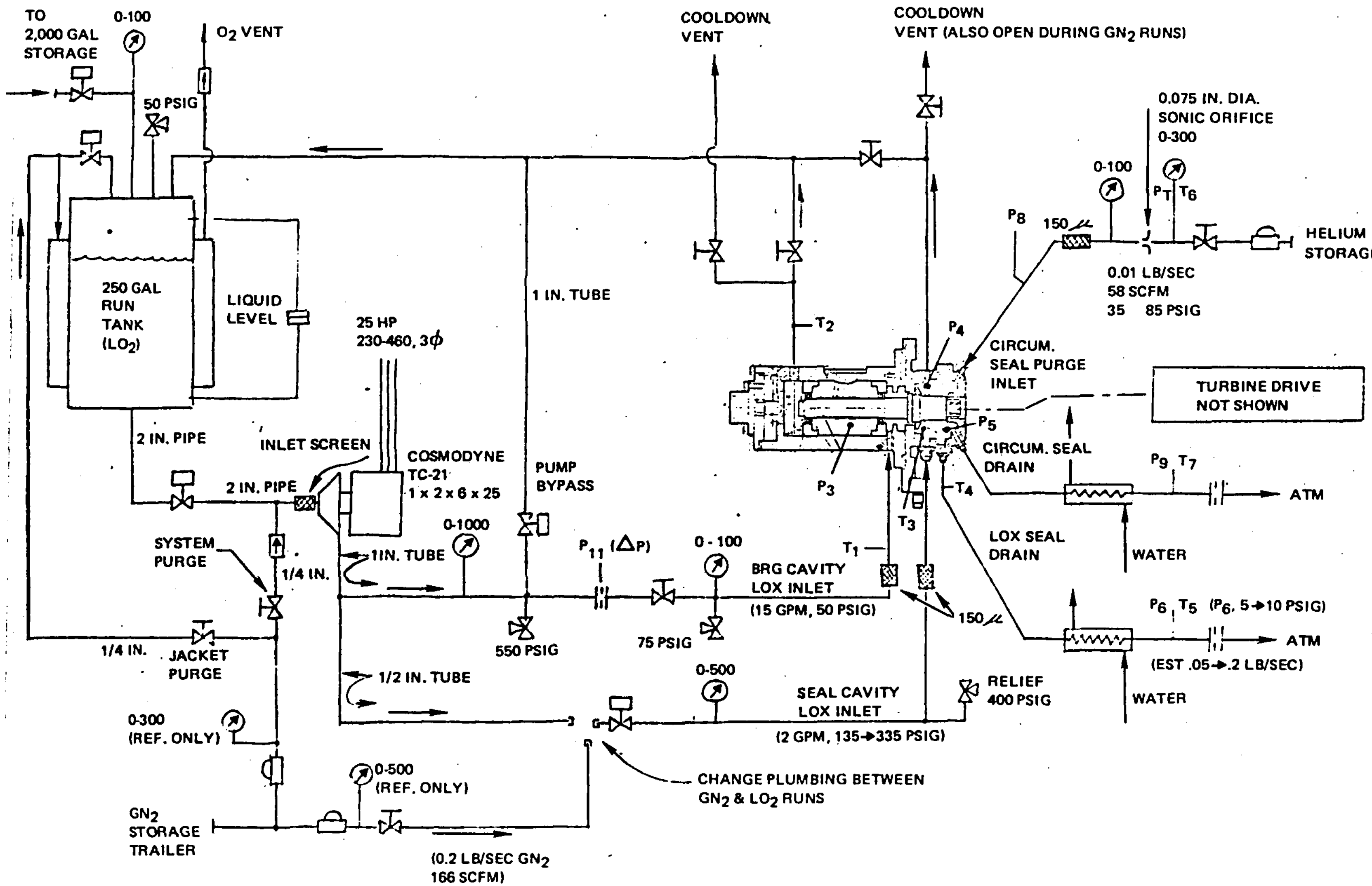


Figure 43. Wyle Laboratories Facility Schematic

Compressed air and gaseous nitrogen for the tester drive turbine also were supplied from a pressurized tank through a 150 micron filter. Solenoid and motorized valves were used to control the GN_2 pressure to achieve the desired test speed or seal cavity pressure. Persistent overspeed problems caused by slow reacting turbine inlet line regulators finally resulted in replacement of a gate valve with a Powell No. 675 needle globe valve during Phase V of the program. This valve was found to be very helpful in controlling turbine inlet pressure and resulting speed and was used for the duration of the test program. The turbine inlet pressure was manually controlled so that proper acceleration required by the test plan could be obtained.

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 or 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 test facility is shown in Fig. 44; the control panel and the strip charts used to record data are shown in Fig. 45.

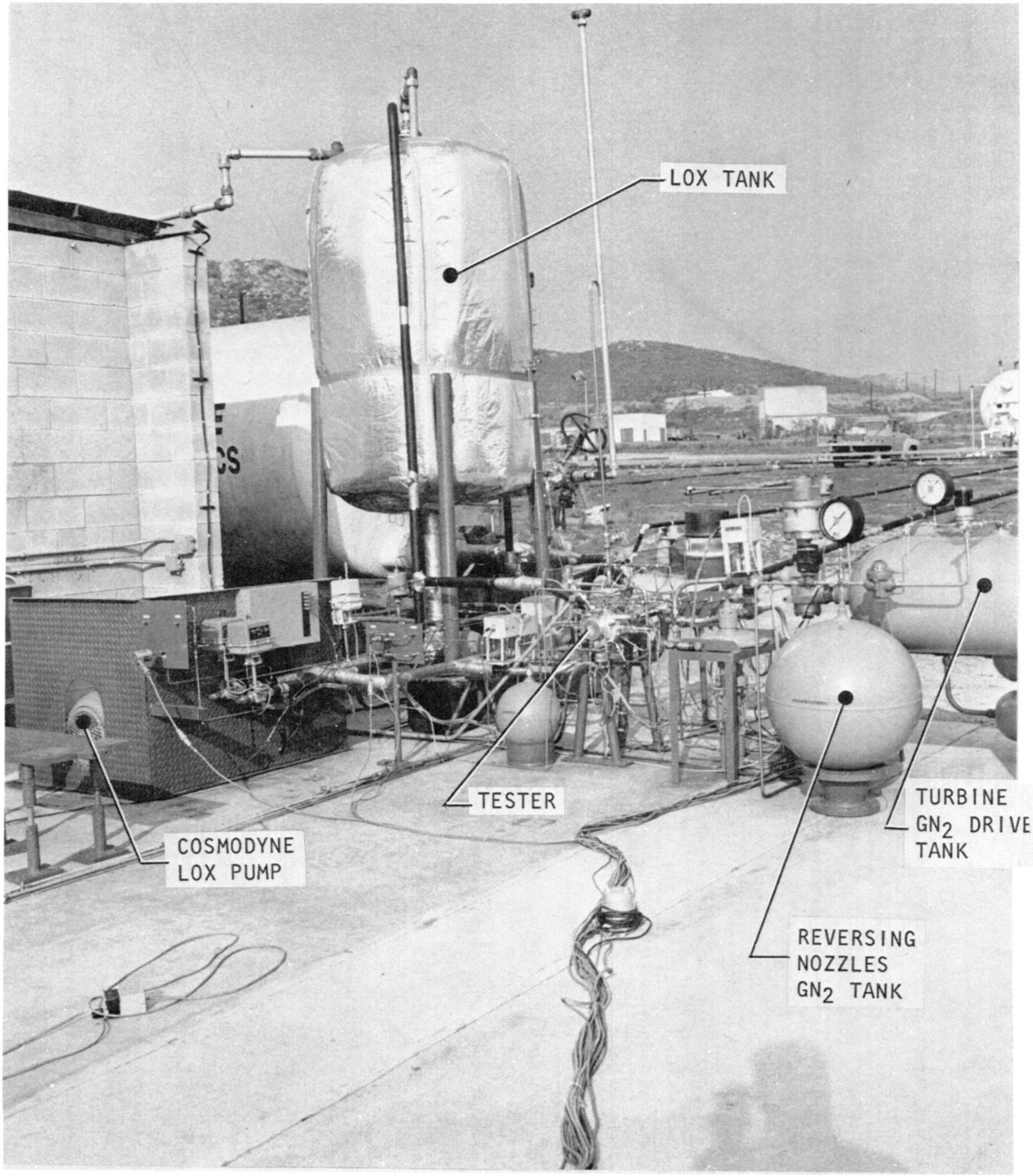


Figure 44. Wyle Laboratories Test Facility

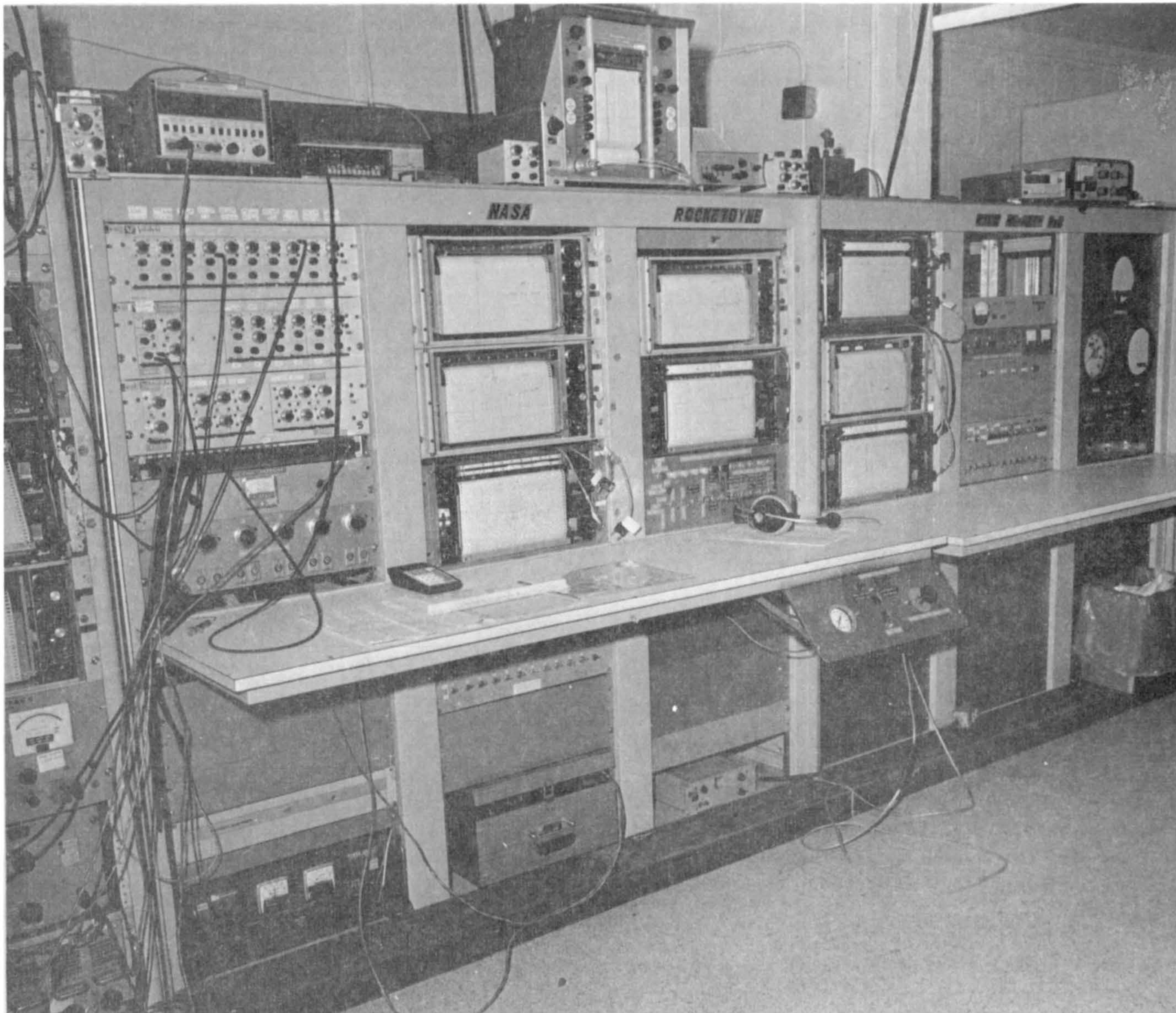


Figure 45. Wyle Laboratories Control Panel

TEST REQUIREMENTS

TEST PROCEDURES

Santa Susana Field Laboratories, CTL 1-4B

The test program consisted of two parts: preliminary checkout testing and cryogenic temperature tests. During checkout testing one cryogenic test seal was exposed to ambient nitrogen gas at progressively higher pressures in 344.7 kPa (50 psi) increments from 1034 to 2758 kPa (150 to 400 psia). The test speed was also varied in 15.24 m/sec (50 ft/sec) increments ranging from 91.44 to 121.9 m/sec (300 to 400 ft/sec) at 1034 kPa (150 psia), 106.7 to 137.1 m/sec (350 to 450 ft/sec) at 1379 kPa (200 psia), and 137.1 m/sec (450 ft/sec) at all pressures greater than that. Total test time for this phase was to be 10 starts for 150 minutes. Inspection of the seal hardware was to be conducted, as needed, if the test parameters indicated unusual operation. The helium seal was also tested by exposing it to helium at 241.3 kPa (35 psia) for all test points.

Cryogenic temperature testing consisted of exposing one cryogenic seal to liquid oxygen at four pressures ranging from 344.7 to 2758 kPa (50 to 400 psia). The speeds for these tests were 60.9 m/sec (200 ft/sec), at 344.7 kPa (50 psia), 91.44 m/sec (300 ft/sec) at 689.5 kPa (100 psia), 121.9 m/sec (400 ft/sec) at 1379 kPa (200 psia), and 137.1 m/sec (450 ft/sec) at 2758 kPa (400 psia) seal inlet pressure. A total of 5 hours accumulated test time was to be performed for each pressure/speed increment. The total test time for the seal was 20 hours. The helium seal was exposed to helium at 344.7 kPa (50 psia) for all the test points.

Inspection of the seals was scheduled for all new hardware and as-required based upon the test parameters. Posttest inspection following any replacement of seal hardware was also performed.

Wyle Laboratories

Testing at Wyle Laboratories consisted of gaseous nitrogen checkout testing and cryogenic temperature testing for all five phases of the program. Helium seal testing was also conducted at the same time as the other tests.

Phase I testing consisted of four checkout tests of 15 minutes each (1 hour total) with ambient temperature GN_2 as the sealed fluid, and four cryogenic temperature tests of varying duration for a total of 20 test hours. The GN_2 checkout tests were performed by exposing one cryogenic seal to gaseous nitrogen at progressively higher pressures in 344.7 kPa (50 psia) increments ranging from 1034 to 2413.25 kPa (150 to 350 psia). The shaft speed was set at 3351 rad/sec (32,000 rpm). The circumferential seal was simultaneously exposed to gaseous helium at 241.3 kPa (35 psia) for all test points. Seal inspection was conducted when the test parameters indicated unusual seal operation and at the end of the test series.

Phase I cryogenic testing consisted of exposing one cryogenic seal to liquid oxygen at four pressures: 1034 kPa (150 psia), 1723.7 kPa (250 psia), 2413.25 kPa (350 psia) and 2758 kPa (400 psia). The shaft speed was again fixed at 3351 rad/sec (32,000 rpm). Total accumulated test time for Phase I testing was 21 hours. Inspection of the seals was scheduled for all new hardware and at the completion of 5, 10, 11, 15, and 20 hours accumulated test time, respectively.

Phase II testing was eliminated due to insufficient funding.

Phase III testing consisted of 150 acceleration tests of 6 minutes each (15 hours total) with LO_2 as the sealed fluid. The type of testing and test parameters were identical to those of Phase I cryogenic testing, except that the LOX seal inlet pressure was increased from 206 kPa to 2758 kPa (30 to 400 psia) during the first 10 seconds and helium was pressure set at 344.75 kPa (50 psia). Seal inspection was conducted every 5 hours accumulated test time.

Phase IV testing consisted of four checkout tests of 15 minutes each (1 hour total) with liquid oxygen as the sealed fluid and 100 acceleration tests of 6 minutes each (10 hours total) with liquid oxygen as the sealed fluid. The total accumulated test time for Phase IV testing was 11 hours.

Phase IV checkout testing involved exposing one cryogenic seal to liquid oxygen at the following pressures: 1034, 1723.7, 2413.2, 2758 kPa (150, 250, 350 and 400 psia). The circumferential seal was simultaneously subjected to gaseous helium at 344.7 kPa (50 psia) for the first two tests and 689.5 kPa (100 psia) for the last two. The shaft speed for all tests was 3351 rad/sec (32,000 rpm). Seal inspection was scheduled for the end of the test series, or when the test parameters indicated unusual seal operation.

Phase IV acceleration testing consisted of exposing the cryogenic LOX face seal to liquid oxygen while simultaneously flowing gaseous helium through the circumferential shaft seal. The test runs were made with shaft accelerations of 0 to 3351 rad/sec (0 to 32,000 rpm) in 10 seconds or less and simultaneous LOX pressure rises of 0 to 2758 kPa (0 to 400 psia). The helium purge pressure was 344.7 kPa (50 psia). The tests were repeated to accumulate 100 starts. Inspection was scheduled for when the test parameters indicated unusual seal operation, on all new hardware, or the completion of testing.

Phase V testing consisted of eight preliminary checkout tests of 15 minutes each (2 hours total) using liquid nitrogen for the LOX seal and gaseous helium for the circumferential shaft seal, eight preliminary checkout tests of 15 minutes each (2 hours total) using LOX for the cryogenic seal and helium for the shaft seal, and 100 cryogenic acceleration tests of 6 minutes each (10 hours total) using LOX and helium as the sealed fluid. Total accumulated test time for Phase V testing was to be 14 hours. Phase V liquid nitrogen preliminary checkout tests involved exposing one cryogenic LOX seal to liquid nitrogen at pressures of 1034, 1723.7, 2413.2, 2758, 3102.7, and 3447.5 kPa (150, 250, 350, 400, 450, and 500 psia). The circumferential seal was simultaneously exposed to gaseous helium at pressures of 344.7, 689.5, 861.87 kPa (50, 100, and 125 psia). Prior to the start of each test the LOX seal and helium seal inlet pressures were increased to approximately 344.7 kPa (50 psia). After those pressures were reached, the shaft was accelerated to 3141.3 rad/sec (30,000 rpm) in 10 seconds or less with a simultaneous LOX seal pressure increase to the specific value. The helium seal pressure was increased to the specified value after the tester was brought up to speed. Inspection was scheduled for all new hardware and at the completion of the test series. Liquid oxygen preliminary checkout testing followed the same procedure as the nitrogen tests, except that liquid oxygen was used as the sealed fluid instead of liquid nitrogen.

Phase V cryogenic acceleration testing consisted of exposing one LOX seal to liquid oxygen and one circumferential seal to gaseous helium for 100 6-minute tests. The test runs were made with shaft accelerations of 0 to 3141.3 rad/sec (0 to 30,000 rpm) in 10 seconds or less with a simultaneous LOX seal pressure rise of 206.8 to 3447.5 kPa (30 to 500 psia). The helium seal purge pressure was increased to 861.87 kPa (125 psia) prior to start of the test. Seal inspections were scheduled for all new hardware and after 5 and 10 hours of accumulated test time.

Pretest procedures involved strenuous inspection of the seal hardware and test facility. First, the static cryogenic seal leakage and tester turning torque were measured at each test pressure increment with the helium seal purge pressure vented. The helium circumferential seal leakages and tester turning torque were then measured at each test pressure with the LOX seal pressure vented. The cryogenic and circumferential seal dam height and recess pad depth were measured as were the diameters of the mating rings. In addition, cryogenic seal surface profile traces and optical flatness readings were obtained for the seal mating ring and nose piece.

In addition to the inspections listed above, three facility drive checkout tests were conducted to measure shaft deflections and critical speeds. Two Bently transducers were installed into the tester in place of the helium seal. Both the LOX seal and the outboard slave seal were also left out for these tests. Three, 10-minute tests, at 3351 rad/sec (32,000 rpm), were performed. Data were recorded on high frequency magnetic tape and analyzed to ensure that shaft deflections were within the operating limits. Corrections to the setup were made, as necessary.

Posttest procedures involved a rigorous inspection of the seal hardware similar to that performed during pretest operations. In addition, to those measurements, a careful visual examination of each seal was performed. Photographs of normal, as as well as unusual, posttest conditions were taken, as required. Light band flatness of the seal mating rings and nose piece were omitted when the surface finish quality prevented this type of inspection.

INSTRUMENTATION

The instrumentation requirements, including redlines, are listed in Table 3. Location of the instrumentation taps on the tester is shown in Fig. 46.

Data were recorded continuously on direct inking graphic recorder charts and high speed Visicorder.

TABLE 3. INSTRUMENTATION REQUIREMENTS NASA SEAL TESTER

JOB NO.________________

DATE____________
NEXT TEST:________
DURATION:________

CODE	PARAMETER	RANGE	NOMINAL	REDLINE
P_1/T_6	CIRCUMFERENTIAL SEAL PURGE FLOW ORIFICE ΔP (0.075)	0-137.9 kPa (0-20 PSID)	--	--
P_2	LOX PUMP DISCHARGE	0-6895 kPa (0-1000 PSIG)	--	--
P_3	LOX BEARING CAVITY PRESURE	0-1379 kPa (0-200 PSIG)	344.7 ±103 (50 ±15)	1034 MAX** (150 MAX.**)
*, ***P_4	LOX SEAL UPSTREAM PRESSURE	0-6895 kPa (0-1000 PSIG)	--	3447 MAX** (500 MAX.**)
*, ***P_5	LOX SEAL DOWNSTREAM PRESSURE	0-6895 kPa (0-1000 PSIG)	--	689 MAX** (100 MAX.**)
***P_6/T_5	LOX SEAL LEAKAGE ORIFICE PRESSURE ΔP	0-1379 kPa (0-20 PSID)	--	--
P_7	CIRCUMFERENTIAL SEAL PURGE FLOW NOZZLE UPSTREAM PRESSURE (0.075)	0-1379 kPa (0-200 PSIG)	--	--
*P_8	CIRCUMFERENTIAL SEAL PURGE INLET PRESS	0-1379 kPa (0-200 PSIG)	344.7 ±56 (50 ±5)	--
***P_9/T_7	CIRCUMFERENTIAL SEAL DRAIN LEAKAGE ORIFICE PRESSURE ΔP	0-137.9 kPa (0-20 PSID)	--	--
P_{10}	LOX BEARING CAVITY FLOW ΔP (0.411)	0-344.7 kPa (0-50 PSID)	48 kPa (0.028 M^3/MIN) 137.9 kPa (0.0473 M^3/MIN) (7 PSID (7.5 GPM)) (20 PSIG (12.5 GPM))	20.68 kPa (0.0189 M^3/MIN) 3 PSID (5 GPM)
P_{11}	TURBINE INLET PRESSURE	689 kPa (0-100 PSIG)	--	517 kPa (75)
*P_{12}	TURBINE SIDE DRAIN CAVITY	344.7 kPa (0-50 PSIG)	--	--
TEMPERATURES				
T_1	LOX BEARING CAVITY INLET TEMPERATURE	-8.1 MV/O 82 K/338K (-312/+150)	-99.9 K MAX (-280 F MAX)	116 K MAX (-250 F MAX)
T_2	LOX BEARING CAVITY OUTLET TEMPERATURE	-8.1 MV/O 82 K/338 K (-312/+150)	--	SUDDEN INCREASE
*T_3	LOX SEAL UPSTREAM TEMPERATURE	-8.1 MV/O 82 K/338 K	--	--
*T_4	LOX SEAL DOWNSTREAM TEMPERATURE	-8.1 MV/O 82 K/338 K (-312/+150)	--	--
***T_5	LOX SEAL LEAKAGE ORIFICE UPSTREAM TEMPERATURE AT ORIFICE	-8 MV/O 88 K/338 K (-300/+150 K)	--	--
***T_6	CIRCUMFERENTIAL SEAL PURGE ORIFICE UPSTREAM TEMPERATURE AT ORIFICE	0/-3MV 283 K/338 K (+50/+150)	--	--
***T_7	CIRCUMFERENTIAL SEAL DRAIN LEAKAGE ORIFICE UPSTREAM TEMPERATURE AT ORIFICE	0/-3MV 283 K/338 K (+50/+150)	--	--
*A_1	TESTER ACCEL (800 CPS LOW PASS FILTER)	0-20G P-P	--	20G P-P**
*S_1	SPEED	0-4188.4 RAD/SEC (0-40 K RPM)	3141.3/±52.3 RAD/SEC (3000 ±500)	3351 RAD/SEC MAX 2617.7 RAD/SEC MIN (32 K MAX**) (25 K MIN**)

VISICORDER CHANNELS

CHANNEL	1	6	2	4	3	5	7	8	9
MARKER	1	11	3	7	5	9	13	15	17
PARAMETER	A_1	S_1	P_4	P_8	P_5	P_{12}	T_3	T_4	

*RECORDED ON VISICORDER
**AUTOMATIC CUTOFF
***RECORDED ON BRUSH RECORDER

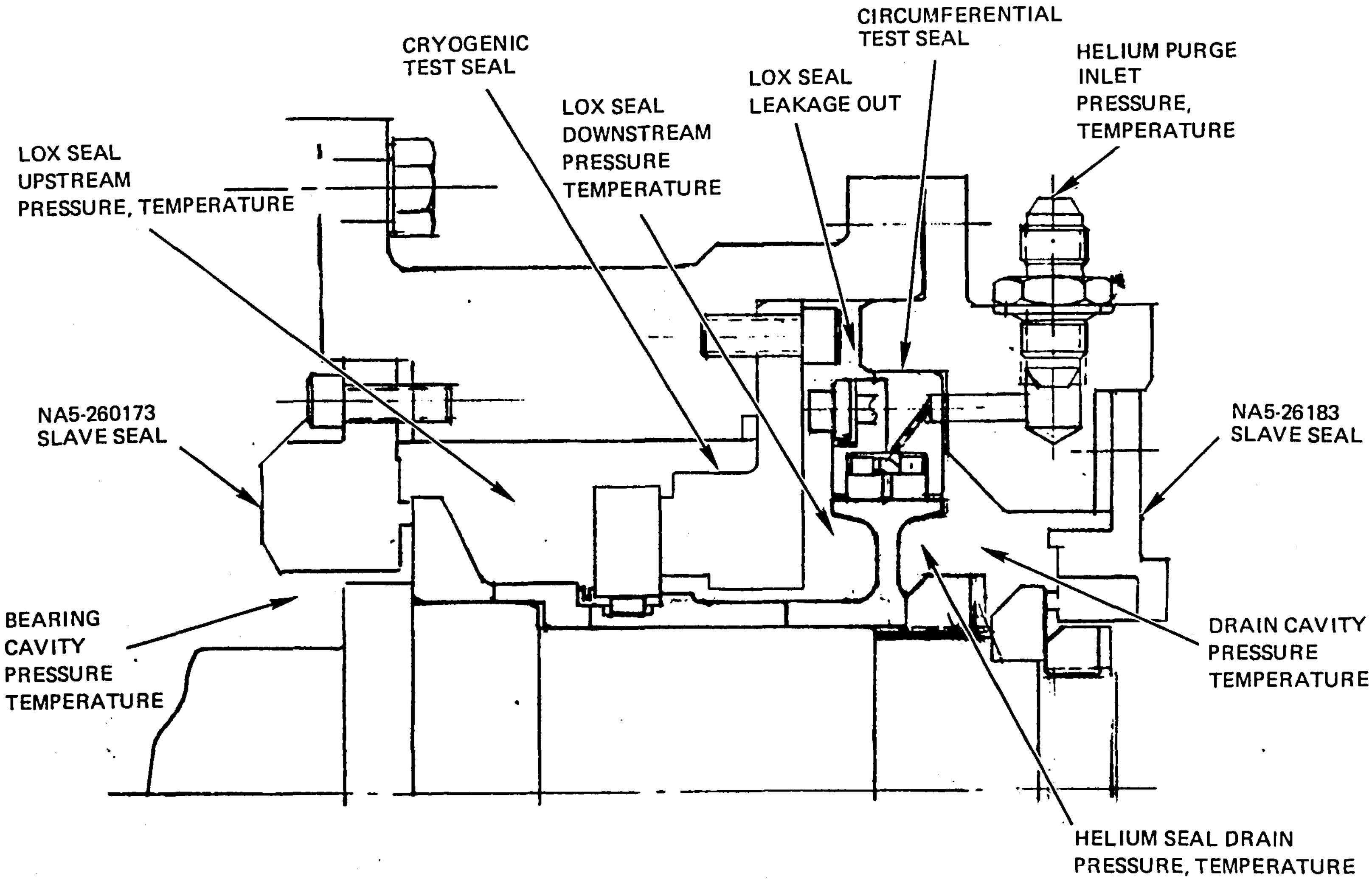


Figure 46. Instrumentation Location

The seal leakage rate during cryogenic testing was measured by utilizing a heat exchanger on the seal drainline to convert the leakage fluid to a gas at approximately ambient temperature. The gas leakage then could be measured using a gas flowmeter. The other parameters were measured using conventional instrumentation, i.e., calibrated transducers and thermocouples. System vibration was monitored by accelerometers positioned directly above the bearings.

TEST PLAN

<u>Phase I Test Schedule I: Preliminary GN_2 Checkout Testing</u>

Preliminary checkout tests were conducted on one cryogenic seal and one circumferential seal at ambient temperature with gaseous nitrogen and helium. Test points, conditions, and inspection points per seal are as follows:

TEST POINT	SPEED RAD/SEC (RPM)	CRYOGENIC SEAL GASEOUS NITROGEN PRESSURE, kPa (PSIA)	CIRCUMFERENTIAL SEAL HELIUM PURGE PRESSURE, kPa (PSIA)	DURATION, MINUTES
1	3351 (32,000)	1034 (150)	241.3 (35)	15
2	3351 (32,000)	1379 (200)	241.3 (35)	15
3	3351 (32,000)	2068.5 (300)	241.3 (35)	15
4	3351 (32,000)	2413.2 (350)	241.3 (35)	15
Inspect seals				

<u>Phase I Test Schedule II: Cryogenic Temperature Testing</u>

Cryogenic temperature tests were conducted on one set of seals using LOX as the sealed fluid for the cryogenic seal and gaseous helium as the purge fluid for the circumferential seal at the following conditions:

TEST POINT	SPEED RAD/SEC (RPM)	CRYOGENIC SEAL LIQUID OXYGEN PRESSURE, kPa (PSIA)	CIRCUMFERENTIAL SEAL HELIUM PURGE PRESSURE, kPa (PSIA)	ACCUMULATED TIME, HOURS
1	3351 (32,000)	1034 (150)	241.3 (35)	5
Inspect Seals				
2	3351 (32,000)	1034 (150)	241.3 (35)	5
Inspect Seals				
3	3351 (32,000)	1723.7 (250)	344.7 (50)	0.5
4	3351 (32,000)	2068.5 (300)	344.7 (50)	0.25
5	3351 (32,000)	2413.2 (350)	344.7 (50)	0.25
Inspect Seals				
6	3351 (32,000)	2758 (400)	344.7 (50)	4
Inspect Seals				
7	3351 (32,000)	2758 (400)	344.7 (50)	5
Inspect Seals				

Phase III Test Schedule I: Cryogenic Acceleration Testing

Cryogenic acceleration tests were conducted on the selected seals using liquid oxygen as the sealed fluid for the LOX face seal and gaseous helium as the purge fluid for the circumferential shaft seal. The test runs were made with shaft accelerations of 0 to 3351 rad/sec (0 to 32,000 rpm) in 10 seconds or less and simultaneous LOX pressure rises of 206.8 to 2758 kPa (30 to 400 psia). The tests were performed at the following conditions:

TEST POINT NUMBER	SHAFT SPEED RAD/SEC (RPM)	LOX SEAL PRESSURE, kPa (PSIG)	HELIUM SEAL PRESSURE, kPa (PSIG)	DURATION, MINUTES
1-50	3351 (0-32,000)	206.8-2758 (30-400)	344.7 (50)	6
Inspect (5 Hours)	3351 (0-32,000)	206.8-2758 (30-400)	344.7 (50)	6
51-100	3351 (0-32,000)	206.8-2758 (30-400)	344.7 (50)	6
Inspect (10 Hours)	3351 (0-32,000)	206.8-2758 (30-400)	344.7 (50)	6
101-150	3351 (0-32,000)	206.8-2758 (30-400)	344.7 (50)	6
Inspect (15 Hours)	3351 (0-32,000)	206.8-2758 (30-400)	344.7 (50)	6

Phase IV Test Schedule I: Preliminary Liquid Oxygen Checkout Testing

A preliminary checkout test was conducted of each LOX face seal design using liquid oxygen for the LOX seals and gaseous helium for the circumferential shaft seal. Test points and conditions were as follows.

TEST POINT NO.	SHAFT SPEED RAD/SEC (RPM)	CRYOGENIC SEAL PRESSURE kPa, (PSIA)	CIRCUMFERENTIAL SEAL PRESSURE, kPa (PSIA)	DURATION, MINUTES
1	3351 (32,000)	1034 (150)	344.7 (50)	15
2	3351 (32,000)	1723 (250)	344.7 (50)	15
3.	3351 (32,000)	2413.2 (350)	689.5 (100)	15
4.	3351 (32,000)	2758 (400)	689.5 (100)	15
Inspect Seals				

Each test point was to be run for a maximum of 15 minutes to establish equilibrium and to obtain a meaningful leakage rate measurement.

Phase IV Test Schedule II: Cryogenic Acceleration Testing

Cryogenic acceleration test runs were conducted on the two LOX face seal designs using liquid oxygen as the sealed fluid for the LOX face seal and gaseous helium as the purge fluid for the circumferential shaft seal. The test runs were made with shaft accelerations of 0 to 3351 rad/sec (0 to

32,000 rpm) in 10 seconds or less and simultaneous LOX pressure rises, 0 to 2758 kPa (0 to 400 psia). The helium purge pressure was 344.7 kPa (50 psia). Test duration at each test point number was 6 minutes at maximum shaft rpms and pressures.

SHAFT SPEED, RAD/SEC (RPM)	CRYOGENIC PRESSURE, kPg, (PSIA)	CIRCUMFERENTIAL SEAL PRESSURE, kPg, (PSIA)	DURATION, MINUTES
0-3351 (0-32,000)	0-2758 (0-400)	344.7 (50)	6

The above test conditions were to be repeated to accumulate 100 starts and a total test time of 10 hours at maximum rpm and pressure. Seal inspection was scheduled at the completion of the test series.

<u>Phase V Test Schedule I: Liquid Nitrogen Preliminary Checkout</u>

Preliminary checkout tests were conducted on one helium seal using liquid nitrogen for the LOX seal and gaseous helium for the helium seal. Prior to start of each test, the LOX seal and helium seal pressures were increased to 344.7 ±68.9 kPg (50 ±10 psia). The shaft was then accelerated to 3141.5 ±52.3 (30,000 ±500 rpm) in 10 seconds or less with simultaneous LOX seal pressure increase to the specified value after the tester was up to speed. Test points and conditions were as follows.

TEST POINT NO.	SHAFT SPEED RAD/SEC (RPM)	CRYOGENIC SEAL PRESSURE kPa, (PSIA)	CIRCUMFERENTIAL SEAL PRESSURE, kPa (PSIA)	DURATION, MINUTES
1	3141.5 ±52.3 (30,000 ±500)	1034 ±103.4 (150 ±15)	344.7 ±34.4 (50 ±5)	15
2	3141.5 ±52.3 (30,000 ±500)	1723 ±103.4 (250 ±15)	344.7 ±34.4 (50 ±5)	15
3	3141.5 ±52.3 (30,000 ±500)	2413.2 ±103.4 (350 ±15)	689.5 ±34.4 (100 ±5)	15
4	3141.5 ±52.3 (30,000 ±500)	2758 ±103.4 (400 ±15)	689.5 ±34.4 (100 ±5)	15
5	3141.5 ±52.3 (30.000 ±500)	3102.5 ±103.4 (450 ±15)	689.5 ±34.4 (100 ±5)	15
6	3141.5 ±52.3 (30.000 ±500)	3447.5 ±103.4 (500 ±15)	861.8 ±34.4 (125 ±5)	15
7	3141.5 ±52.3 (30,000 ±500)	3447.5 ±103.4 (500 ±15)	861.8 ±34.4 (125 ±5)	15
8	3141.5 ±52.3 (30,000 ±500)	3447.5 ±103.4 (500 ±15)	861.8 ±34.4 (125 ±5)	15
Inspect Seals				

Phase V Test Schedule II: Liquid Oxygen Preliminary Checkout

The checkout test series was repeated, using liquid oxygen for the LOX seal. At completion of the test series, a seal inspection was conducted.

Phase V Test Schedule III: Cryogenic Acceleration Testing

Cryogenic acceleration test runs were conducted on one LOX seal and one helium seal using liquid oxygen for the LOX seal and gaseous helium for the helium seal. The test runs were made with shaft accelerations of 0 to 3141.3 rad/sec (0 to 30,000 rpm) in 10 seconds or less with simultaneous LOX seal pressure rise from 344.7 to 3447 kPa (50 to 500 psia). The helium seal purge pressure was increased to the specified value prior to start. A total of 100 starts and 10 hours was to be performed at the following conditions.

SHAFT SPEED, RAD/SEC (RPM)	CRYOGENIC PRESSURE, kPg, (PSIA)	CIRCUMFERENTIAL SEAL PRESSURE, kPg, (PSIA)	DURATION, MINUTES
0 to 3141.3 (0 to 30,000)	344.7 to 3447 (50 to 500)	861.8 (125)	6

The seals were to be inspected at 5 hours and at completion of 10 hours.

RESULTS AND DISCUSSION

TEST SUMMARY

The test summary is given in Table 4.

HARDWARE AND INSPECTION SUMMARY

The LOX seal hardware and inspection summary is given in Appendix A.

The helium seal hardware and inspection summary is given in Appendix B.

TEST DATA SUMMARY

The test data summary is given in Appendix C.

PHASE I GASEOUS NITROGEN CHECKOUT TEST

Build 1 Assembly

The tester was assembled with a new Rayleigh Step Carbon P03N face type seal using a carbon P5NR2 secondary piston ring and a chrome plated K-Monel mating ring. The spring load was 102.3 N (23 lb) compressing and 88.9 N (20 lb) releasing with 18 springs installed.

A new three-segment Rayleigh Step carbon G84 helium seal was installed. The recess pads varied from the print requirement of 0.00127 to 0.00203 cm (0.0005 to 0.0008 in.) to 0.0000 to 0.00254 cm (0.0000 to 0.0010 in). The pad land height was irregular and tapered below the sealing dam surface by as much as 0.00381 cm (0.0015 in.) The discrepant segments were used to initiate the test program, while the other segments were being reworked to print requirements.

Test 001 (CTL1-4Br 1973)

The test was run for the scheduled duration of 15 minutes at 20,000 rpm, 1034 kPa (150 psia) LOX seal pressure and 345 kPa (50 psia) helium seal pressure. The tester operation and seal performance appeared satisfactory during the test. The measured seal operating leakage rates were on the low side of the expected range. However, the posttest seal static leakage check indicated excessive leakage.

Build 1 Disassembly

Seal inspection revealed that both seals had rubbed during the test. The LOX seal recess pads were worn away and the seal face had worn 0.025 cm (0.010 in.). The chrome surface on the LOX seal mating ring was scored and worn. The helium seal wear was negligible. The helium seal mating ring had a very slight wear pattern and heat discoloration.

TABLE 4. CRYOGENIC SELF-ACTING SHAFT SEAL TEST SUMMARY

BUILD NO.	TESTS NO.	STARTS	TIME MINUTES	TEST OBJECTIVE	SEAL HARDWARE		REMARKS
					LOX SEAL	HELIUM SEAL	
1	001	1	15	PHASE I GASEOUS NITROGEN CHECKOUT	NEW RAYLEIGH STEP CARBON P03N, P/N CF851218, S/N 01	NEW 3 SEGMENT RAYLEIGH STEP CARBON G84, P/N CB851250, S/N A3/A5	INSPECTION DUE TO EXCESSIVE POSTTEST STATIC LEAKAGE. LOX SEAL LIFT PADS WORN AND MATING RING SCORED. H_e SEAL RUBBED. TESTER ROTATED WRONG DIRECTION.
2	002-003	2	5.9		NEW RAYLEIGH STEP CARBON P03N, P/N CF851218, S/N 02	NEW 3 SEGMENT RAYLEIGH STEP CARBON G84, P/N CB851250, S/N A1/A7	INSPECTION DUE TO EXCESSIVE POSTTEST STATIC LEAKAGE. LOX SEAL SCORED AT OUTER EDGE DUE TO CHIPPING. H_e SEAL CARBON SEGMENTS BROKEN.
3	004	1	15		SAME AS BUILD 2 RELAPPED CARBON	NEW SEGMENTS CARBON G84, P/N CB851250, S/N A4/A6	SCHEDULED INSPECTION. LOX SEAL CARBON FACE WORN. H_e SEAL SEGMENTS BROKEN. SUSPECT FAILURE CAUSED BY EXCESSIVE TESTER SHAFT DEFLECTION.
4	005-007	3	1.8	TESTER SHAFT DEFECTION MEASUREMENT	SAME AS BUILD 2 RELAPPED	NOT INSTALLED	TESTER BEARING FAILED DUE TO HIGH ROTATING RADIAL LOAD. LOX SEAL RECESS PADS WORN OFF.
5	008	1	0.03		SAME AS BUILD 2 RELAPPED	NOT INSTALLED	TESTER BEARING FAILED DUE TO HIGH ROTATING RADIAL LOAD. LOX SEAL DAMAGED FROM RUBBING.
6	001-002	2	1.6		NOT INSTALLED	NOT INSTALLED	START TRANSIENT TESTING WITH REWORKED TESTER MOUNT AND ALIGNMENT. SHAFT DEFLECTION AND VIBRATION SATISFACTORY.
7	003	1	0.4	PHASE I GASEOUS NITROGEN CHECKOUT	NEW RAYLEIGH STEP CARBON P03N, P/N CF851218, S/N 03	NEW 3 SEGMENT CARBON G84 RAYLEIGH STEP, P/N CB851250, S/N A8/A2	INSPECTION DUE TO VIBRATION INCREASE. H_e SEAL CARBON SEGMENTS BROKEN. LOX SEAL IN GOOD CONDITION. TESTING MOVED FROM ROCKETDYNE CTL 1-4B TO WYLE LABORATORIES TO ALLOW CLOSE COUPLED TURBINE DRIVE SYSTEM FOR REDUCED SHAFT DEFLECTION.
8	076-103	28	18.8		SAME SEAL AS BUILD 7, RELAPPED. MATING RING REPLATED	NEW 6 SEGMENT CARBON P5N RAYLEIGH STEP P/N CB120673, S/N B5/B10	INSPECTION DUE TO SPEED CONTROL PROBLEM, LOX SEAL IN GOOD CONDITION. H_e SEAL WORN UNEVEN. DRIVE TURBINE GAS CHANGED FROM AIR TO GASEOUS NITROGEN TO ELIMINATE ICING.
9	104-132	29	85.8		SAME AS BUILD 8	SAME AS BUILD 8	COMPLETED PHASE I GASEOUS NITROGEN CHECKOUT TESTING. LOX SEAL IN GOOD CONDITION WITH NO WEAR. HELIUM SEAL WORN UNEVEN DUE TO MATING RING DISTORTION.
10	133-139	7	10.4	PHASE I LIQUID OXYGEN TESTING	SAME AS BUILD 9	SAME HOUSING, NEW SEGMENTS B-1/B-7. THIN WEBB MATING RING	INSPECTION DUE TO EXCESSIVE LOX SEAL LEAKAGE. LOX SEAL IN GOOD CONDITION. HELIUM SEAL WORN UNEVEN.
11	140-152	13	148.1		SAME AS BUILD 10. RELAPPED. INCREASED SPRING LOAD	NEW HOUSING. SAME LOX SEGMENTS AS BUILD 10. TURB SEGMENT B-5. NEW MATING RING	COMPLETED SCHEDULED 2.5 HOURS TESTING. SEAL PERFORMANCE SATISFACTORY. LOX SEAL IN GOOD CONDITION WITH NO WEAR. HELIUM SEAL WORN UNEVEN.
12	153-159	9	158.2		SAME AS BUILD 11	SAME HOUSING. NEW SEGMENTS B-3/B-9. MATING RING REPLATED	INSPECTION DUE TO INDICATION OF LEAKAGE AND ICING OF THE SEALS. LOX SEAL IN GOOD CONDITION. HELIUM SEAL WORN UNEVEN.
13	160-161	2	120		SAME AS BUILD 12	SAME SEAL AS BUILD 12. MATING RING FROM BUILD 11	COMPLETED SCHEDULED 5 HOURS TESTING. SEAL PERFORMANCE SATISFACTORY. LOX SEAL IN GOOD CONDITION EXCEPT CARBON DAM WORN. HELIUM SEAL CONDITION SAME AS BUILD 12.
14	162-176	15	62.3		NEW RAYLEIGH STEP CARBON P03N, P/N CF851218 S/N 05. NEW MATING RING S/N 01. INCREASED SPRING LOAD	SAME AS BUILD 13	TESTER BEARING FAILURE. LOX SEAL IN GOOD CONDITION EXCEPT CARBON DAM WORN. HELIUM SEAL CONDITION SAME AS BUILD 13.
15	177-222	46	211.3		REWORKED SEAL RING S/N 01. NEW MATING RING S/N 04	SAME AS BUILD 14	FIRE IN SEAL AREA. SEALS, TESTER AND FACILITY EXTENSIVELY DAMAGED. POSSIBLE SOURCES OF IGNITION INCLUDE CONTAMINATION AND RUBBING AT LOX SEAL. THE TESTER AND FACILITY WERE REPAIRED FOR CONTINUED TESTING.
16	223-232	10	28.5		NEW PHASE III RAYLEIGH STEP CARBON P692. P/N CF851218-1 S/N 01. VESPEL PISTON RING	NEW PHASE III FLOATING RING CARBON G84. P/N 99 RS006215, S/N 02/02. NEW INCO 903 Z MATING RING	HELIUM SEAL LOX SIDE RING SEIZED AND RUBBED GROOVE IN MATING RING. LOX SEAL IN GOOD CONDITION WITH NO WEAR.

TABLE 4. (Continued)

BUILD NO.	TESTS NO.	STARTS	TIME MINUTES	TEST OBJECTIVE	SEAL HARDWARE LOX SEAL	SEAL HARDWARE HELIUM SEAL	REMARKS
17	233-239	7	31.1	PHASE I LIQUID OXYGEN TESTING	SAME AS BUILD 16	NEW PHASE III FLOATING RING CARBON G84. P/N 99 RS006215, S/N 03/03. INCREASED CLEARANCE. NEW INCO 903 Z MATING RING	SCHEDULED INSPECTION. LOX AND HELIUM SEALS IN GOOD CONDITION WITH NO WEAR. SEAL PERFORMANCE SATISFACTORY.
18	240-259	20	204.8		SAME AS BUILD 17	SAME AS BUILD 17	INSPECTION DUE TO HIGH VIBRATION. TESTER BEARING FAILED. LOX SEAL IN GOOD CONDITION WITH NO WEAR. HELIUM SEAL IN GOOD CONDITION WITH SLIGHT WEAR. SEAL PERFORMANCE SATISFACTORY.
19	260-271	12	136.2		SAME AS BUILD 18	SAME AS BUILD 18 EXCEPT MATING RING REPLATED	INSPECTION DUE TO HIGH VIBRATION. TESTER BEARING FAILED. SEALS IN GOOD CONDITION WITH NO SIGNIFICANT WEAR. SEAL PERFORMANCE SATISFACTORY.
20	272-295	24	204.8		SAME AS BUILD 19	SAME AS BUILD 19 EXCEPT MATING RING BURNISHED TO CLEAN	COMPLETED PHASE I TESTING. TOTAL TIME 10 HOURS ON LOX SEAL AND 9.6 HOURS ON HELIUM SEAL. SEALS IN GOOD CONDITION WITH NO SIGNIFICANT WEAR. SEAL PERFORMANCE SATISFACTORY.
21	296-347	52	236.5	PHASE III LIQUID OXYGEN ACCELERATION	NEW PHASE III RAYLEIGH STEP CARBON P692, CF851218-1, S/N 02	NEW PHASE III FLOATING RING CARBON G84. P/N 99 RS006215, S/N 01/01. NEW INCO 903 Z MATING RING	INSPECTION DUE TO HIGH VIBRATION. HELIUM SEAL LOX SIDE RING SEIZED AND WORE GROOVE IN MATING RING. TURBINE SIOE RING RUBBED. LOX SEAL IN GOOD CONDITION.
22	348-417	70	313.6		SAME AS BUILD 21	NEW PHASE III FLOATING RING CARBON G84. P/N 99 RS006215, S/N 04/04. NEW INCO 903 Z MATING RING. INCREASED CLEARANCE	SCHEDULED INSPECTION. SEALS IN GOOD CONDITION WITH NO SIGNIFICANT WEAR. SEAL PERFORMANCE SATISFACTORY.
23	418-490	73	366.7		SAME AS BUILD 22. CARBON LAPPED	SAME AS BUILD 22. MATING RING CLEANED	COMPLETED PHASE III TESTING. TOTAL TIME 15.28 HOURS ON LOX SEAL AND 11.34 HOURS ON HELIUM SEAL. SEAL PERFORMANCE SATISFACTORY. LOX SEAL IN SATISFACTORY CONDITION WITH SLIGHT WEAR SPOTS. HELIUM SEAL IN GOOD CONDITION WITH NO SIGNIFICANT WEAR.
1	1-10	10	52.3	PHASE IV RAYLEIGH STEP LIQUID OXYGEN CHECKOUT	NEW PHASE IV RAYLEIGH STEP CARBON P692, P/N 5636-8, S/N 04. NEW MATING RING S/N 02	NEW PHASE IV 6 SEGMENT CARBON G84 RAYLEIGH STEP P/N 201001, S/N C3/C11. NEW INCO 903 Z MATING RING	COMPLETED PHASE IV CHECKOUT TEST. SEAL PERFORMANCE SATISFACTORY. SEALS IN GOOD CONDITION WITH NEGLIGIBLE WEAR.
2	11-77	67	299.6	PHASE IV RAYLEIGH STEP LIQUID OXYGEN ACCELERATION TESTING	SAME AS BUILD 1	SAME AS BUILD 1	SCHEDULED 5-HOUR INSPECTION. SEALS IN GOOD CONDITION WITH NO ADDITIONAL WEAR. SEAL PERFORMANCE SATISFACTORY.
3	78-133	56	302.8		SAME AS BUILD 2	SAME AS BUILD 2	COMPLETED RAYLEIGH STEP LOX SEAL TEST. TOTAL TIME 10.91 HOURS. SEALS IN GOOD CONDITION WITH NO ADDITIONAL WEAR. SEAL PERFORMANCE SATISFACTORY.
4	134-142	9	10.5	PHASE IV SPIRAL GROOVE LIQUID OXYGEN CHECKOUT	NEW BASIC INWARD PUMPING SPIRAL GROOVE MATING RING RS009696E, S/N 01. CARBON P692 RING, P/N 6563-1, S/N 01	NEW 6 SEGMENT CARBON G84 RAYLEIGH STEP P/N 201001, S/N C8/C10. NEW INCO 903 Z MATING RING S/N 6	EXCESSIVE LOX SEAL LEAKAGE. HEAVY RUBBING AND WEAR ON SPIRAL GROOVE SURFACE. HELIUM SEAL DAMAGED BY LOX SEAL FAILURE.
5	143-145	3	0.3	PHASE IV MOD I SPIRAL GROOVE LIQUID OXYGEN CHECKOUT	NEW MOD I INWARD PUMPING SPIRAL GROOVE MATING RING RS009696E, S/N 02. DECREASED ID CARBON RING P/N 6888-1, S/N 01	NEW 6 SEGMENT CARBON G84 RAYLEIGH STEP P/N 201001, S/N C1/C16. NEW INCO 903 Z MATING RING S/N 8	EXCESSIVE LOX SEAL LEAKAGE. RUBBING AND WEAR ON SPIRAL GROOVE SURFACE. HELIUM SEAL IN GOOD CONDITION.
6	146-169	24	34.3	PHASE IV MOD II SPIRAL GROOVE LIQUID OXYGEN CHECKOUT	NEW MOD II INWARD PUMPING SPIRAL GROOVE (NARROW DAM, DEEPER GROOVES) RS009696E-1, S/N 03. CARBON RING P/N 6888-1, S/N 02	SAME AS BUILD 5	LOX SEAL PERFORMANCE SATISFACTORY AT 1034 kPa (150 psia). SUDDEN INCREASE IN LEAKAGE AT 1724 kPa (250 psia). RUBBING AND WEAR ON SPIRAL GROOVE SURFACE. HELIUM SEAL IN GOOD CONDITION.

TABLE 4. (Concluded)

BUILD NO.	TESTS NO.	STARTS	TIME MINUTES	TEST OBJECTIVE	SEAL HARDWARE		REMARKS
					LOX SEAL	HELIUM SEAL	
7	170-176	7	45.3	PHASE IV MOD III SPIRAL GROOVE LIQUID OXYGEN CHECKOUT	NEW MOD III INWARD PUMPING SPIRAL GROOVE (OPTIMIZED DESIGN) RS009696E-2, S/N 04, CARBON RING 6888-1 P/N 6888-1, S/N 03	SAME AS BUILD 6	EXPLOSION AND FIRE IN SEAL AREA. SEALS AND TESTER EXTENSIVELY DAMAGED. MOST PROBABLE CAUSE WAS RUBBING AT LOX SEAL. THE PHASE IV TESTING WAS TERMINATED. THE TESTER AND FACILITY WERE REPAIRED AND MODIFIED FOR PHASE V TESTING.
1	1-31	31	24.3	PHASE V LIQUID NITROGEN CHECKOUT	NEW PHASE V PRESSURE BALANCED OUTWARD PUMPING SPIRAL GROOVE MATING P/N 7R0012691-7, S/N 01 CARBON P5N RING P/N 7R0012691-11, S/N 01	NEW PHASE V SEGMENTED CARBON RAYLEIGH STEP RES 1377 S/N 2/3	SEALS DAMAGED BY TESTER OVERSPEED. LOX SEAL RUBBED AND WORN AT THREE SPOTS. HELIUM SEAL RAYLEIGH PADS WORN OFF.
2	031-048	17	34.3		NEW PHASE V PRESSURE BALANCED OUTWARD PUMPING SPIRAL GROOVE MATING RING P/N 7R0012691-7, S/N 03 CARBON P5N RING, P/N 7R0012691-11, S/N 02	NEW SEGMENTS WITH SAME HOUSING AS BUILD 1, RES 1377 S/N 4/1	INBOARD SLAVE SEAL WORE GROOVE IN MATING RING. LOX SEAL IN GOOD CONDITION WITH NEGLIGIBLE WEAR. HELIUM SEAL LIFT PADS WORN OFF AND TWO SEGMENTS WERE BROKEN ON TURBINE SIDE. LOX SIDE SEGMENTS IN GOOD CONDITION. SEAL PERFORMANCE SATISFACTORY.
3	049-071	23	25.2		SAME AS BUILD 2	SAME AS BUILD 2, EXCEPT NEW SEGMENTS S/N 9/7 AND NEW MATING RING	INBOARD SLAVE SEAL WORE GROOVE IN MATING RING. LOX SEAL IN SATISFACTORY CONDITION WITH NO SIGNIFICANT WEAR ON MATING RING AND SLIGHT WEAR ON THE SEALING DAM. HELIUM SEAL LIFT PADS WORN OFF. SEAL PERFORMANCE SATISFACTORY. PROGRAM TERMINATED DUE TO INSUFFICIENT FUNDS.

Investigation revealed that the seals did not develop the necessary hydrodynamic lift to maintain a fluid film at the seal interface due to the tester rotation being in the wrong direction. Corrective action was taken to ensure proper rotation on subsequent tests.

Build 2 Assembly

The tester was rebuilt with a new LOX seal, serial number 067302, reworked to reduce the spring load to 44.5 N (10 lb) by installing 10 springs for additional margin against rubbing contact. The anti-rotation tang clearance was increased 0.013 cm (0.005 in.) to prevent possible binding which could affect the seal dynamic response. The piston ring lead-in chamfer was increased from 36 to 45 degrees to prevent breaking the piston ring at installation. A new piston ring with the stronger joint design was installed by Stein Seal Company during their rework to correct dimensional discrepancies.

Installation of the new LOX seal with the unused side of mating ring 067301 resulted in excessive leakage due to warpage caused by severe rubbing during test 001. The static leakage with new mating ring 067302 was satisfactory.

Helium seal serial number 001 was rebuilt with the same housing and a new set of reworked segments (A-2 and A-8); however, the static leakage with a new mating ring, serial number 002, was excessive. Inspection revealed a visible light gap between the segments and the mating ring. A new seal, serial number 002, with discrepant recess pads was installed and the leakage was satisfactory. It was agreed to test with seal 002 pending resolution of the leakage problem on the reworked segments.

Surface profile traces of the inside radius on the reworked helium seal carbon segment A-2-2 revealed that the segment radius varied by approximately 0,0005 cm (0.0002 in.) from a true radius of 4.986 cm (1.9630 in.). Measurement of segment A-4-3 from the second reworked set indicated closer alignment to a true radius of 4.989 cm (1.9642 in.).

Tests 002 - 003

Test 002 was terminated after 56 seconds because the speed would not exceed 12,000 rpm. The tester operation and seal performance was satisfactory. Reversing the direction of rotation resulted in a speed control problem due to electrical feedback in the motor wiring. The motor was modified to correct the problem.

Test 003 was run for a scheduled duration of 5 minutes to allow inspection of the seals to check for rubbing before excessive wear occurred. The tester accelerated to 23,000 rpm within 2 seconds when the motor was started and stabilized at 20,000 rpm for the remainder of the test. The helium seal leakage increased suddenly at start and pegged the chart in excess of 0.0023 m^3/s (5 SCFM) for the entire test. The helium seal purge pressure decreased at start indicating a sudden increase in leakage. The LOX seal leakage appeared to be constant at approximately 0.0014 m^3/s (3 SCFM) for both pretest static and operating. The posttest static leakage was excessive on both seals.

Build 2 Disassembly

Seal inspection revealed that the helium seal carbon segments were broken at most of the joints and through the section at the first pad feed groove on each set. The inside radius of the segments showed slight even contact with negligible wear. The mating ring surface showed only a slight trace of rubbing contact.

The LOX seal rubbed slightly at the outer edge of the recess pads; however, the wear was negligible. The mating ring had a slight contact pattern which was heavier at the outer edge but no wear.

Investigation indicated that small chips of carbon had broken loose from the edge of the LOX seal recess pads and had been smeared around the outer edge causing the wear. The surface profile traces indicated that the seal face wear was even across the face. The wear at the outer edge of the pads was approximately 0.0003 cm (0.000125 in.). Touching the seal face to a lapping plate also confirmed that the face was flat.

The LOX seal carbon material was changed from P03N to P692 on the Phase III hardware to reduce the carbon chipping problem.

Build 3 Assembly

The LOX seal was relapped to pick up even contact around the outer edge of the recess pads, but not to clean up the wear groove. The mating ring was cleaned to remove the carbon pattern.

The failed helium seal was sent to Koppers Company for failure analysis. A replacement seal was assembled using housing 001, and reworked segments A-4 and A-6. It was agreed to test the reworked segments with the excessive leakage to determine if the segments would wear-in to conform to the mating ring.

Test 004

The tester was started twice for a total time of 15 minutes and 40 seconds. The first start was cut at 40 seconds because of the speed chart reading twice the actual speed. The actual speed came in at 25,000 rpm and was adjusted to 12,500 rpm at cut-off. The second start was constant at 25,000 rpm for 15 minutes. The LOX seal presure was 1034 kPa (150 psig) and the helium seal pressure 241 kPa (35 psig).

The LOX seal leakage increased from 0.109:a3/s (3.9 SCFM) static to 0.193 m^3/s (6.9 SCFM) at the first start and leveled off at 0.159 m^3/s (5.7 SCFM) before cut. The leakage spiked at the second start then dropped to about 0.252 m^3/s (9 SCFM) and held steady.

The helium aeal purge inlet leakage increased from 0.246 m^3/s (8.8 SCFM) static to about 0.280 m^3/s (10 SCFM) at the first start and held steady until cut-off. The purge leakage increased to 0.0056 m^3/s (12 SCFM) at the second start and held steady until the purge pressure was vented after cut-off.

The post test LOX seal static leakage was 0.154 m^3/s (5.5 SCFM) compared to 0.070 m^3/s (2.5 SCFM) pretest. The helium seal static leakage was approximately the same, pre- and posttest.

Build 3 Disassembly

Seal inspection revealed that the helium seal carbon segments were broken in several places through the sections and at the joints. The broken sections of the segments were polished at the inside radius indicating slight rubbing contact. The helium seal mating ring showed only a slight trace of rubbing contact.

The LOX seal had rubbed and worn the carbon face 0.00127 cm (0.0005 in.). The recess depth varied from near zero to about 0.0005 cm (0.0002 in.). The face wear was even, as indicated by the contact pattern and surface profile traces. The carbon wear debris was accumulated at the end of the recess pads.

The LOX seal mating ring showed a heavy rub pattern in the pad area and a spotted pattern in the dam area. The surface profile traces indicated that the mating ring surface was still flat and not worn except the spots at the seal dam were slightly lower than the surface. It is suspected that the spots were higher during operation causing slight wear.

Investigation of the helium seal failure indicated excessive movement of the segments relative to the seal housing. The carbon contact pattern on the housing side plate showed abnormally large radial motions in the order of 0.0127 to 0.178 cm (0.005 to 0.007 in.). There was also evidence that the garter spring had contacted the inside diameter of the seal housing. The garter-spring-to-housing clearance is greater than the mating-ring-to-housing clearance; therefore, it is not possible to bottom out the segments by radial shaft deflection.

It is suspected that either violent shaft motion or fluid dynamics overloaded the carbon segments and caused the breakage. Experience indicates that high speed shaft runouts in excess of 0.013 cm (0.005 in.) can cause similar failures due to the inertia and impact loads which result when the segments attempt to follow the eccentric motion.

The helium seal design was changed from a three-segment design to a six-segment design to increase the strength of the segments. The material was changed from G84 to P5N for higher strength. Consideration was given to increase the garter spring and wave spring loads to improve dynamic stability, relocating the anti-rotation pin to reduce the friction load and changing the joint closure to a step joint design.

Build 4 Assembly

The tester was instrumented to measure the shaft deflection at the helium seal mating ring by removing the helium seal and installing an adapter ring with two Bently displacement transducers located 90 degrees apart.

The LOX seal was modified to reduce the spring load from 44.5 N (10 lb) to 31.1 N (7 lb) to eliminate rubbing contact and carbon face wear. The shaft sleeve shoulder which locates the LOX seal mating ring was lapped flat within three helium light bands to eliminate the possibility of uneven loading. The LOX seal mating ring flatness was checked in the assembled position to ensure that it was not being distorted by the assembly.

Tests 005 - 007

The speed was increased gradually to 32,550 rpm and the displacement transducers indicated a critical speed at 19,000 rpm with 0.030 cm (0.012 in) peak-to-peak deflection. The following shaft deflections were measured at the helium seal mating ring:

Speed, rpm	Deflection, cm	Peak-to-Peak, inch
12,000	0.0025	(0.001)
15,000	0.0025	(0.001)
19,000	0.0304	(0.012)
22,000	0.0076	(0.003)
27,000	0.0107	(0.0042)
32,000	0.0140	(0.0055)

The motor speed adjustment was preset for 32,000 rpm. The motor was started and the speed accelerated to 32,725 rpm within 2 seconds. The shaft deflection increased suddenly from 0.0102 cm (0.004 in.) peak-to-peak at 22,000 rpm up to 0.107 cm (0.042 in.) peak-to-peak at 26,400 rpm where the transducer signal was lost.

Posttest inspection revealed the shear neck on the tester drive coupling was sheared. The tester shaft was loose and the bearings were rough. The displacement transducers, which had been installed with 0.076 cm (0.030 in.) radial clearance, were damaged from rubbing contact.

Build 4 Disassembly

Inspection revealed that the drive end bearing failed from an excessive rotating radial load. The radial load had exceeded the axial load, which caused the balls to run down on the inner race and wear a groove approximately 180 degrees around the race. The bearing apparently was damaged by the rotating radial load resulting from operation at or near the critical speed. The forward end bearing was in good condition.

A critical speed analysis of the tester rotating parts and drive coupling system indicated that the calculated second critical speed is approximately the same as the measured critical speed. The analysis indicated that the system should be satisfactory for operation at the required 32,000 rpm test point.

It was agreed to delete the 20,000 rpm and 25,000 rpm checkout test points to avoid the tester critical speed. The tester will be accelerated through the 19,000 rpm critical and operated at 32,000 rpm to eliminate excessive shaft deflection which could damage the bearings and seals.

Build 5 Assembly

The tester was rebuilt with new bearings and improved balance. All rotating parts were balanced and indexed to the shaft to maintain balance at reassembly. The drive coupling was also balanced.

Test 008

A normal fast start test was performed with two Bently displacement transducers installed in place of the helium seal. The high frequency data indicate that the tester bearing failed at approximately 2.0 seconds and 27,000 rpm during the start transient. A plot of the shaft peak-to-peak deflection vs speed (Fig. 47) indicates that the deflection started to increase at 20,000 rpm and reached 0.221 cm (0.087 in.) maximum at 27,000 rpm when the signal was lost. It is theorized that the bearing failed as the tester accelerated through the critical speed.

Build 5 Disassembly

Inspection revealed that the drive end bearing was failed from an excessive rotating radial load. A groove was worn approximately 180 degrees around the bearing inner race similar to the failure on Test 007. The Bently transducers, which had been installed with 0.127 cm (0.050 in.) radial clearance, were damaged from rubbing contact. The LOX seal was damaged from rubbing contact with the shaft sleeve on the inside of the housing. The housing was distorted causing the seal to bind-up and overload the seal face. The LOX seal mating ring was heavily rubbed from the face overload.

The results of the investigation indicate that the most probable causes of the excessive tester shaft deflection were loose tester facility mounts and excessive misalignment of the tester shaft and drive motor gearbox output shaft. The loose mounts and misalignment apparently caused the excessive rotating radial load which deflected the tester shaft and failed the bearings.

The facility mount was reworked by replacing the spherical bearings and cylindrical adapters with heavy gusset plates to provide a rigid mount for the tester mounting pins. The facility mounting frame was welded to the adjacent structure to provide a rigid base for the mounting adapter. The tester was realigned and rechecked at chilldown. The results indicated no significant change in alignment due to chilldown.

Build 6 Assembly

The tester was assembled for start testing without the LOX seal and with two Bentlys installed in place of the helium seal to measure shaft deflection.

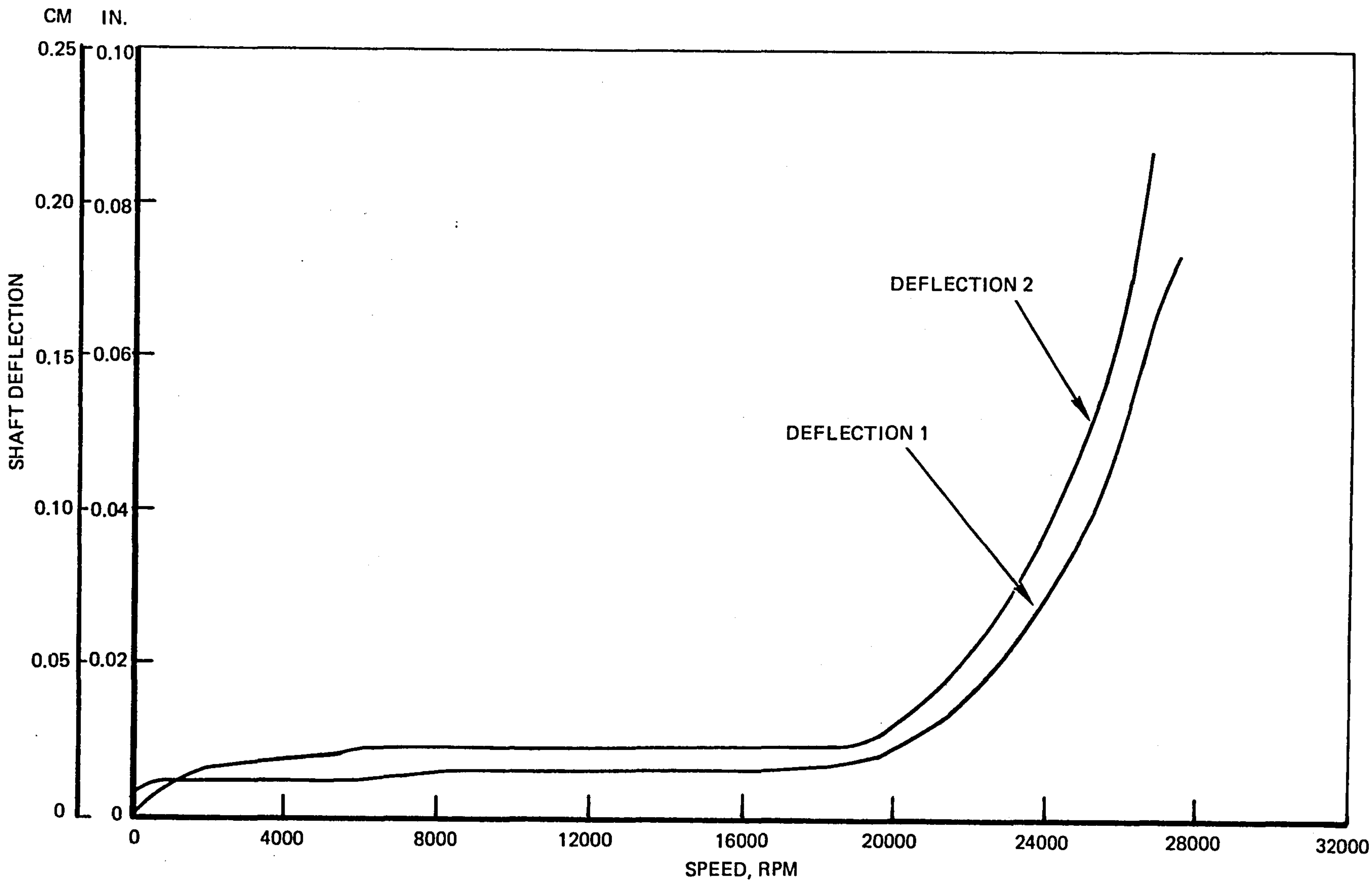


Figure 47. NASA Seal Tester Shaft Deflection vs Speed, Test 008

Test 001 - 002 (CTL1-4B, 1974)

Gradual and fast start tests to measure tester shaft deflection. The results (Fig. 48) indicate satisfactory tester operation.

Build 6 Disassembly

Inspection of the tester and bearings revealed the hardware to be in good condition. Review of the test data indicated satisfactory tester operation and shaft deflection; therefore, the LOX and helium test seals were installed for continuation of the gaseous nitrogen checkout testing.

Build 7 Assembly

The LOX seal was assembled using housing part number CF 851217, serial number 067304, and new seal composite ring part number CF 851218, serial number 067303. The spring load at the installed length of 2.413 cm (0.950) inch measured 30.2 N (6.8 lb) with seven springs installed.

The helium seal was assembled using housing serial number 003 and new segments A-8 and A-2 which had been reworked by Koppers Company to remachine the recess pads with a straight bore.

Test 003

Gaseous nitrogen checkout test scheduled for 15 minutes at 32,000 rpm with 1034 kPa (150 psig) LOX seal GN_2 pressure and 241 kPa (35 psig) helium seal pressure. A normal fast start was made. The speed accelerated to 32,000 rpm within 3 seconds and was steady until the test was terminated at 24 seconds due to a sudden increase in tester vibration level. The high frequency data revealed that the vibration level was steady at 3 to 4 gs peak-to-peak through the start transient and during the test until it suddenly spiked up to a maximum of 70 gs. All other test data appeared to be satisfactory.

Build 7 Disassembly

Inspection revealed that the helium seal carbon segments and the outboard slave seal carbon seal ring were broken due to excessive tester shaft deflection. The helium seal mating ring rubbed the inside diameter of the helium seal housing, indicating shaft radial displacements of approximately 0.076 to 0.102 cm (0.030 to 0.040 in.) maximum. The mating ring contact pattern indicated satisfactory operation prior to the breakage.

The LOX seal was in good condition. The mating ring indicated uniform contact across the seal face with a slight contact pattern at the inner and outer edges. The carbon face contact pattern was slightly polished and uniform, indicating satisfactory operation.

The tester bearings were in good condition, except the contact pattern on the balls indicated that the axial load was insufficient to maintain radial

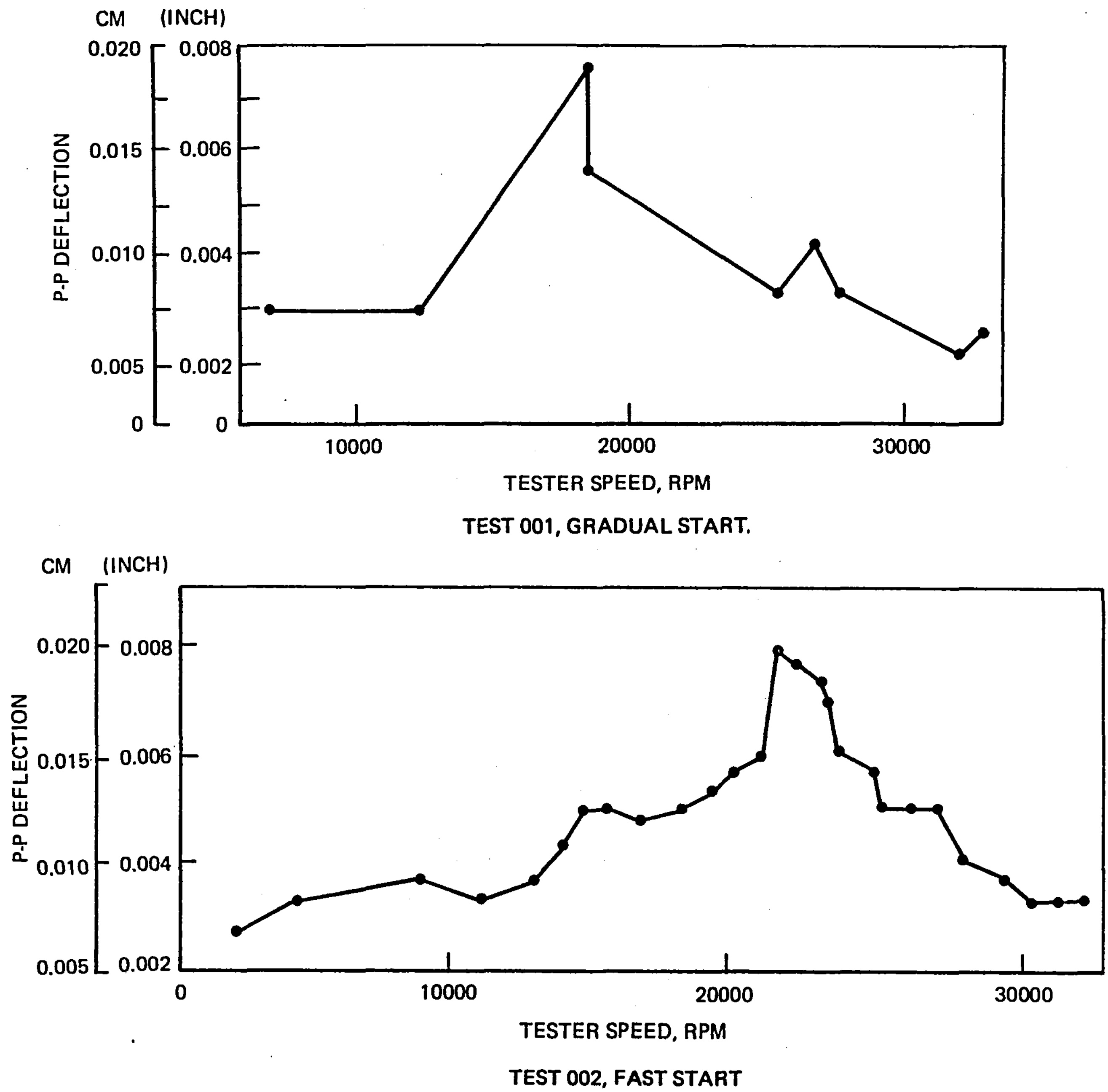


Figure 48. Tester Shaft Peak-to-Peak Deflection

alignment. Investigation indicates that the bearings ran in the unloaded position with increased radial clearance, which allowed the shaft to rotate in an eccentric path and resulted in a progressively higher rotating radial load as the shaft deflection increased.

The tester was reworked to replace the bearing axial load piston with preload springs. The bearing axial load was increased from 200 pounds minimum to 300 pounds minimum to ensure sufficient preload to maintain radial alignment.

It was decided to perform the remainder of the testing at Wyle Laboratories, Norco to allow the use of a close-coupled tester drive to eliminate the possibility of the existing long coupling causing excessive tester shaft deflection. The tester drive system was modified (Fig. 49) to utilize a turbine with a short 5.08 cm (2 in.) spline drive coupling to the tester to drive the tester. A critical speed analysis of the complete rotating system including the turbine, coupling shaft and tester was performed. The following critical speeds were calculated:

First Critical = 20,589 rpm
Second Critical = 24,372 rpm
Third Critical = 75,418 rpm

The analysis indicates that the tester and drive system critical speeds are satisfactory for operation at 32,000 rpm. The deflection mode shapes indicate that the first critical speed is the only one which results in deflection of the tester shaft. It will be necessary to accelerate through the first and second critical speeds to reach the operating speed; however, this is considered standard practice on other rotating machinery.

Tester Checkout Testingr Wyle Laboratories

A total of 75 checkout tests was performed on the modified tester and turbine drive without the seals installed. Satisfactory operation of the tester for two 15 minute tests at 32,000 rpm was demonstrated. Analysis of the high frequency data from the tester checkout tests indicated that the tester shaft deflection at the helium seal mating ring is a maximum of 0.0172 cm (0.0068 in.) peak to peak at the 18,000 rpm critical speed and 0.0096 cm (0.0038 in.) peak to peak at a steady state speed of 33,000 rpm (Fig. 50).

Build 8 Assembly

The LOX seal assembly, Part Number CF 851216, Serial Number 03, was assembled using housing Part Number CF 851217, Serial Number 067301, and relapped seal at the installed length of 2.418 cm (0.952 in.) measured 27.6 N (6.2 lb) with seven springs installed and 0.246 cm (0.097) in. compression. A typical surface profile trace of the seal face is shown in Fig. 51. Replated LOX seal mating ring Part Number 067301 was installed. The mating ring optical flatness was two helium light bands prior to installation and five bands after installation.

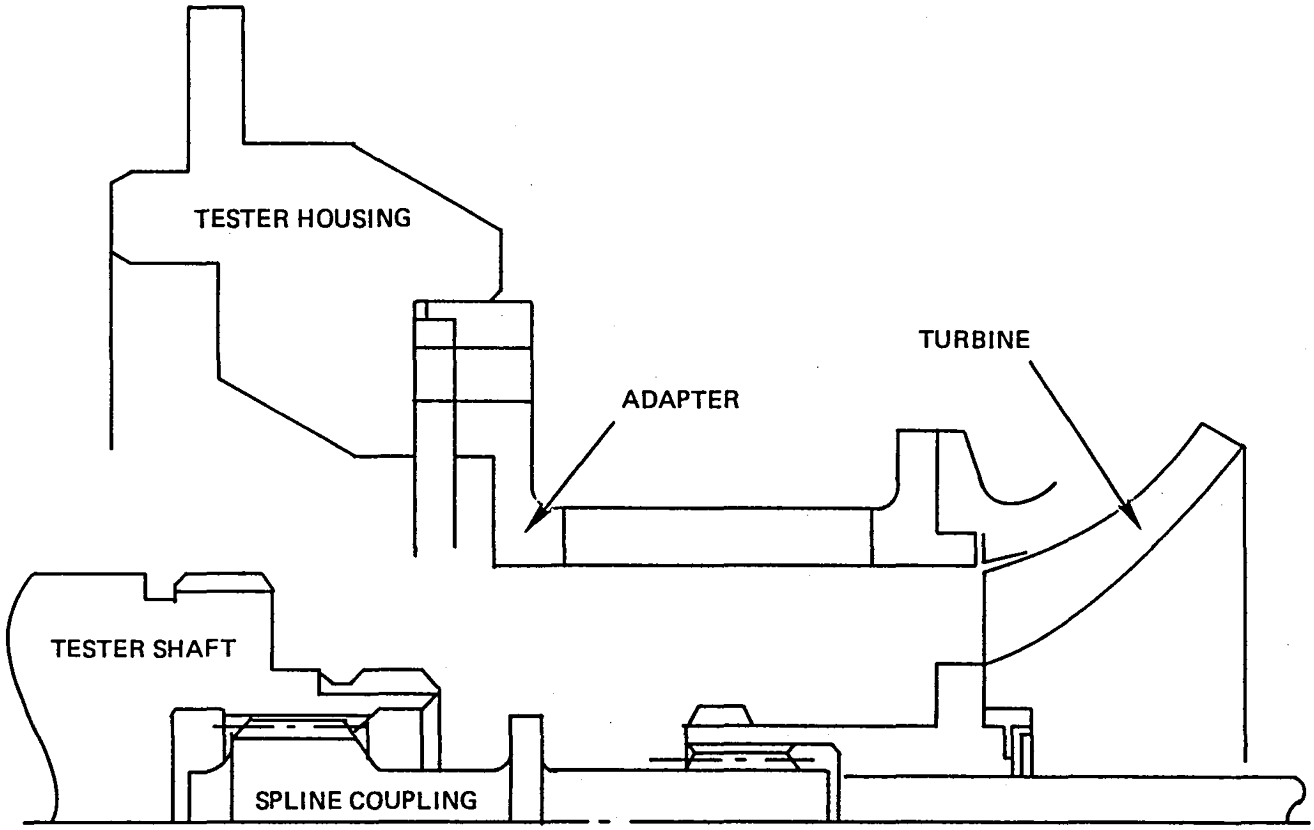


Figure 49. Modified Tester Drive With Close Coupled Turbine

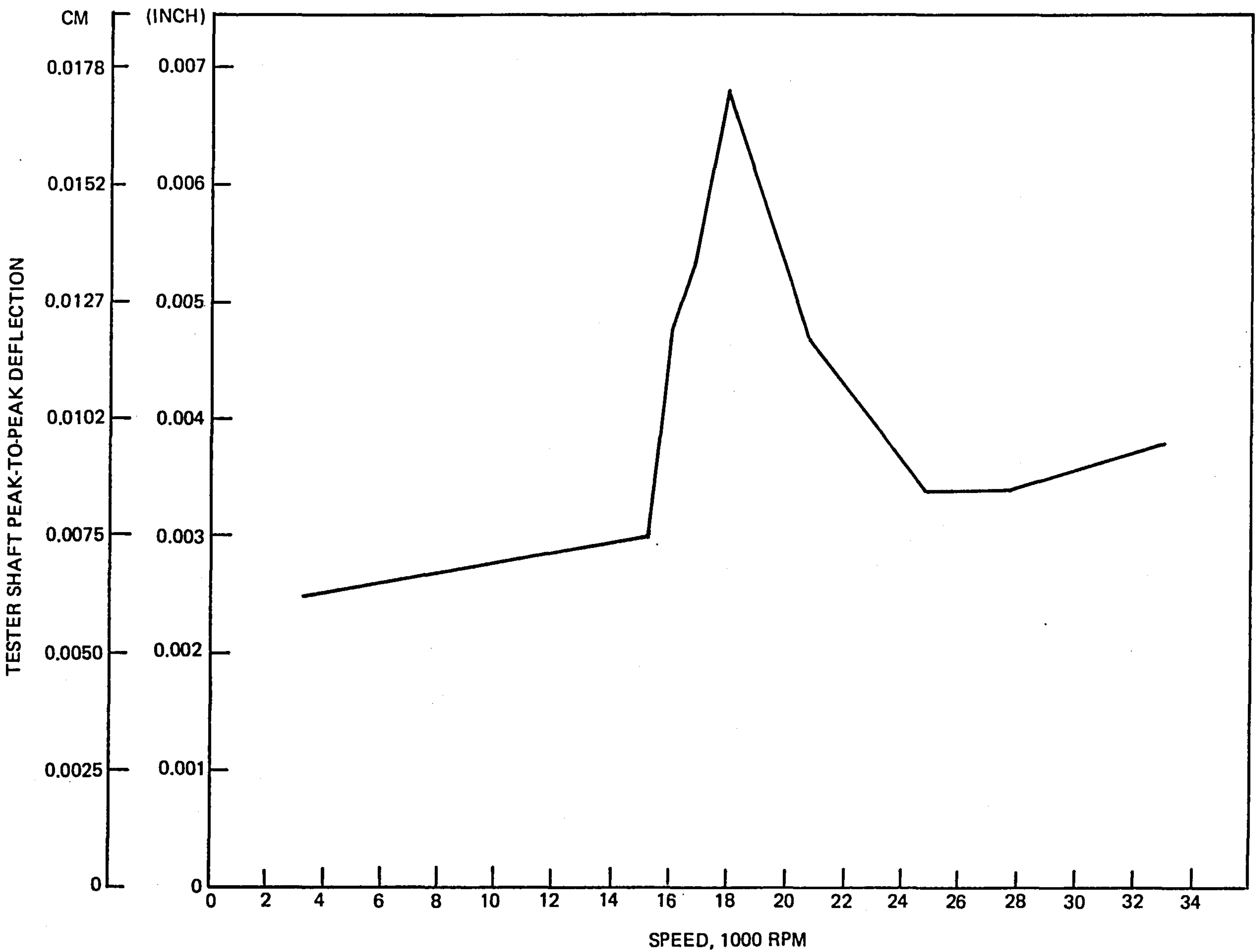


Figure 50. Tester Shaft Peak-to-Peak Deflection at Helium Seal Mating Ring With Close Coupled Turbine Drive System

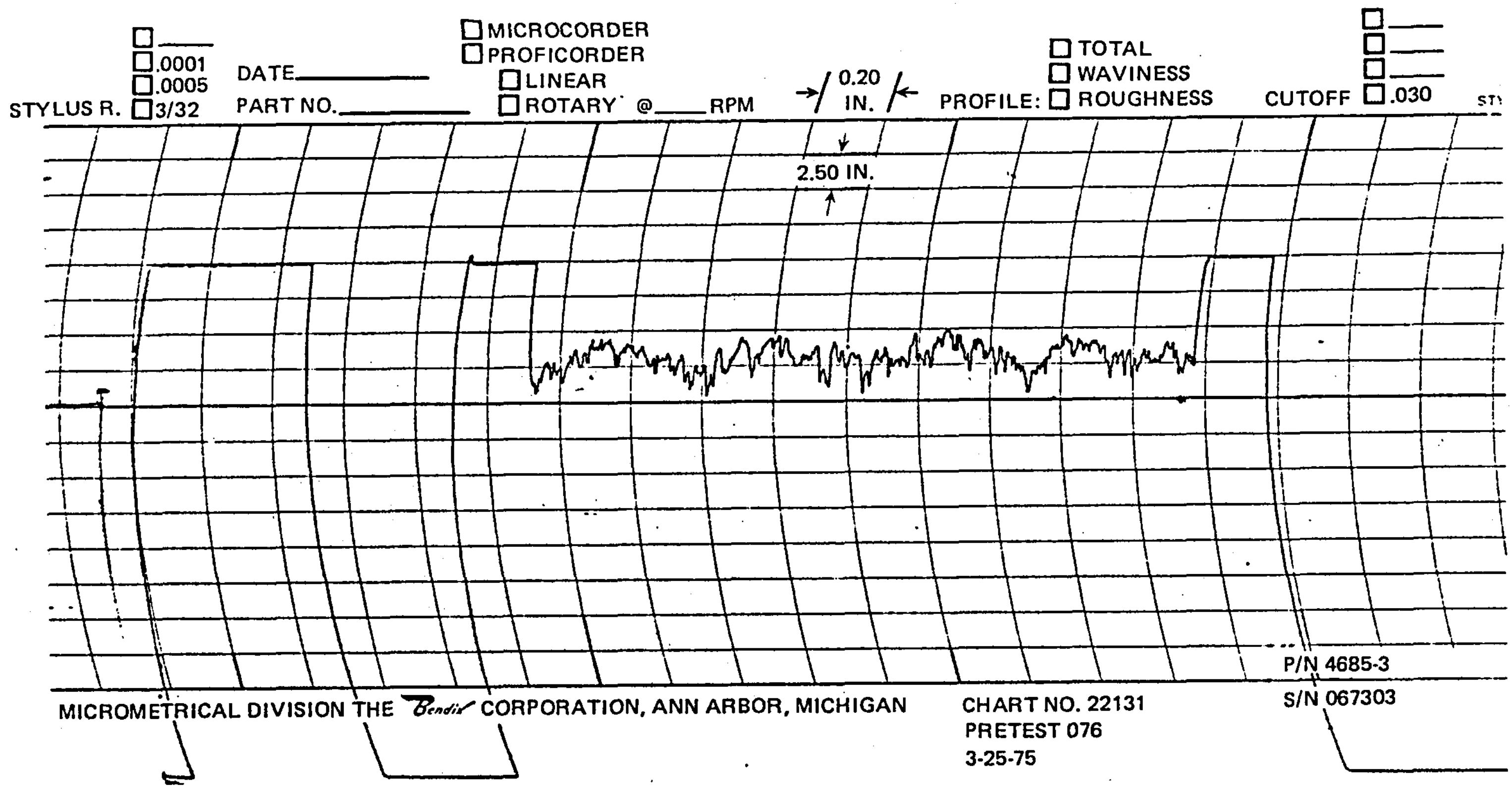


Figure 51. Typical Surface Profile Trace of LOX Seal Face, P/N CF851218, S/N 067303

The helium seal was assembled using housing Part Number CB120673, Serial Number 001, modified for six-segment seal rings. Figure 52 shows the hydrodynamic lift pads of the six carbon segments of seal rings B-5 and B-10. Figure 53 shows the B-5 seal ring assembly.

Tests 076 - 103 (Wyle Laboratories)

A total of 27 gaseous nitrogen checkout tests with 1034 kPa (150 psig) on the LOX seal and 345 kPa (50 psig) on the helium seal were performed. Most of the tests were less than 1 minute in duration and were terminated because of speed control problems. The seal performance was satisfactory.

Investigation of the speed control and speed decay problem indicated that moisture in the turbine drive air was freezing and icing up the turbine. The pressure ratio across the turbine causes the outlet temperature to drop below freezing. The lower temperature freezes the moisture in the air and results in ice build-up in the turbine. The ice build-up in the turbine nozzles and on the turbine wheel apparently causes the erratic speed control and speed decay problem. The turbine drive gas was changed from compressed air to gaseous nitrogen to eliminate the icing problem.

Build 8 Disassembly

The tester inspection revealed that the tester was in good condition with nothing being found which would explain the speed problem.

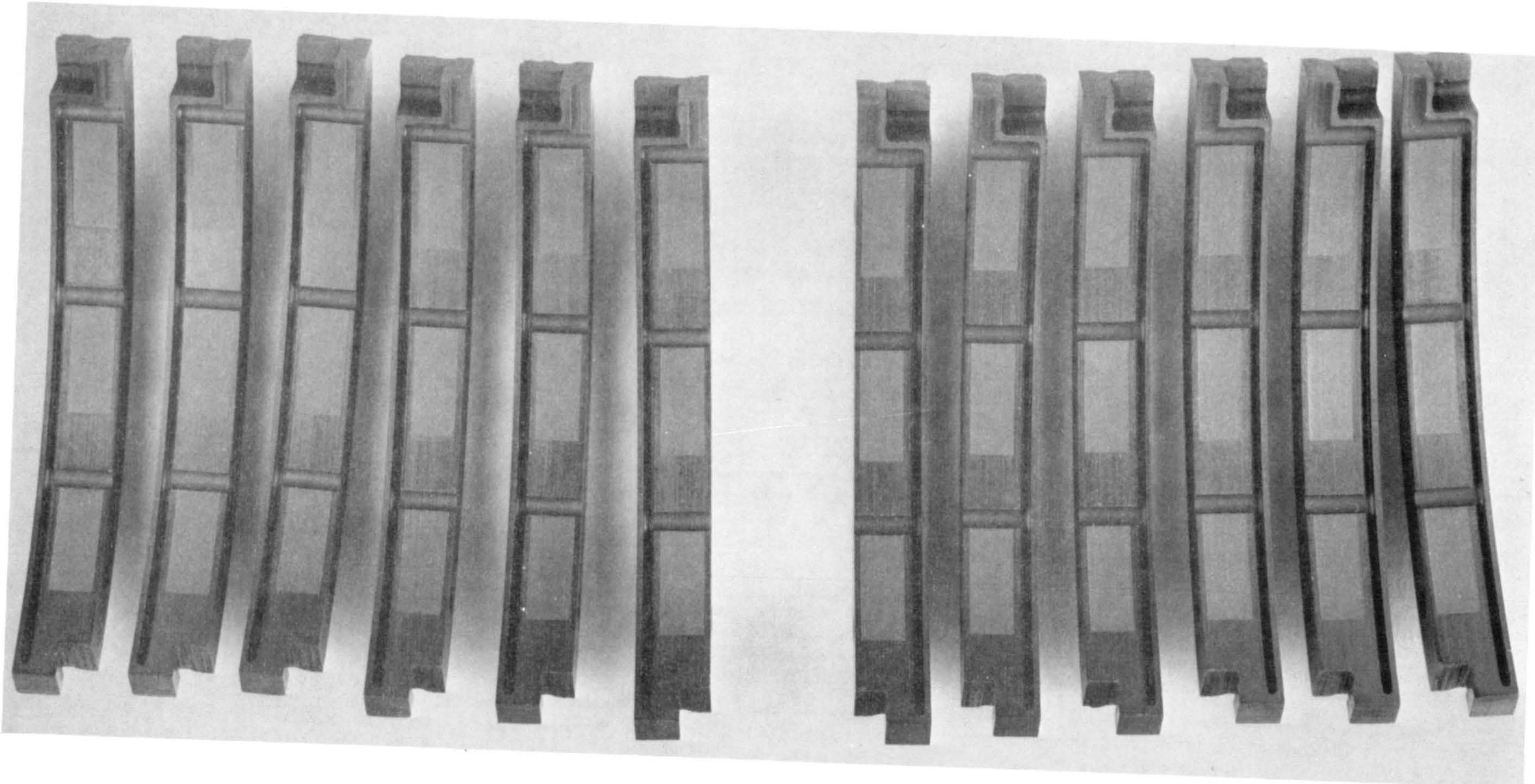
The LOX seal was in good condition with no measureable wear and only a very slight contact pattern on the carbon sealing face and the mating ring.

The helium seal was in good condition except for uneven wear across the carbon sealing faces. The LOX side carbon segments were worn 0.0026 cm (0.00103 in.) on the inner land and the turbine side segments were worn 0.0026 cm (0.00102 in.) on the seal dam and outer land (Fig. 54). The recess pads were nearly worn away. The mating ring pattern indicated slight rubbing contact. The uneven carbon wear indicates that the mating ring is running in a conically distorted condition with the LOX side smaller.

The posttest helium seal static leakage was high on the turbine side because the sealing dam was worn down below the pad surface.

Build 9 Assembly

The tester was reassembled using the hardware removed following Test 103. An operating change in the helium seal inlet pressure was made in an attempt to lower the seal wear during tester acceleration. The initial helium seal pressure was 0 psig at start, then increased to 243.25 kPa (35 psig) as the tester reached operating speed.



SEGMENTS B-5-1 THROUGH 6

SEGMENTS B-10-1 THROUGH 6

Figure 52. Helium Seal Carbon Rings CB 120673

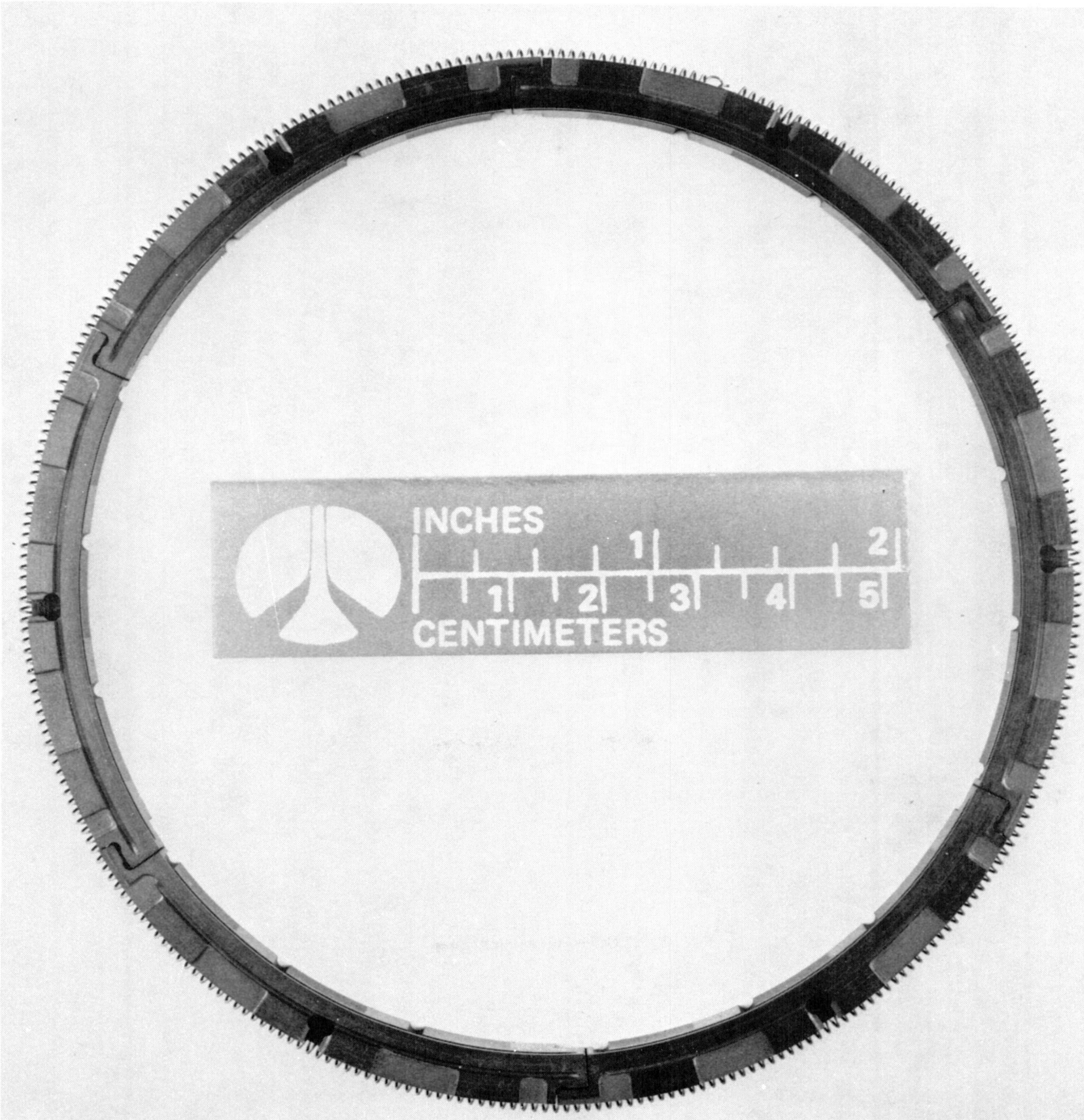
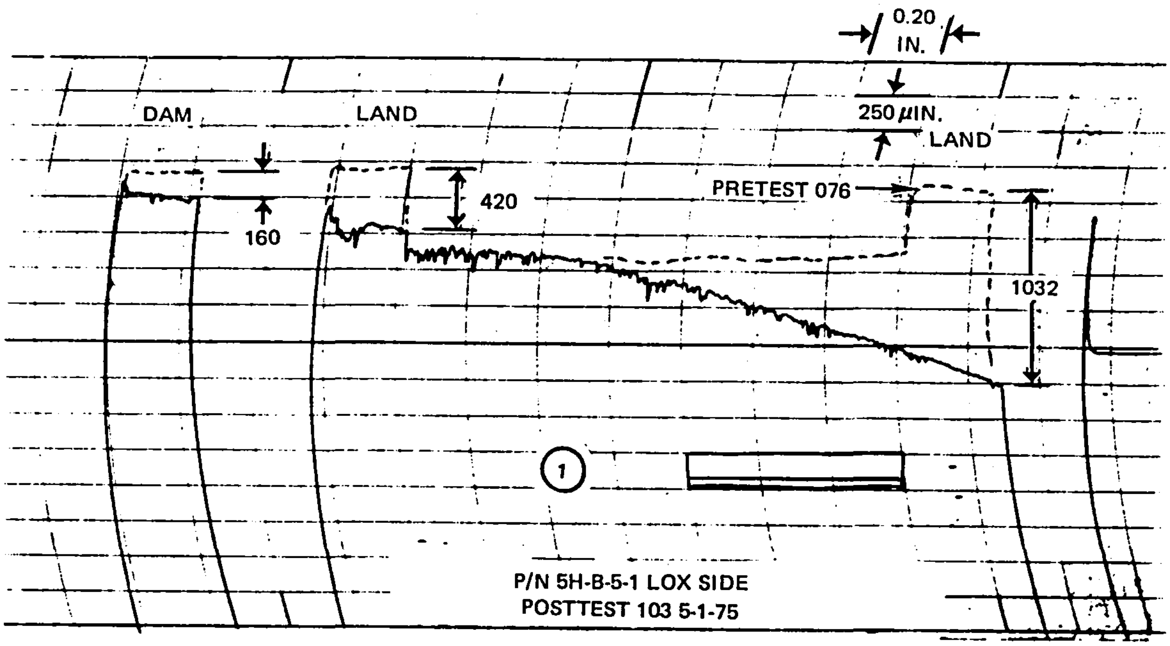


Figure 53. Assembled Six-Segment Helium Seal Ring, Segments B-5



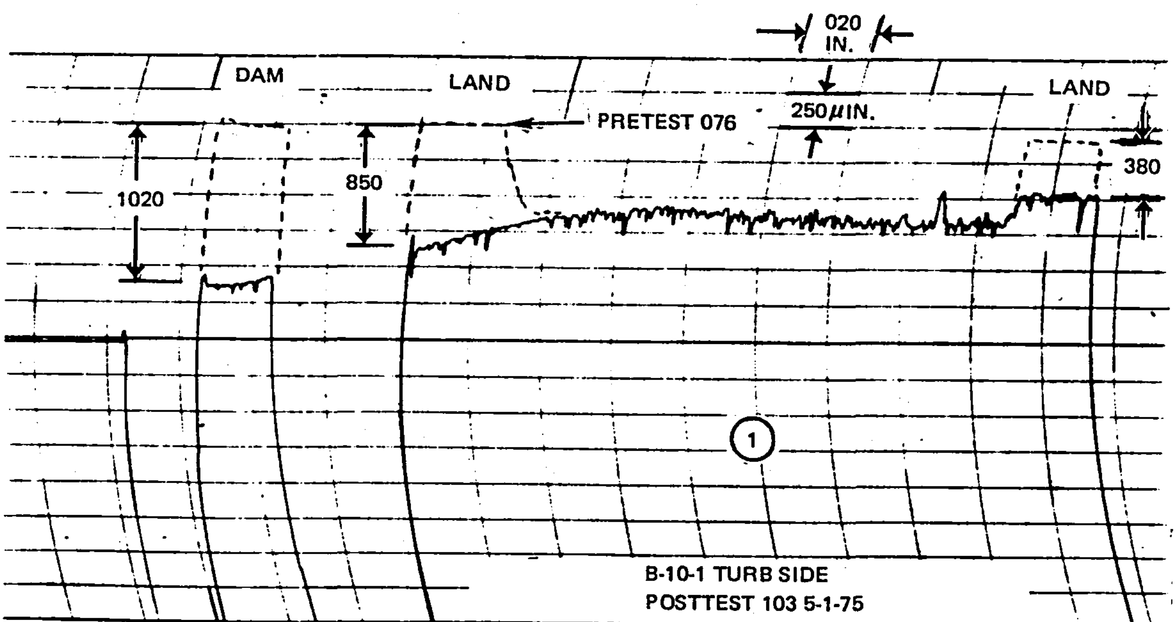


Figure 54. Typical Profile Trace of Helium Seal CB120673, S/N001, Posttest 103

Tests 104 - 132

The Phase I gaseous nitrogen checkout testing was completed. A total of 29 tests for 85.8 minutes was performed at pressures from 1034 to 2413 kPa (150 to 350 psia). The seal leakage rate varied from 0.0056 to 0.0093 m^3/s (12 to 20 SCFM).

Build 9 Disassembly

The LOX seal was in good condition with no measurable wear and only a slight contact pattern. Photographs of the seal and mating ring are shown in Fig. 55 through 58.

The helium seal was in good condition except for the same uneven wear across the carbon sealing faces which was present at the posttest 103 inspection. The LOX side segment B-5-1 did not show any significant additional wear posttest 132. The turbine side segment B-10-1 showed 0.0013 cm (0.0005 in.) additional wear in the same tapered direction posttest 132. The recess pads were worn away on both the LOX and turbine side segments. Photographs of the seal segments and mating ring are shown in Fig. 59 and 60.

Investigation of the helium seal uneven wear problem indicates that the segment wear is caused by the mating ring running in a conically distorted condition with an increasing diameter toward the turbine side. The mating ring distortion is apparently caused by the combined thermal and centrifugal loading.

The Phase III helium seal mating ring design was revised to minimize the operating distortion by reducing the thickness of the center web from 0.381 to 0.178 cm (0.150 to 0.070 in.) and moving the web toward the turbine side to balance the thermal and centrifugal loads.

PHASE I LIQUID OXYGEN TESTING

Build 10 Assembly

The tester was assembled for the LOX testing using the same LOX seal (S/N 03) and spring load used for the gaseous nitrogen testing. The seal was in good condition with no measurable wear, and did not require lapping or rework. The helium seal was rebuilt using the same housing (S/N 01) and new carbon segments (S/N B-1/B-7) for the LOX testing. A new Phase I helium mating ring, reworked to the Phase III configuration by reducing the thickness of the center web from 0.381 cm (0.150 in.) to 0.178 cm (0.070 in.) with the web moved toward the turbine side to balance the thermal and centrifugal loads, was used for the LOX testing in an attempt to reduce the uneven carbon segment wear.

Tests 133 - 139

The Phase I, Test Schedule II, Cryogenic Temperature Testing with liquid oxygen, was initiated. A total of seven tests was made at test point 1 conditions with an accumulated time of 10.4 minutes.

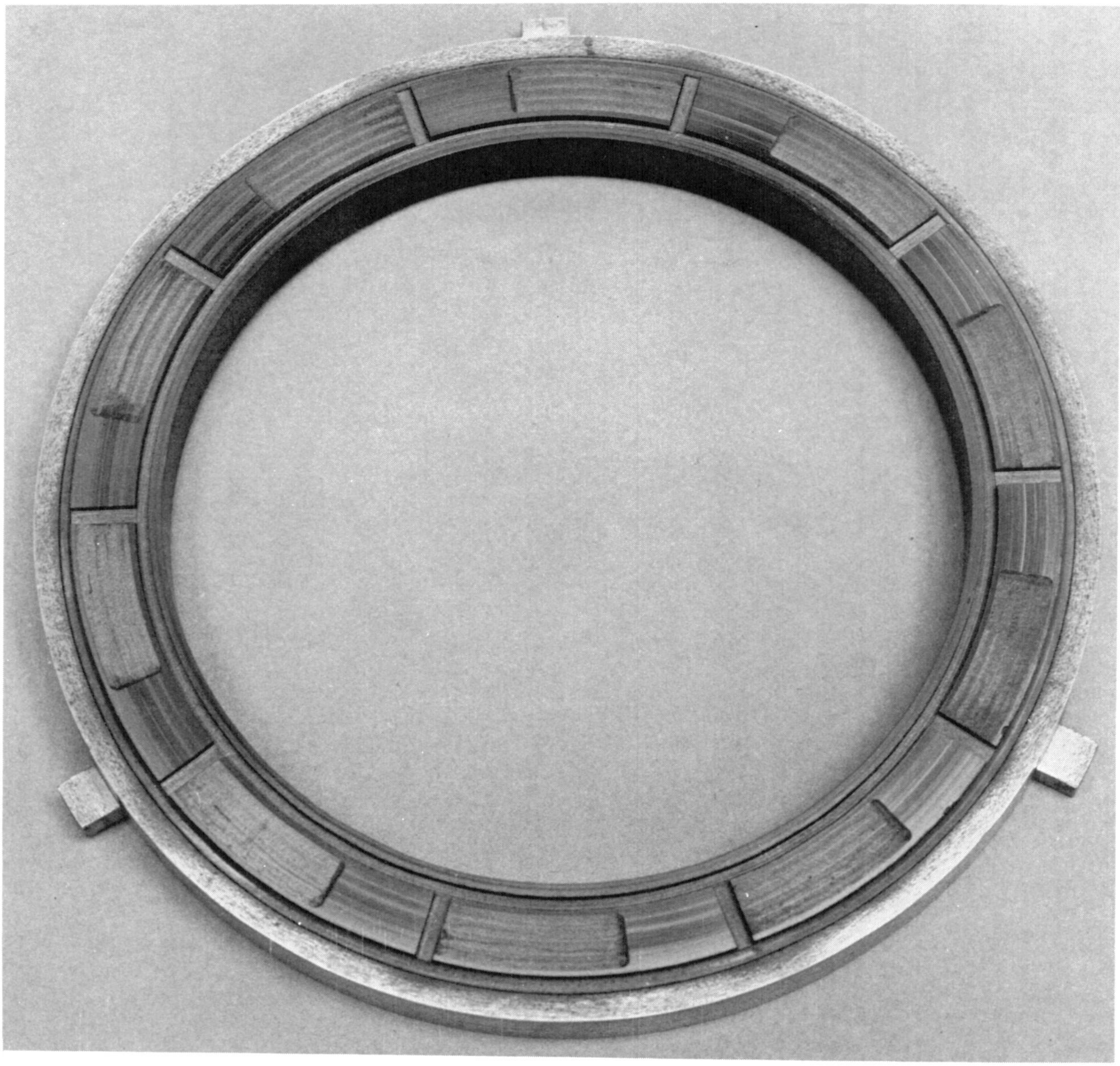


Figure 55. LOX Seal Carbon Ring CF851218, S/N 067303, Posttest 103

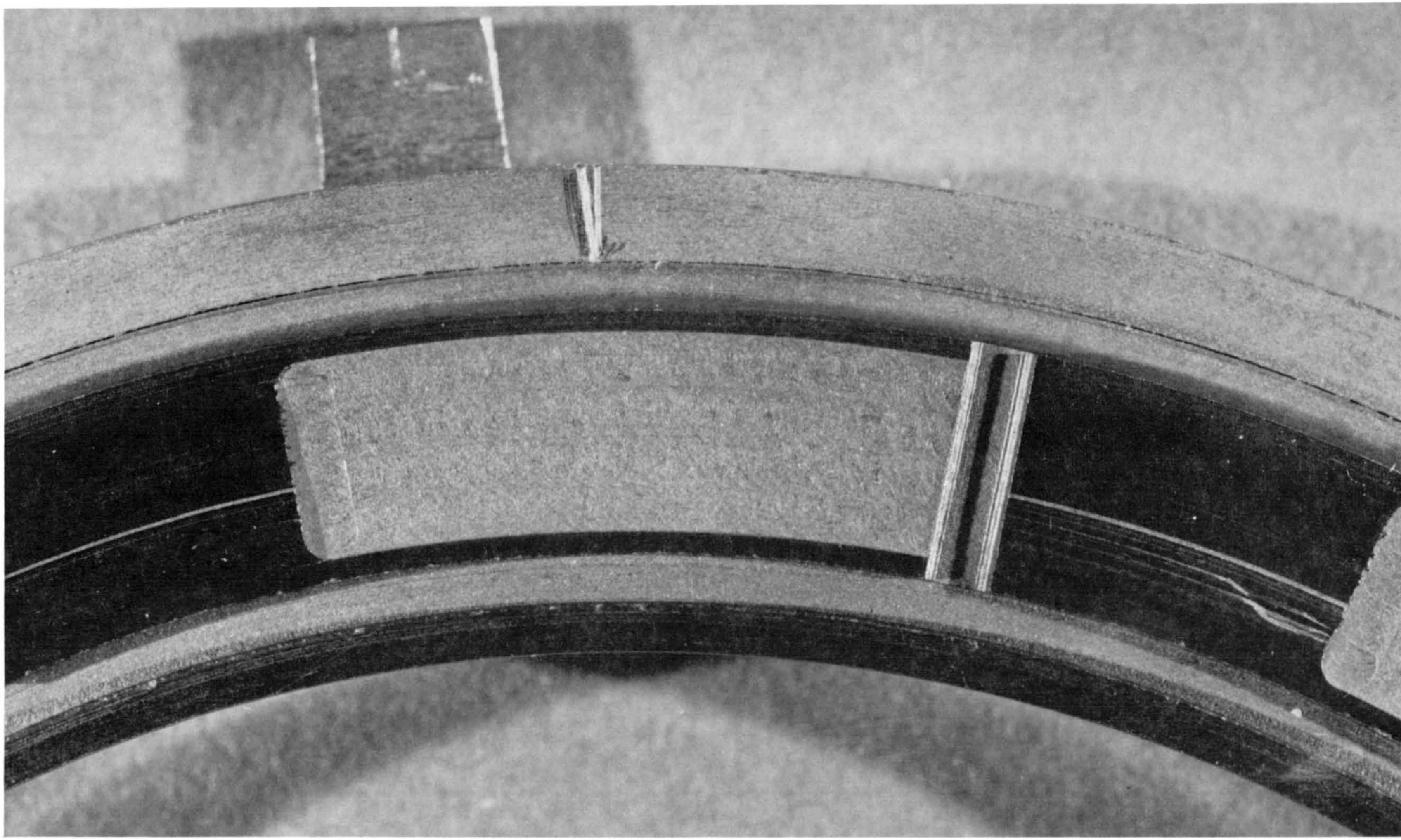


Figure 56. Typical LOX Seal Carbon Recess Pad CF851218, Position 1, S/N 067303, Posttest 132

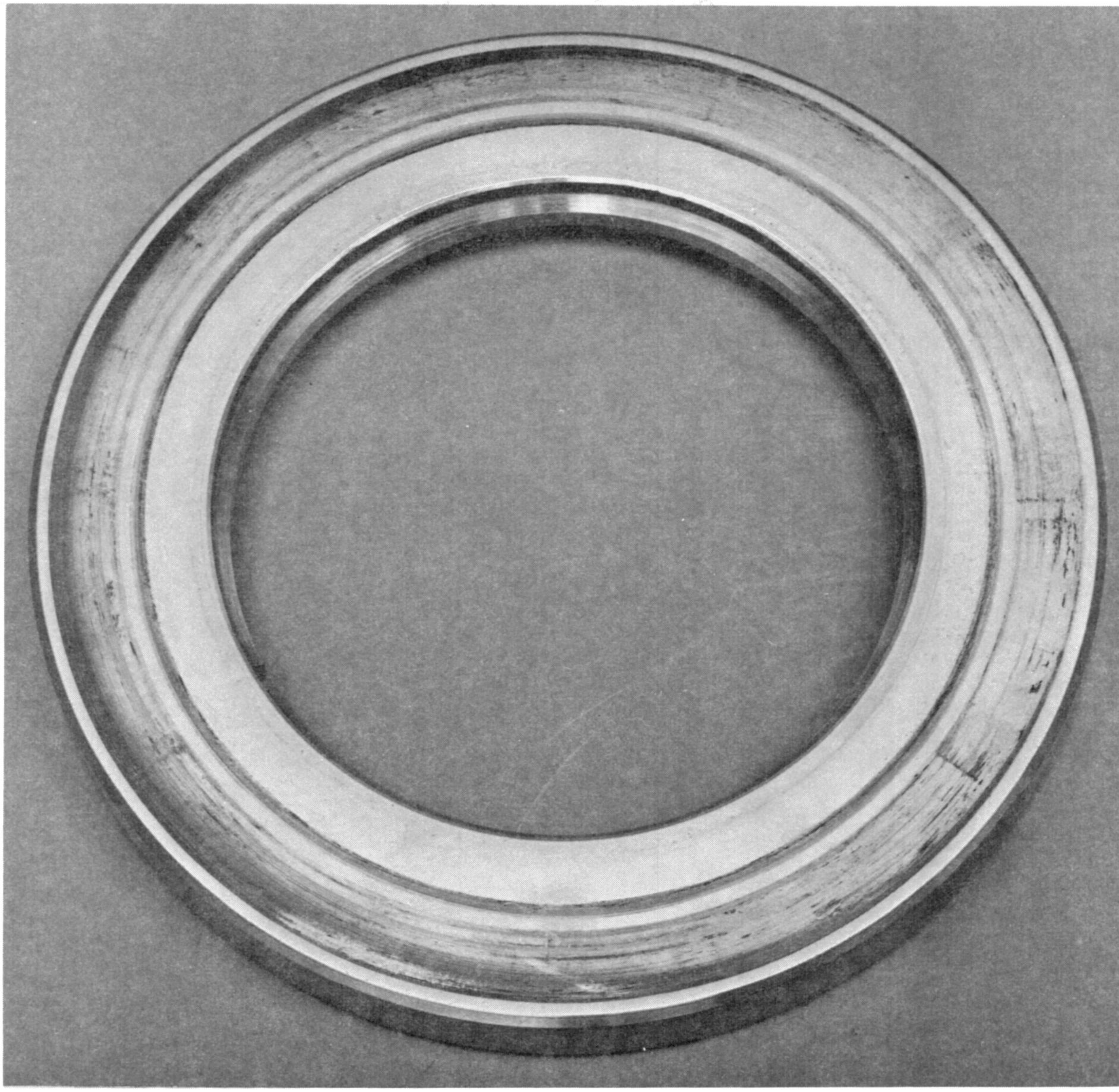


Figure 57. LOX Seal Mating Ring CF851226, S/N 01, Posttest 132

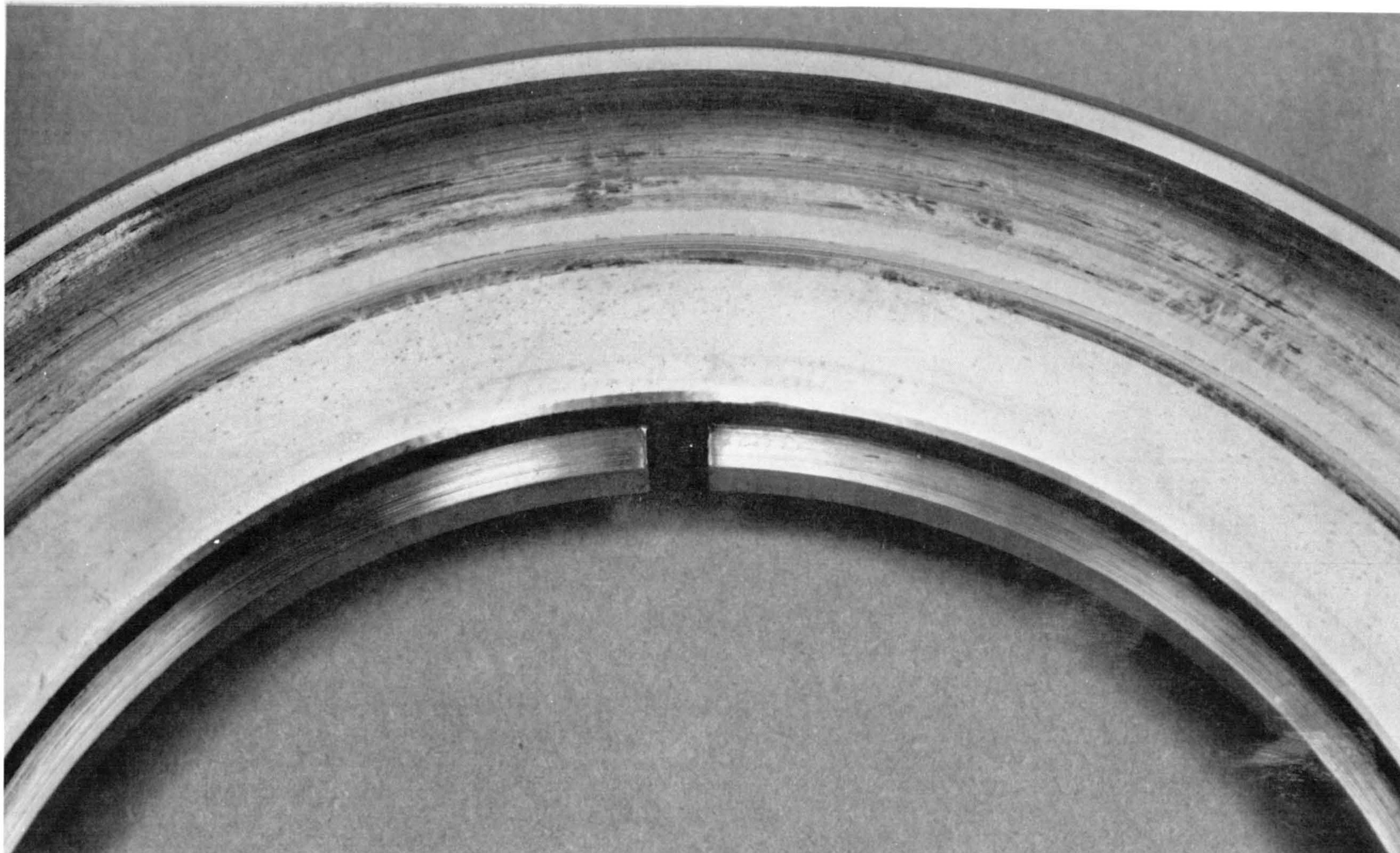
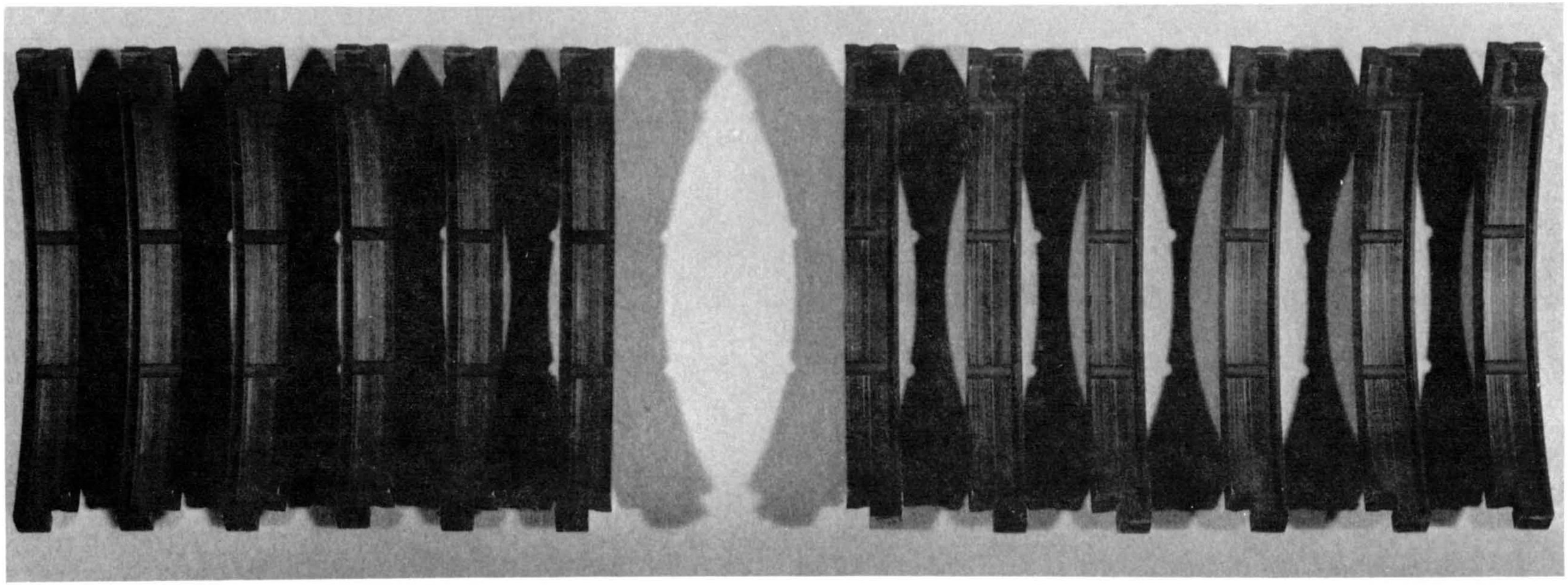


Figure 58. LOX Seal Mating Ring CF851226, S/N 01, Posttest 132



1 2 3 7 5 6 1 2 3 7 5 6

LOX SIDE SEGMENTS B-5 TURBINE SIDE SEGMENTS B-10

Figure 59. Helium Seal Carbon Segments CB120673, S/N 001, Posttest 132

Figure 60. Helium Seal Mating Ring RS004406X, S/N 004, Posttest 132

The first two LOX tests were terminated due to the LOX seal drain pressure exceeding the 345 kPa (50 psig) redline, indicating either excessive LOX seal leakage or insufficient drain size. The LOX seal drain leakage orifice size was increased to reduce the back-pressure. The drain pressure decreased to approximately 241 kPa (35 psig) on the subsequent tests; however, the pressure was still too high for proper evaluation of the helium seal performance. The LOX drain pressure exceeded the helium seal purge pressure and caused backflow through the helium seal.

Build 10 Disassembly

The tester was removed to inspect the seals and to increase the LOX seal spring load to reduce the leakage. The lower spring load used for the gaseous nitrogen testing is apparently insufficient for liquid oxygen due to the increased hydrodynamic lift. The spring load will be increased to 44.5 N (10 lb) on the next build to reduce the sealing interface film thickness.

Seal inspection revealed the LOX seal to be in good condition, except the carbon dam was scored with circumferential grooves approximately 0.00025 to 0.0013 cm (0.0001 to 0.0005 in.) deep. The groove peaks were at the same level as the original surface. The scoring was apparently caused by either foreign particles or particles from the carbon face being ground around the dam.

The helium seal was in good condition, except the carbon segments were worn uneven across the sealing faces. The turbine side segments were worn 0.00025 to 0.0013 cm (0.0001 to 0.0005 in.) on the inner land and 0.0081 to 0.0114 cm (0.0032 to 0.0045 in.) on the dam. The LOX side segments had no measurable wear on the dam or outer land and 0.0025 to 0.0048 cm (0.0001 to 0.0019 in.) wear on the inner land.

The posttest 139 helium mating ring profile trace indicates that the ring outside diameter is flared out approximately 0.0076 cm (0.003 in.) radial on the turbine side. It is suspected that the flared edge contributed to the uneven carbon segment wear.

Build 11 Assembly

The tester was assembled using the same LOX seal (S/N 03) with the carbon face relapped slightly to polish the surface. The concentric grooves in the dam surface were not removed, The spring load was increased from 29.3 to 45.4 N (6.6 to 10,2 lb) by increasing the number of springs from seven to nine. A new helium seal housing reworked to the six-segment design was used. The same LOX segments usêd on build 10 were installed. The segments used on the turbine side were the LOX segments from Builds 8 and 9. A new phase I helium mating ring was inatalled.

Tests 140 - 152

A total of 13 tests for 148.1 minutes was performed to complete the scheduled 2.5 hours of testing. The initial tests were terminated due to facility operation and speed control problems. Tests 150 and 152 were successful facility duration tests of approximately 1 hour duration.

The LOX seal leakage was very consistent on all tests. The static LOX leakage pretest and posttest was approximately 0.007 to 0.009 m^3/s (15 to 20 SCFM). The leakage increased at start to approximately 0.023 m^3/s (50 SCFM) and returned at shutdown, indicating that the seal lifted off properly and operated as predicted with a fluid film thickness of 0.00076 to 0.0010 cm (0.0003 to 0.0004 in,).

The helium seal leakage during operation was satisfactory. The low leakage indicates that the carbon segments are wearing in to conform to the distorted mating ring surface. The uneven segment wear causes excessive posttest static leakage.

Build 11 Disassembly

Seal inspection revealed the LOX seal to be in good condition. The carbon dam that was scored with concentric grooves during the previous set of tests (133 - 139) remained the same with no measurable wear.

The helium seal mating ring conical distortion was again evident on the wear pattern of the helium seals. The LOX side segment shows wear on the dam and outer land. The inner land was completely worn off. The turbine side dam and lands were completely worn off and the greatest wear was on the dam side. The cone apparently starts somewhere between the outer and inner lands on the LOX side as evidenced by the wearing off of the inner lands of the seals on the LOX side.

Build 12 Assembly

The tester was assembled for LOX testing using the same LOX seal (S/N 03) and the same mating ring (S/N 01). The same helium seal housing was used with new segments on both the LOX and turbine sides. The LOX side segments had S/N B-3, the turbine side segments had S/N B-9. The helium seal mating ring was the same as from Build 10, but it had been ground round and replated.

Tests 153 - 159

A total of seven tests for 38.11 minutes was performed. During the first two tests the speed of the tester was erratic. After the second run the tester would not turn over. It was discovered that water from the pump that is used to load the turbine that drives the tester had forced its way through the grease-packed bearings and blown into the tester cavity where it had frozen solid, The tester was allowed to thaw out and tests 155 through 159 were run. During these tests the speed again tended to be erratic except for a period about 300 seconds into run 159 when the tester ran smoothly for 607 seconds. The speed then dropped suddenly, the run was cut and the tester was again found to be iced up. The tester was removed for inspection due to evidence of high leakage and icing.

Build 12 Disassembly

Seal inspection after disassembly revealed the LOX seal to be in good condition. The carbon dam that had been scored with concentric grooves during tests 133 - 139 remained the same with no measurable wear.

Inspection of the LOX seal assembly revealed that the pilot ring had distorted tangs, and marks from the tangs on the bottom of the housing indicated that the pilot ring had, at some time, been bottomed. A check on both sides of the carbon seal ring showed that both sides were still optically flat and the ring was found to hold a very good vacuum between it and the carbon seal.

The helium seal mating ring conical distortion was again evident on the wear pattern of the helium seal segments. There was no appreciable wear on the dam and outer land; however, the inner land was completely worn off.

Build 13 Assembly

The tester was assembled for LOX testing using the same LOX seal (S/N 03) and the same mating ring (S/N 01). The same helium seal housing and segments were used, but because of the permanent distortion in the surface of the mating ring, the ring was changed back to the one used in Build 11 (RS004406X, S/N 05). The only other change was that the LOX seal carbon faces were very lightly lapped.

Tests 160 - 161

Test 160 was cut immediately because there was no speed trace. The instrument sensitivity was changed and then run 161 resulted in a 2-hour test during which the speed, the seal cavity pressure and all other parameters remained very steady. This completed the 5 hours of testing required at 1034 kPa (150 psia).

Build 13 Disassembly

Seal inspection after disassembly revealed the LOX seal lands and pads to be in good condition with no measurable wear. Photographs of the LOX seal are shown in Fig. 61 and 62. The leak tests made before disassembly show a high static leakage across the LOX seal due to wear on the dam. The LOX mating ring, shown in Fig. 63, was still in excellent condition. It was still optically flat and the profile trace showed no wear.

The helium seal mating ring, housing and carbon segments were substantially the same as they were before the 2-hour test. During the run, leakage through these seals was low. During the static leak tests made before disassembly, the leakage through the seals on the LOX side was low while, the leakage through the turbine-side seals was high due to the uneven wear.

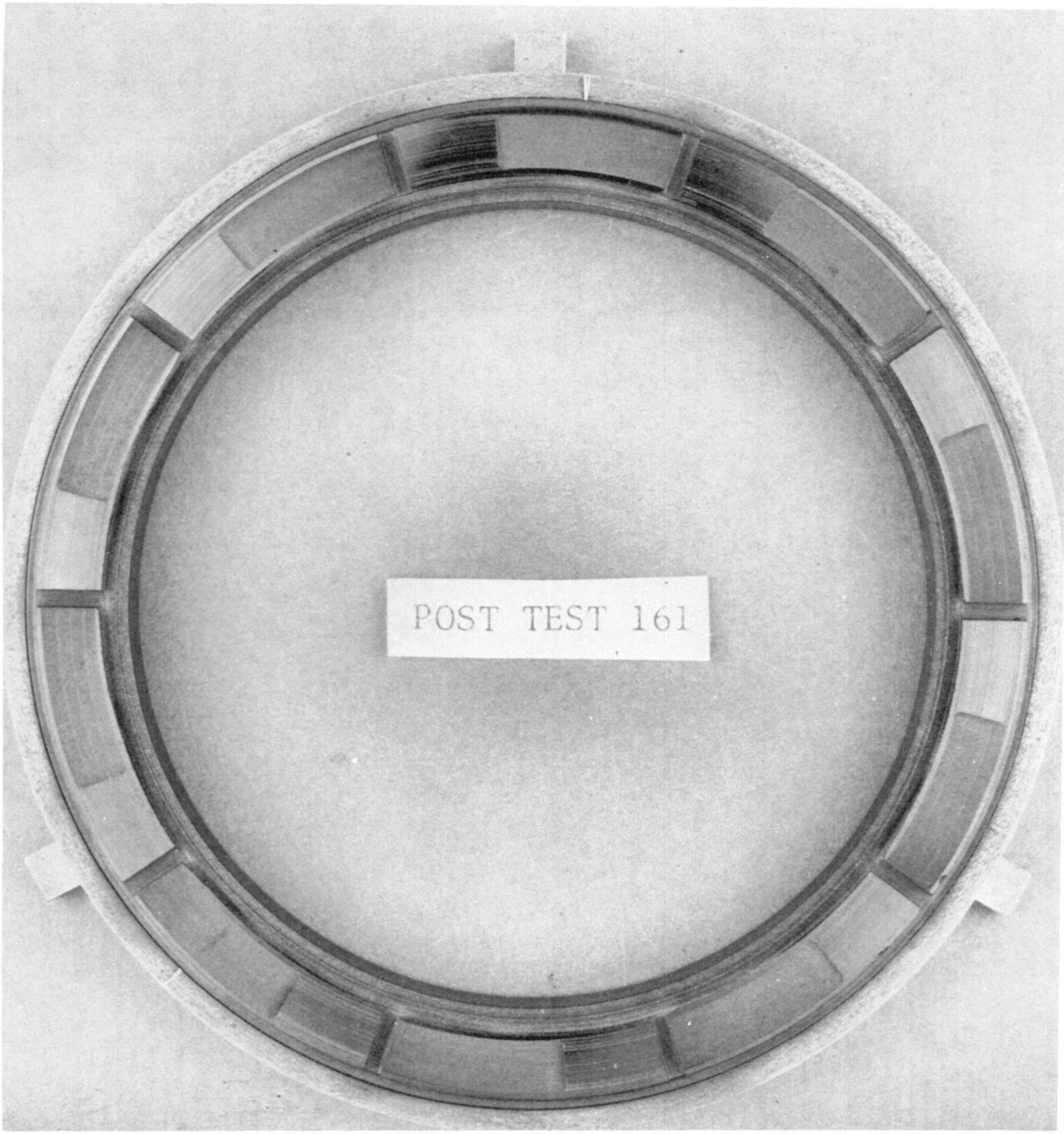


Figure 61. LOX Seal Carbon Ring CF851218, S/N 067303, Posttest 161

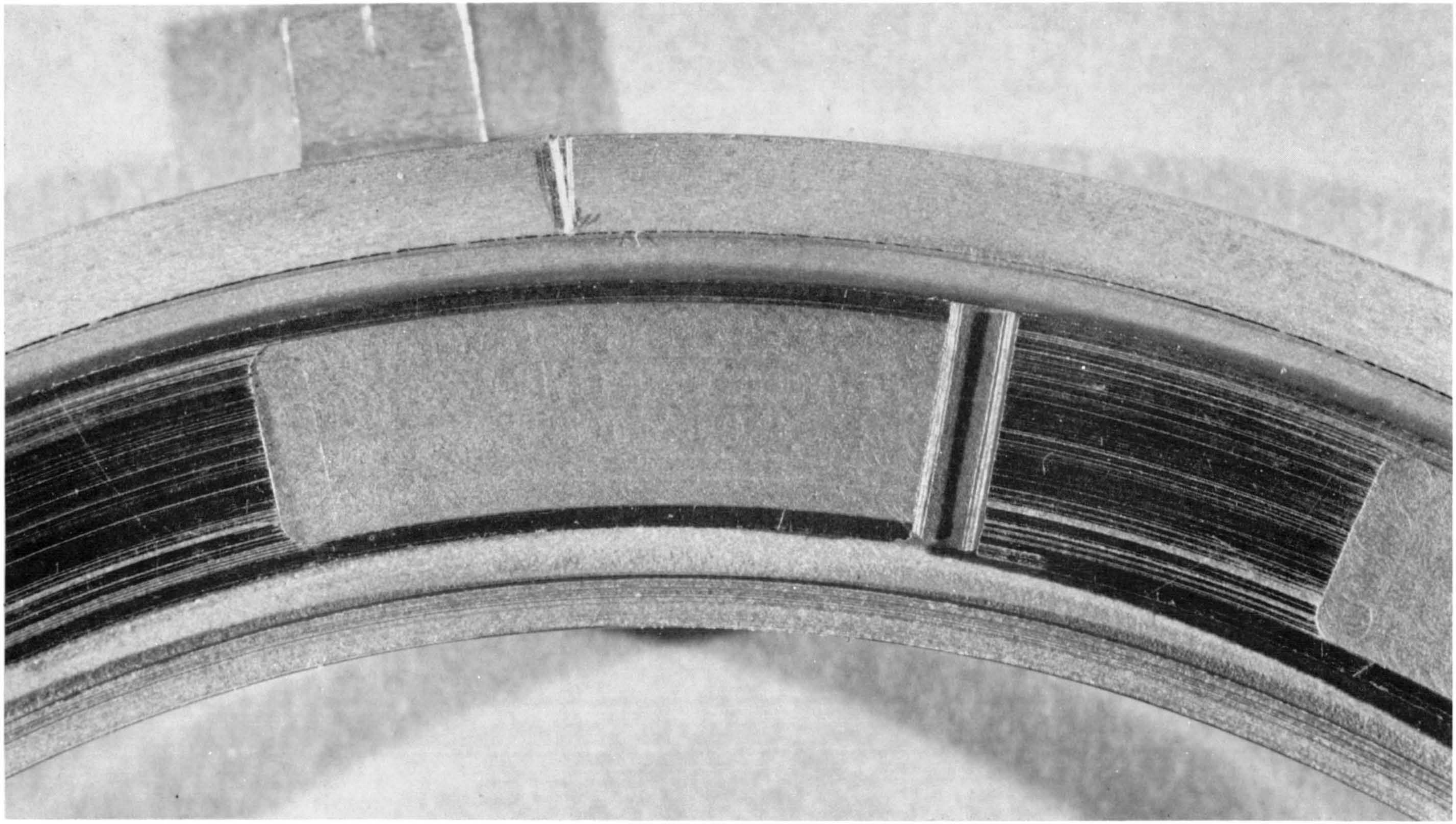


Figure 62. Typical Seal Carbon Recess Pad CF851218, Position 1, S/N 067303, Posttest 161

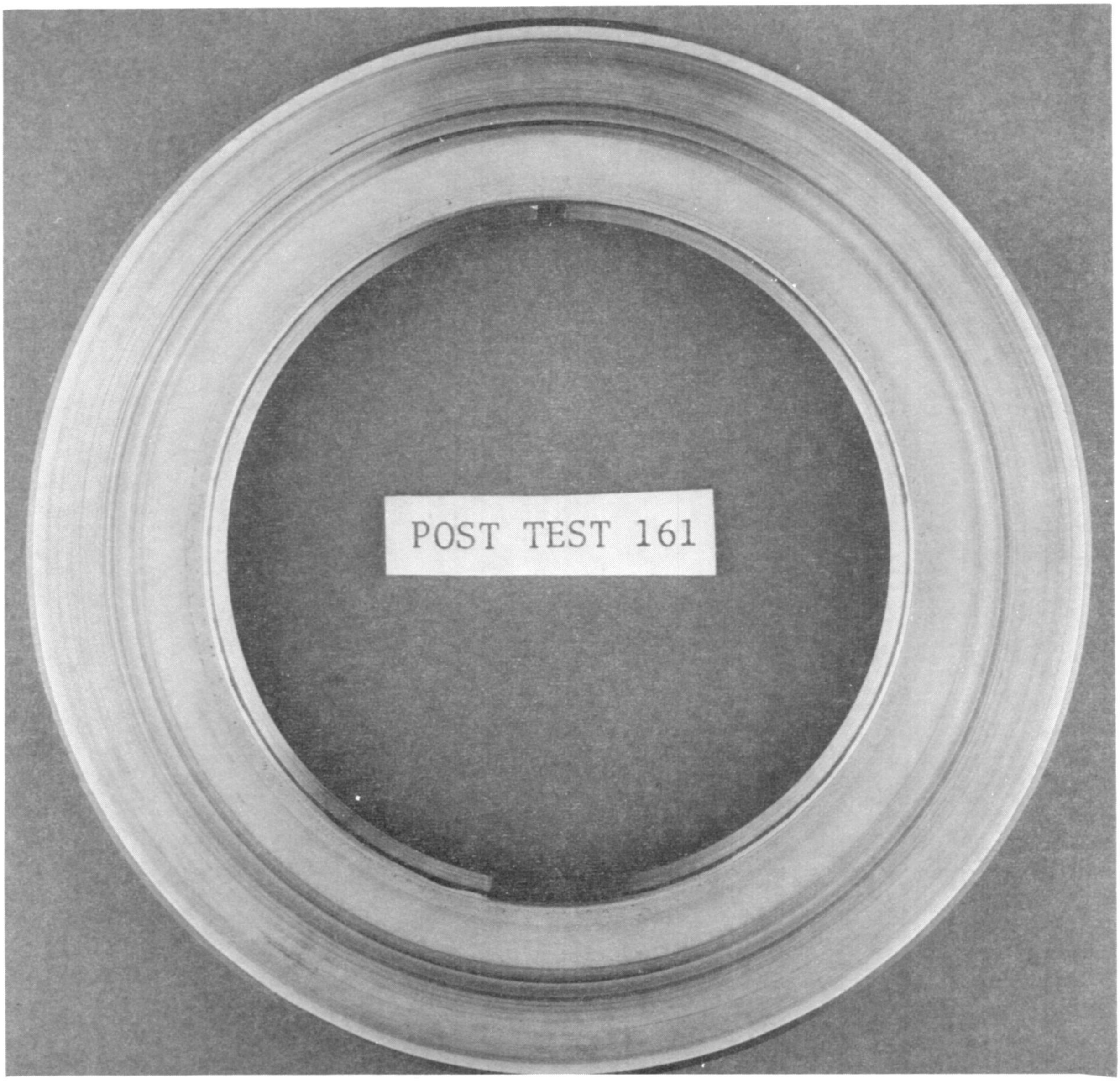


Figure 63. LOX Seal Mating Ring CF851226,
S/N 01, Posttest 161

Build 14 Assembly

The tester was assembled for LOX testing using a new LOX seal carbon ring (S/N 05) and a new mating ring (S/N 01). The spring load was increased from 45.4 to 52.5 N (10.2 to 11.8 lb) by increasing the number of springs from 9 to 12. The static GN_2 leakage through the LOX seal was low.

The same helium seal housing and segments and the same helium seal mating ring were used as in the previous build. The segments on the LOX side had no appreciable wear on the dam and outer land but the inner lands had been completely worn off. The dam and lands of the segments on the turbine side were completely worn off and the ring of segments had a conical shape caused by the thermal distortion of the mating ring during cryogenic testing.

Tests 162 - 176

Tests 162, 163 and 164 were of short duration and all were automatically cut because of overspeed. Test 165 was cut because there was no accelerometer reading, test 166 had no speed trace and tests 167 and 168 were cut because the LOX seal discharge pressure was above the redline. Run 169 was cut in order to reset the seal cavity pressure to the specification value of 1724 kPa (250 psi). Run 170 was a fairly smooth test of 2679 seconds, but during the test the seal cavity pressure steadily decayed from 1723.75 kPa (250 psi) down to 1027.35 kPa (149 psi). Near the end of the run the speed became erratic and there was an overspeed cut.

The tester was removed for inspection due to speed control and LOX seal pressure decay.

Build 14 Disassembly

Bearing inspection after disassembly revealed that one of the bearings had a broken ball. Inspection of the turbine drive showed that the radial-inflow turbine had rubbed on the outer shroud. The high drag load prevented the tester from reaching design speed.

During the tests it had been noted that the LOX seal leakage was very high. Profile inspection of the LOX seal after disassembly showed that although the seal lands and pads were in perfect condition, the dam was badly worn. It is suspected that the wear was caused by abrasion from the debris that resulted from the bearing failures. The test data show that the large increase in leakage occurred between runs 170 and 171.

Build 15 Assembly

The tester was assembled for LOX testing with new ball bearings, a reworked (new recess pads) LOX seal carbon ring (S/N 01) and a new mating ring (S/N 04). Twelve springs were used to provide a spring load of 52.5 N (11.8 lb).

The same helium seal housing and segments and the same helium seal mating ring were used as in the previous two builds. The segments on the LOX side had no appreciable wear on the dam and outer lands but the inner lands had been completely worn off. The dam and lands of the segments on the turbine side were completely worn off, the ring of segments having a conical shape caused by wear from the thermally distorted mating ring during cryogenic testing.

Tests 177 - 222

Tests 177 to 184 were very brief acceleration tests attempting to reach the design speed of 32,000 rpm. The speed leveled off at about 20,000 rpm, and each was quickly cut. Between runs, the pressure of the GN_2 driving the turbine was gradually increased to its maximum allowable value.

It was decided to use the maximum turbine pressure and the minimum bearing flow to minimize the power absorbed by the bearings. It had also been noted during previous tests that the tester speed tended to increase with time. Therefore, it was decided to let the tester run to see if its speed would gradually increase to the design value.

Testing was resumed and the first test was cut because the speed was too near the critical. On run 187 the speed gradually increased from 26,400 rpm to 27,200 rpm, at which time the LOX run tank was depleted. On test 190 the tester drag decreased and there was an overspeed cut. On the last four tests, design speed was reached but control was erratic. At the conclusion of test 194, the tester would not turn over and it was found that the turbine water seal had failed and water had leaked from the centrifugal pump through the turbine. The water spilled into the tester slave seal cavity and froze the tester shaft.

Since no replacement water seals were available, it was decided to eliminate the water and allow the water pump to pump air. The water pump was required originally to provide drag for speed control. Since the tester drag is higher at the current operating conditions, the water is no longer required.

Tests 195 - 204 were made accumulating 3.08 minutes attempting the test point 2 conditions of 1724 kPa (250 psig) LOX pressure and 32,000 rpm. Problems included low drive turbine power at the maximum allowable turbine inlet pressure of 965 kPa (140 psig). Tester power requirements increased as the LOX seal pressure increased. The turbine pump seal was removed to eliminate friction drag heat buildup. A labyrinth spacer was installed in place of the seal.

Tests 205 - 212 were made for a total of 52.63 minutes, including 30 minutes at 1724 kPa (250 psia) LOX pressure to complete the 5 hours at test point 2 condition. A total of 15 minutes at test point 3 conditions of 2241 kPa (325 psig) LOX pressure was included.

It was decided to increase the diameter of the 26 conical, convergent turbine nozzles from 0.156 to 0.187 in. diameter. The nozzle area was increased 40 percent to allow increasing the turbine flowrate and power output at the maximum inlet pressure.

The test plan was revised to run 0.151 to 0.163 kPa (325 to 350 psig) LOX sealed pressure for 30 minutes, 0.163 to 0.175 kPa (350 to 375 psig) LOX sealed pressure for 30 minutes, and then complete the remainder of the 20 hours (approximately 9 hours) at 0.186 kPa (400 psig) sealed pressure. The bearing cavity pressure was increased to minimize the pressure drop across the inboard slave seal between the bearing and LOX seal cavities to reduce the seal friction drag power.

Tests 213 - 222 were made accumulating 25.91 minutes attempting 0.151 to 0.163 kPa (325 to 350 psig) LOX sealed pressure at 32,000 rpm. The LOX seal drain orifice diameter was increased from 1.905 cm (0.75 in.) diameter to 2.540 cm (1.0 in.) diameter to reduce the drain cavity pressure.

Tests 213 - 216 were prematurely cutoff by an erroneous accelerometer cable problem.

Tests 217 - 219 were cut due to low drive turbine inlet pressure. At the cut of test 219, the facility LOX pump was accidently turned off instead of the turbine valve. The tester speed spiked to 40,000 rpm. The bearing and seal LOX flows dropped to zero. Bearing cavity pressure dropped to 345 kPa (50 psig) and seal upstream pressure dropped to 414 kPa (60 psig). No significant change was noted in the bearing and seal upstream cavity temperatures. The posttest shaft turning torque was normal - the same as chilled pretest value. There was no apparent damage and it was decided to continue testing.

On test 220, the LOX seal upstream pressure was gradually increased from 2068 to 2758 kPa (300 to 400 psig) and remained near 2758 kPa (400 psig) for approximately 4 minutes to demonstrate the facility capability for the maximum test condition. The overspeed cutoff level was increased from 33,000 rpm to 34,500 rpm to prevent an overspeed cut during the demonstration. The test was terminated due to run tank LOX depletion. The maximum accelerometer level was 6.35 gs peak to peak.

Test 221 was also terminated due to LOX depletion after 3.7 minutes.

Test 222 was a steady-state test at 2413 kPa (350 psig) LOX sealed pressure and 32,000 rpm for 651 seconds. Accelerometer levels were 4.8 gs peak-to-peak near test start at 2241 kPa (325 psig) sealed pressure and increased to 5 6 gs peak-to-peak at 200 and 400 seconds. The LOX seal leakage was 0.091 m?/s (195 SCFM) at 2344 kPa (340 psig) sealed pressure and 32,120 rpm.

A fire erupted from the seal drain cavity area after 651 seconds of steady-state operation on test 222. A large ball of flame shot out from the tester area to the far side of the test pad and the test was shut down.

Approximately 4 seconds before the fire, the tester speed dropped from 32,000 rpm to 29,000 rpm prior to shut down. The accelerometer trace on the oscilloscope was observed to decrease about 10% concurrent with the speed decrease.

Four holes were burned through the tester housing in the seal drain area. One hole was at a LOX seal drain fitting and three larger holes were burned through the helium seal housing and turbine side drain area. The turbine mounting adapter, drive spline, wheel and manifold were damaged. There was extensive facility damage to the plumbing, tubing, wiring, instrumentation, valves, filters and insulation.

Test data charts indicated the LOX side and turbine side drain and orifice pressures went high, off scale at the time of the fire. The LOX seal upstream pressure increased from 2344 kPa to 3344 kPa (340 to 485 psi) then dropped to zero. The helium orifice pressure increased from 93 kPa to 293 kPa (13.5 to 42.5 psid).

Build 15 Disassembly

The tester was disassembled due to the fire damage. Extensive burning occurred in the LOX and helium seal area. The outboard slave seal carbon ring was missing and the housing was mostly burned away. Figure 64 shows the outboard slave mate ring. A small chunk of the carbon nose attached to the mate ring was removed and showed the rubbing surface in good condition with no grooving.

The turbine side drain housing was burned through in three places, two at the drains. The helium seal mating ring was gone except for the 90-degree section shown in Fig. 65 and 66. The rubbing surface remaining was in good condition as shown in Fig. 65. The remaining helium seal carbon segments shown in Fig. 66 indicate the rubbing surfaces were in good condition. The burning in the helium seal housing, mating ring, and drains appears to have occurred after rotation stopped.

The LOX seal housing was burned through in two areas 180 degrees apart as shown in Fig. 67. The shaft was also burned in the same areas. The LOX seal carbon was missing except for a 60-degree section. The pads remaining on the section were burned and worn, especially at the dam area, and showed rub marks. The LOX seal carbon retainer ring and pilot ring were completely missing. The LOX seal mating ring shown in Fig. 68 had a continuous errosion path burned in the dam area which apparently occurred during rotation. The slag chips on the mating ring have rub marks, indicating rotation after burning.

The clamping ring had burning at the mating ring clamping shoulder and at the puller groove that apparently occurred during rotation. The deep burning into the shaft that occurred after rotation stopped was in two places approximately 180 degrees apart. The shaft burning occurred away from the mate ring surface and appeared to have been pressure feed.

Burning damage was concentrated inside of the LOX seal housing and not upstream in the sealed pressure cavity.

The inboard slave seal and bearings were in good condition with no evidence of burning.

Figure 64. Posttest 222 Fire Showing Outboard Slave Seal Mate Ring, Remaining Helium Seal Mate Ring, and LOX Seal Housing

Figure 65. Posttest 222 Fire Showing Helium Seal Mate Ring

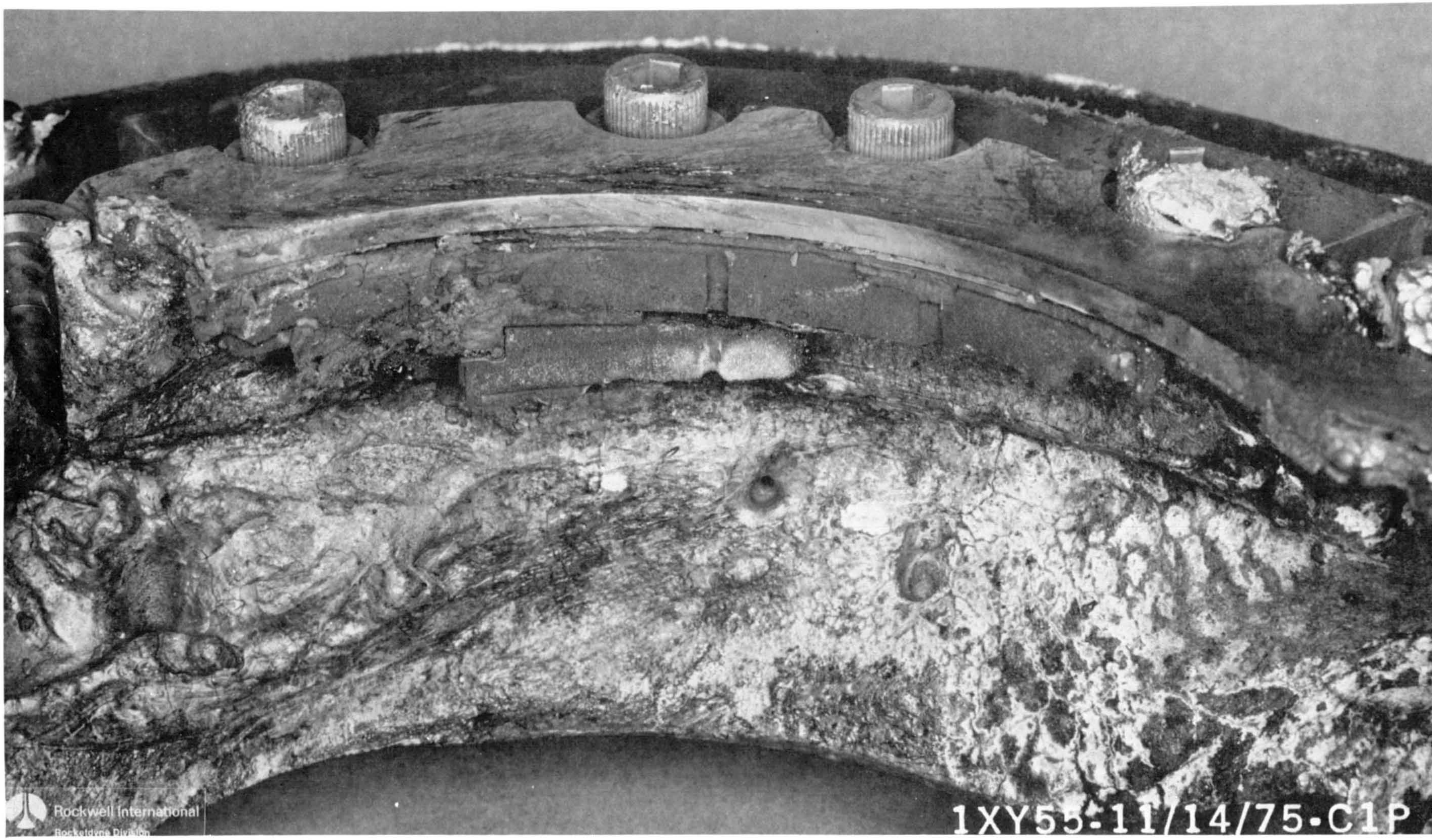


Figure 66. Posttest 222 Fire Showing Helium Seal LOX Side Carbon Segment

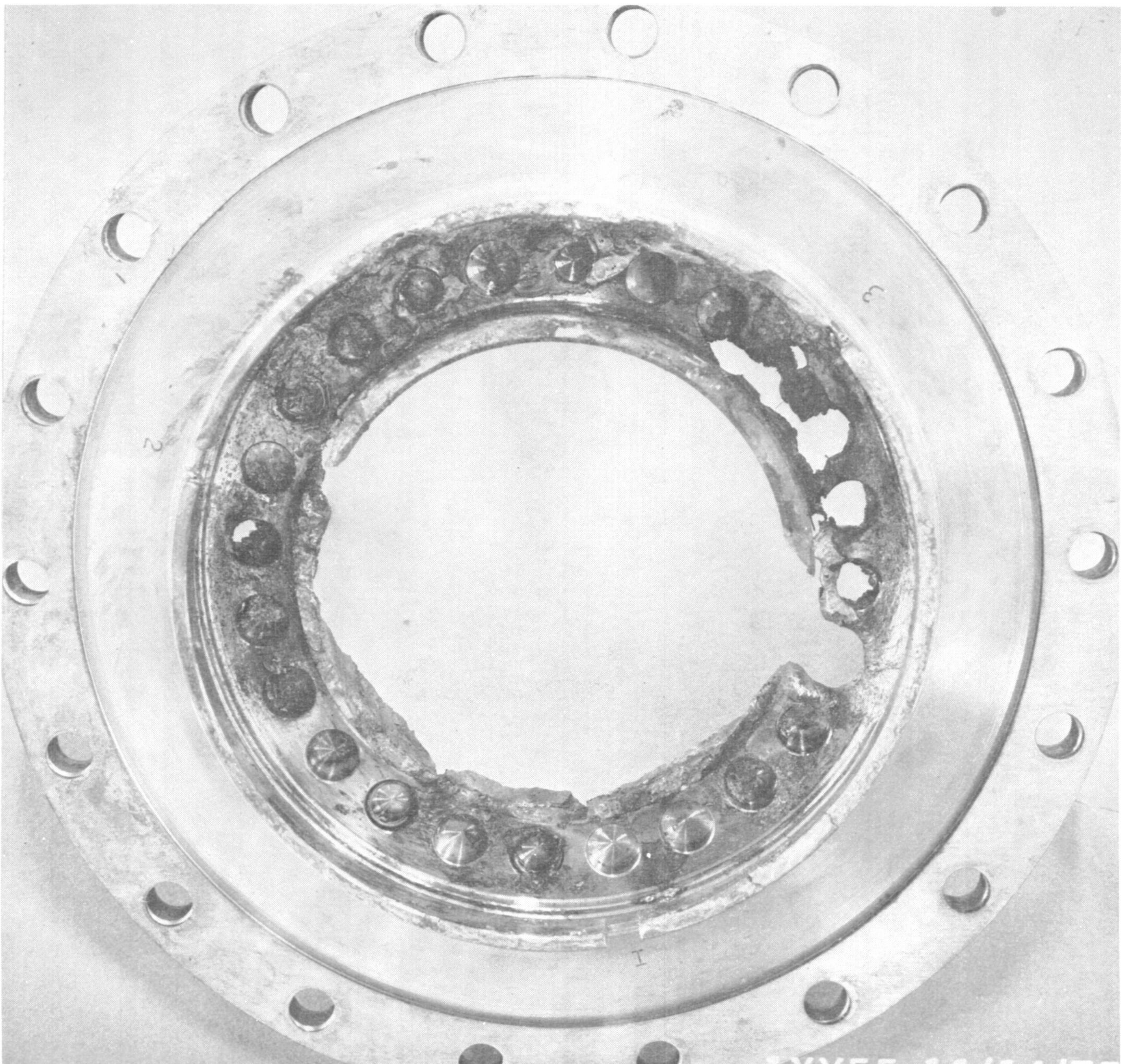


Figure 67. Posttest 222 Fire Showing LOX Seal Housing Upstream Side

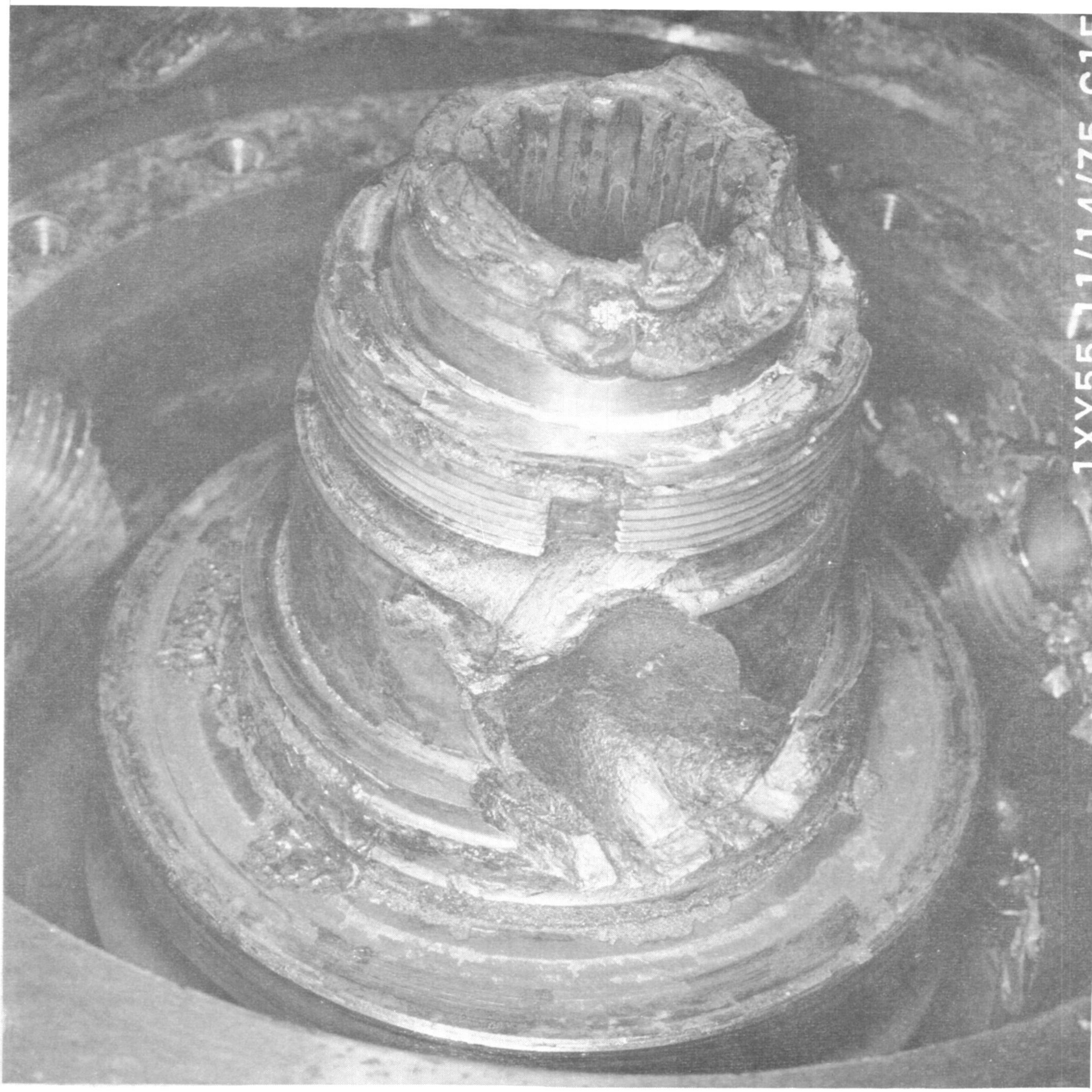


Figure 68. Posttest 222 Showing LOX Seal Mate Ring and Shaft Burning

The tester damage can be classified as rotating and non-rotating damage. Rotating damage appeared at the LOX seal mating ring surface and at the clamping ring outside diameter. Non-rotating damage appeared at the deep grooving of the shaft under the LOX seal housing 180 degrees apart, leaving a 90 degree section of the helium seal and mating ring. The burned out LOX seal drain and a one turbine side drain were in the same plane.

The investigation to determine the cause of the tester fire concluded that no single cause could be pinpointed by the evidence. The possible sources of ignition include non-LOX compatible contamination at the LOX seal dam, excessive rubbing of LOX seal hardware, or carbon dust buildup in the turbine side drain area, resulting in an explosion.

The non-LOX compatible contamination was found in the metallurgical analysis of the slag on the LOX seal mating ring. Tin and lead (probably from solder) were included in the slag composition. Tin is not LOX-compatible. If the contamination became lodged at the seal dam and resulted in a fire, the sealed pressure would force burning through the seal dam and downstream toward the drain area where the major damage occurred. No source of the solder contamination has been determined and a large capacity 10 micron filter was located upstream of the tester.

Excessive rubbing of the LOX seal hardware could have occurred where there is relative motion between seal parts: between the carbon ring and rotating mating ring, between the antirotation tangs on the carbon metal band and the housing, and between the loading springs and the housing and pilot ring. The carbon metal band and pilot ring, both INVAR, were missing at disassembly. Only a small portion of the carbon ring and the springs remained at disassembly. If the fire started due to rubbing at the LOX seal, greater damage would be expected on the upstream and downstream sides of the LOX seal housing.

A concentration of carbon dust in the turbine side drain area was another possible source of ignition. The helium seal carbon rings have been wearing during operation due to coning of the mating ring. The concentration of carbon dust would be increasing with testing at the turbine side drain area. Spontaneous combustion could possibly have caused the explosion and subsequent damage in the drain area.

The tester hardware required to repair the damage caused by the tester burnout was fabricated. The drive turbine mounting adapter, drive spline and spline adapter were ordered from the same supplier who made the original parts.

Repair of the test facility was accomplished. Facility instrumentation and procedures were improved. All seal temperatures will be measured closer to the seals. Helium seal supply pressure will be maintained 68.9 kPa (10 psid) greater than the drain pressure. A speed drop automatic cutoff system is planned to cut the test if the speed drops to 90% of the test speed after conditions have stabilized during a test. Bearing and seal failures have indicated a sudden speed drop from steady state operation to speeds approximately 90% test speed with some continued operation before the tests were cut. Additional high frequency instrumentation will be utilized to measure temperatures and pressures at the seals.

Build 16 Assembly

The tester was assembled with new Phase III seal hardware. The LOX seal is the same as Phase I, except the carbon seal ring material is grade P692 instead of P03N and the piston ring material is Vespel SP21 instead of carbon P5NR2. The seal was assembled with 8 coil springs with a force of 66.7 N (15.0 lb) at the seal installed length.

The Phase III helium seal is a double floating ring type compared to the Phase I and II segmented rings. A new Z shaped helium mating ring will be used to minimize operating distortions. The tester shaft has been reworked to provide a press fit at the helium mating ring pilot for improved operating alignment. The seal ring to mating ring radial clearances were 0.0068 cm (0.0027 in.) on the LOX side, and 0.0063 cm (0.0025 in.) on the turbine side.

The new Z-shaped helium seal mating ring has been designed to maintain a cylindrical sealing surface at the design operating condition. The original T-shape design deflected to a conical sealing surface during operation. The circumferential Rayleigh lift pads will not provide lift on a conical sealing surface and would result in rapid carbon wear. The Z design features a 45 degree web conically thinned toward the attachment point at the turbine side of the sealing ring.

Even temperature distribution results on the ring inside diameter from the LOX leakage and on the outside diameter from the helium purge. The design thermal gradient was determined from estimated operating conditions which resulted in the conical deflection of the T-ring as determined from analysis of carbon ring wear after testing. Sealing surface deflections of the Z-ring at design operating condition were determined using a finite element analysis.

Tests 223 - 232

The Phase I test, Schedule II, Liquid Oxygen testing was resumed to complete the remaining 10 hours of accumulated time as detailed below.

Test Point No.	Speed, rpm	LOX Seal Pressure, kPa (psig)	HEL Seal Pressure, kPa (psig)	Duration, hours
3	32,000	1724 (250)	345 (50)	0.5
4		2068 (300)		0.25
5		2413 (350)		0.25
Inspect (1 hours)				
6		2758 (400)		4
Inspect (5 hours)				
7		2758 (400)		5
Inspect (10 hours)				

A total of 10 tests for 28.49 minutes was performed. The initial tests were terminated at start due to facility operation problems. Steady-state data obtained on the last three tests indicated that the LOX seal performance was satisfactory. The LOX seal steady-state leakage was 0.028 to 0.031 m^3/s (60 to 67 SCFM) at approximately 1724 kPa (250 psig). The leakage rate was apparently decreased because of the higher spring load.

The floating ring helium seal leakage was 0.021 m^3/s (45 SCFM) compared to approximately 0.005 to 0.009 m^3/s (10 to 20 SCFM) on the segmented carbon seal; however, the LOX side seal ring apparently lost clearance and wore a groove into the mating ring on the first test. The LOX side leakage increased from 0.005 m^3/s (12 SCFM) on the first test to 0.015 m^3/s (33 SCFM).

The tester was removed for inspection before the scheduled 1 hour inspection point due to jerky turning torque on the tester shaft. There was also evidence of excessive carbon dust in the helium seal drain, indicating carbon wear.

Build 16 Disassembly

Tester disassembly revealed the jerky turning torque to be caused by flakes of chrome plate catching between the LOX side helium seal ring and the mating ring. The LOX side seal ring had lost clearance and worn a groove into the chrome plated surface of the mating ring. The LOX side carbon seal ring was heavily worn and scored. The dam was broken and the lift pads were worn off. The turbine side seal ring was worn and scored by the debris from the LOX side. The turbine side of the mating ring was scored, but not worn.

The LOX seal was in excellent condition with no measurable wear and only slight traces of rubbing contact.

The loss of helium seal ring clearance on the LOX side was apparently caused by the mating ring running at a warmer temperature than predicted. The additional centrifugal growth on the cantlevered LOX side of the Z-ring resulted in decreasing the clearance until rubbing contact occurred. The rubbing contact heated the ring and caused additional growth until failure occurred.

Build 17 Assembly

The tester was reassembled with a new reworked Z shaped helium seal mating ring and a new Phase III type double floating ring helium seal. The mating ring diameter was reduced to provide diametrical clearances of 0.019 cm (0.0076 in.). The static GHe leakages at 345 kPa (50 psig) purge pressure were 0.010 m^3/s (21.5 SCFM) on the LOX side and 0.0096 m^3/s (20.7 SCFM) on the turbine side.

The same LOX seal and mating ring from Build 16 were reinstalled without rework.

Tests 233 - 239

The test objective was 30 minutes total with 15 minutes at 2068 kPa (300 psig) LOX seal pressure and 15 minutes at 2413 kPa (350 psig) LOX seal pressure.

A total of seven tests for 31.5 minutes was performed to achieve the test objective. The initial tests were terminated due to instrumentation and speed control problems. Steady-state data obtained on the last two tests indicated that the Rayleigh Step LOX seal performance was satisfactory. The LOX seal steady-state leakage was 0.035 to 0.036 m^3/s (75 to 77 SCFM) at approximately 2068 kPa (300 psig) and 0.039 m^3/s (83 SCFM) at 2448 kPa (355 psig).

The floating ring helium seal leakage was 0.012 m^3/s (26 SCFM) on the LOX side and 0.008 m-/s (17 SCFM) on the turbine side for a total of 0.020 m^3/s (43 SCFM) at a purge pressure of 345 kPa (50 psig). The leakage was consistent from the first test to the last test, indicating no deterioration or wear.

Build 17 Disassembly

The tester was removed for a scheduled seal inspection after 31.50 minutes at 2068 to 2413 kPa (300 to 350 psig) LOX pressure.

The inspection revealed the seals to be in excellent condition. The LOX seal carbon face was polished with no measurable wear. The LOX mating ring showed a slight contact pattern with no measurable wear. The static leakage was approximately the same as pretest.

The helium seal with increased diametral clearance 0.018 cm (0.007 in.) was in excellent condition. The wear which occurred with 0.013 cm (0.005 in.) diametral clearance (Build 16) was eliminated. The mating ring had a slight contact mark from the LOX side dam and a very faint pattern on the turbine side, indicating that the new Z shaped mating ring diametral deflections are relatively uniform. The carbon rings were slightly polished with no measurable wear on the lift pads. The posttest static leakage was less than pretest, indicating no wear.

Build 18 Assembly

The tester was reassembled with the same seal hardware without rework.

Tests 240 - 259

The test objective was 4 hours accumulated time at 2758 kPa (400 psig) LOX seal pressure.

A total of 20 tests for 3.41 hours was performed. The LOX seal leakage was consistent through the test series at approximately 0.047 m^3/s (100 SCFM), indicating no wear or deterioration. The LOX seal downstream drain pressure was also consistent at approximately 103 kPa (15 psig). The leakage rate and drain pressure indicate satisfactory seal performance.

The floating ring helium seal leakage was also consistent through the test series. The leakage rate varied from 0.021 m^3/s (46 SCFM) on the first test to 0.020 m^3/s (43 SCFM) on the last test at a purge pressure of 345 kPa (50 psig).

Build 18 Disassembly

The tester was removed for inspection after 3.41 hours due to a high vibration level.

The inspection revealed the tester thrust bearing to be failed. The seals were in good condition. Seal damage due to the bearing failure was prevented by detection of the bearing failure in the preliminary stage. The LOX seal carbon face was polished with some light circumferential scratches and slight chipping at the inside of the lift pads. There was no measurable wear on either the lift pads or the dam. The LOX mating ring had a light contact pattern with faint circumferential marks and no measurable wear. The posttest static leakage was less than pretest and approximately the same as when new.

The helium seal was in good condition except for a slight amount of wear. The lift pad measurements indicate 0.00025 cm to 0.00076 cm (0.0001 to 0.0003 in.) radial wear. The carbon ring inside diameter contact surface was polished with some light circumferential scratches. The helium mating ring had a heavy rub pattern on the LOX side and light rub pattern on the turbine. The rubbing and wear probably occurred after the bearing failed. The posttest static leakage was approximately the same as pretest on the LOX side and higher on the turbine side.

Build 19 Assembly

The tester was reassembled with the same LOX seal and mating ring. The same helium seal was reinstalled. The helium mating ring wear surface was ground down and replated to renew the chrome plating due to the heavy rub pattern caused by the tester bearing failure. New bearings were installed.

Tests 26

The test objective was 5.59 hours accumulated time at 2758 kPa (400 psig) LOX seal pressure to complete the required 10 hours.

A total of 12 tests for 2.27 hours was performed. The testing consisted of two long tests (45 and 67 minutes) and 10 short (0.5 to 7.4 minutes) tests. Several tests were cut due to overspeed when the speed suddenly increased while running at steady conditions. The last test was cut by the automatic g-level redline when the tester vibration level increased to 11.5 g p-p.

The LOX seal leakage at 2758 kPa (400 psig) was consistent through the test series at 0.041 to 0.048 m^3/s (88 to 103 SCFM). The leakage is approximately the same as the previous test series and indicates satisfactory seal performance.

The helium seal leakage was also approximately the same as the previous test series with a variation from 0.020 to 0.022 m^3/s (44 to 47 SCFM) at 345 kPa (50 psig) purge pressure.

Build 19 Disassembly

The tester was removed for inspection after 2.27 hours due to a sudden increase in vibration level.

The inspection revealed the tester thrust bearing to be failed. The bearing failure was detected in the preliminary stage before excessive damage was encountered. The tester hardware was in good condition, except the outboard slave seal carbon was broken by excessive shaft runout when the bearing failed.

The LOX seal was in good condition with no measurable wear. The carbon face was polished with some light circumferential scratches and slight chipping at the inside of the lift pads and dam. The mating ring had a polished contact pattern with faint circumferential marks. The hardware appeared to be in the same condition as the previous inspection (Build 18).

The helium seal was in good condition with no significant wear. The carbon ring was polished with some light circumferential scratches. The mating ring had a slight rub pattern. The rubbing probably occurred after the bearing failed.

Build 20 Assembly

The tester was reassembled with the same seal hardware without rework, except the helium mating ring OD was burnished to remove the rub pattern. New bearings and a new outboard slave carbon were installed.

The tester rotating assembly was rebalanced as a precaution because of the two bearing failures (Builds 18 and 19).

The test facility was modified to separate the LOX seal cavity return line to allow increasing the bearing coolant flow and decreasing the bearing cavity pressure. It was concluded that the bearing failures were caused by excessive thrust load and insufficient coolant flow. The thrust load was reduced by lowering the bearing cavity pressure.

Tests 272 - 295

The test objective was an additional 3.41 hours at 2758 kPa (400 psig) LOX seal pressure to complete the required 10 hours on the test seal for a total accumulated time of 20 hours.

A total of 24 tests for 3.41 hours was performed to achieve the test objective and complete the Phase I, Schedule II testing. Several tests were cut due to overspeed when the tester speed suddenly increased for no apparent reason. The speed was reduced to approximately 28,000 rpm to maintain stable speed control.

The bearing cavity pressure was reduced and the bearing coolant flowrate was increased to lower the tester bearing thrust load and improve the bearing cooling for longer bearing life.

The LOX seal leakage at 2758 kPa (400 psig) was 0.053 to 0.060 m^3/s (113 to 128 SCFM). The leakage increased slightly from the previous test series; however, the increase is not considered significant and the higher leakage is satisfactory.

The helium seal leakage was approximately the same as the previous test series.

Build 20 Disassembly

The tester was removed for inspection due to completion of the Phase I test objective. The inspection after a total time of 10 hours on the LOX seal and 9.6 hours on the helium seal revealed the seals to be in good condition. The LOX seal carbon was polished with faint circumferential rub marks and scratches. The surface profile traces (Fig. 69) of the carbon dam and lift pads indicate no measurable wear during the 10 hours of testing. The secondary element piston ring and carrier ring sealing surface were in good condition with no visible degraduation. The mating ring had a polished contact pattern with faint circumferential rub marks.

The helium seal was in good condition with no significant wear. The carbon ring was polished with slight circumferential rub marks. The mating ring had a uniform rub pattern with a light carbon deposit.

The seal hardware condition is shown on Fig. 70 through 79.

PHASE III LIQUID OXYGEN ACCELERATION TEST

Build 21 Assembly

The tester was reassembled with a new set of Phase III seals for initiation of the Phase III acceleration testing. A new Rayleigh Step pad LOX seal with P692 carbon seal ring and a Vespel SP21 piston ring was installed with a new mating ring.

A new floating ring Rayleigh Step pad helium seal was installed with the same Z shaped mating ring that was used on Builds 19 and 20. The mating ring was cleaned to remove the carbon deposit from rubbing contact. A new seal end thrust bearing was installed as a precaution to ensure running for the planned 5 hours. The same cover end bearing was reinstalled. The bearings were in good condition after 3.41 hours on Build 20 with the increased coolant flowrate and reduced thrust.

Tests 296 - 347

The test objective was 50 acceleration tests to 32,000 rpm in 10 seconds or less with a simultaneous LOX seal pressure increase from 137.3 to 2758.0 kPa (20 to 400 psig) for a total time of 5 hours.

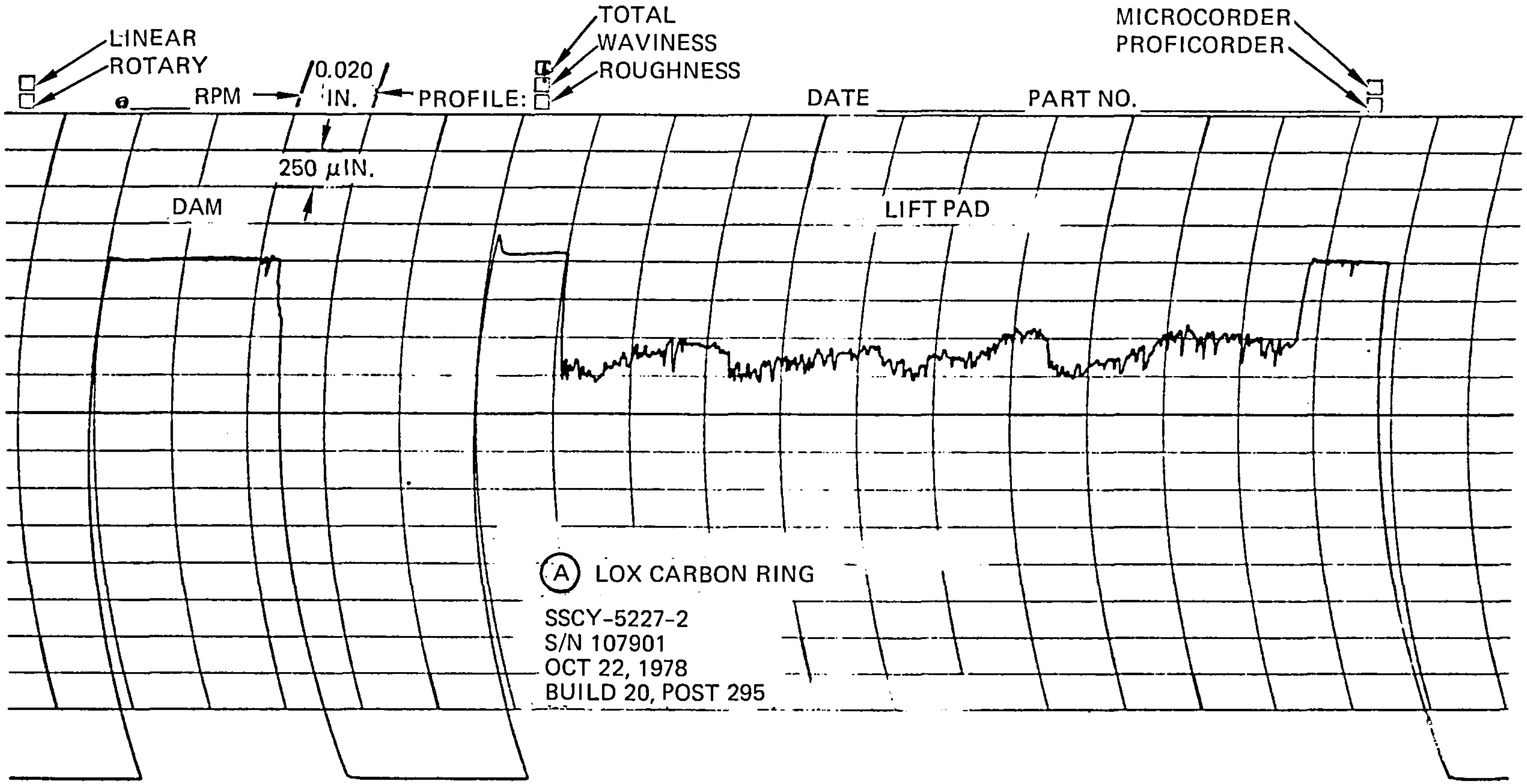


Figure 69. Typical Surface Profile Trace LOX Seal Carbon Ring CF851218-1 (SSCY-5227-2), S/N 01, Posttest 295, Build 20 After 10 Hours

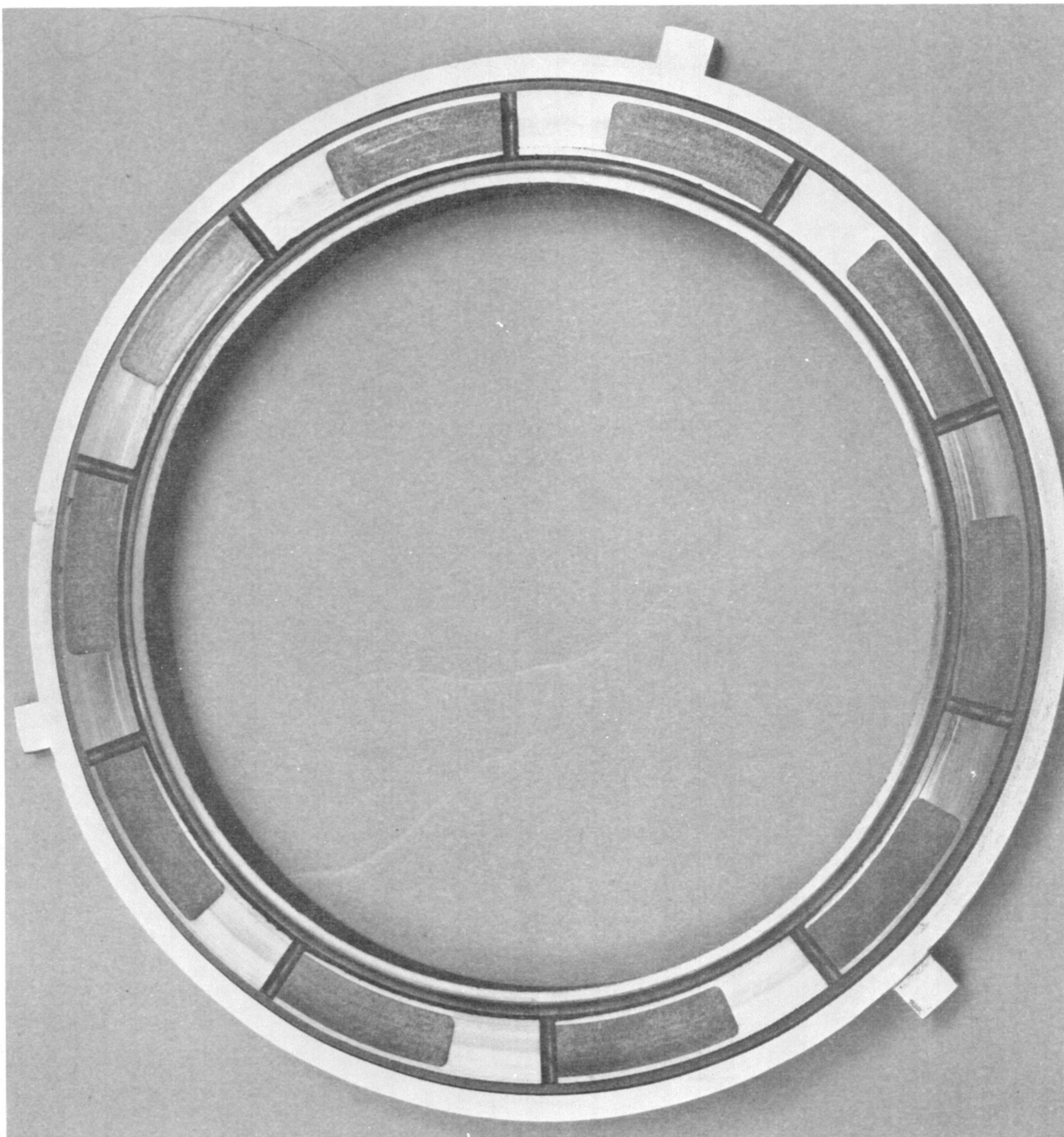


Figure 70. LOX Seal Carbon Ring CF851218-1, S/N 01 (Phase III P692 Carbon), Posttest 295, Build 20 After 10 Hours

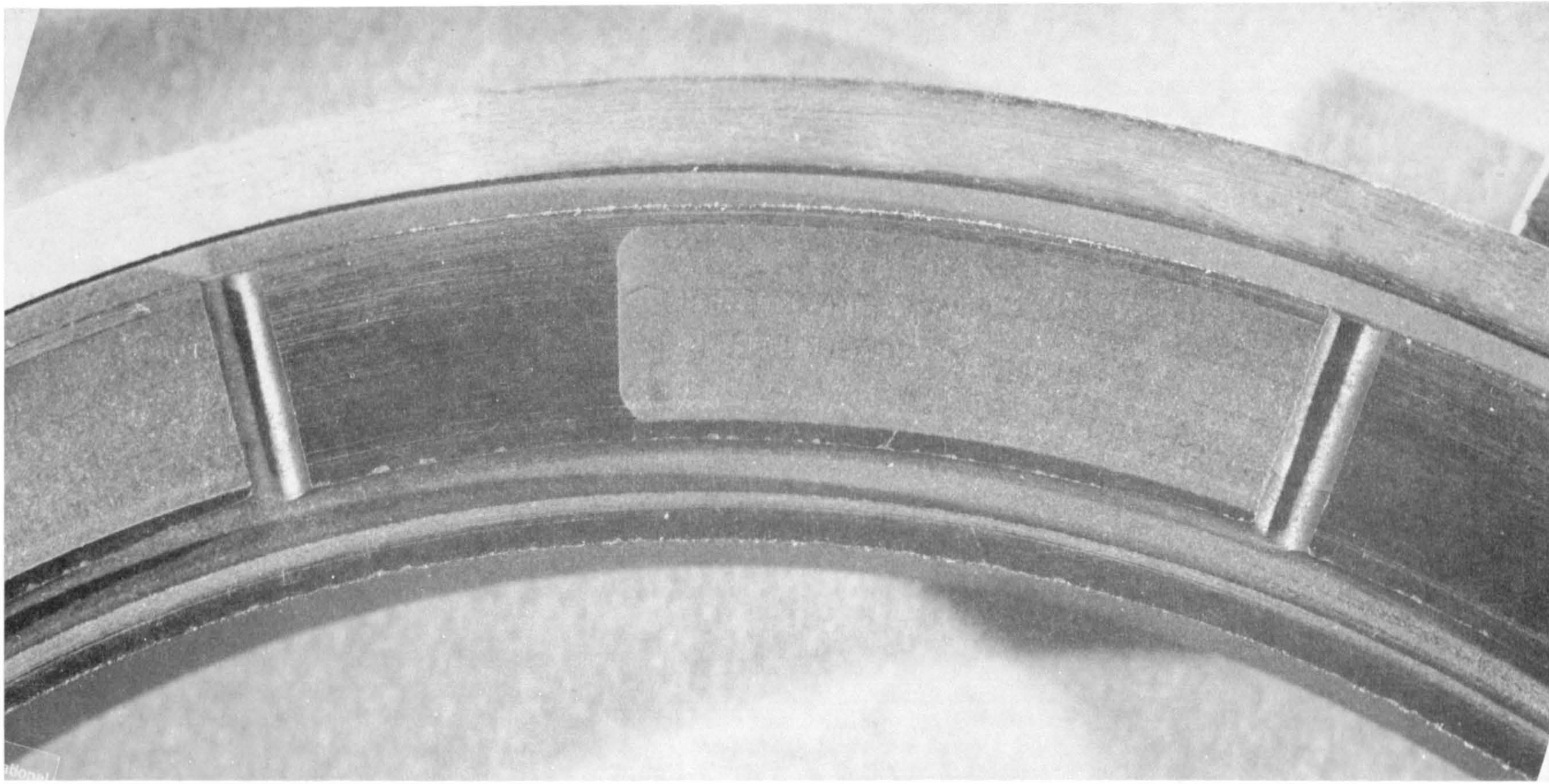


Figure 71. LOX Seal Carbon Ring CF851218-1, S/N 01, Typical Lift Pad, Posttest 295, Build 20 After 10 Hours

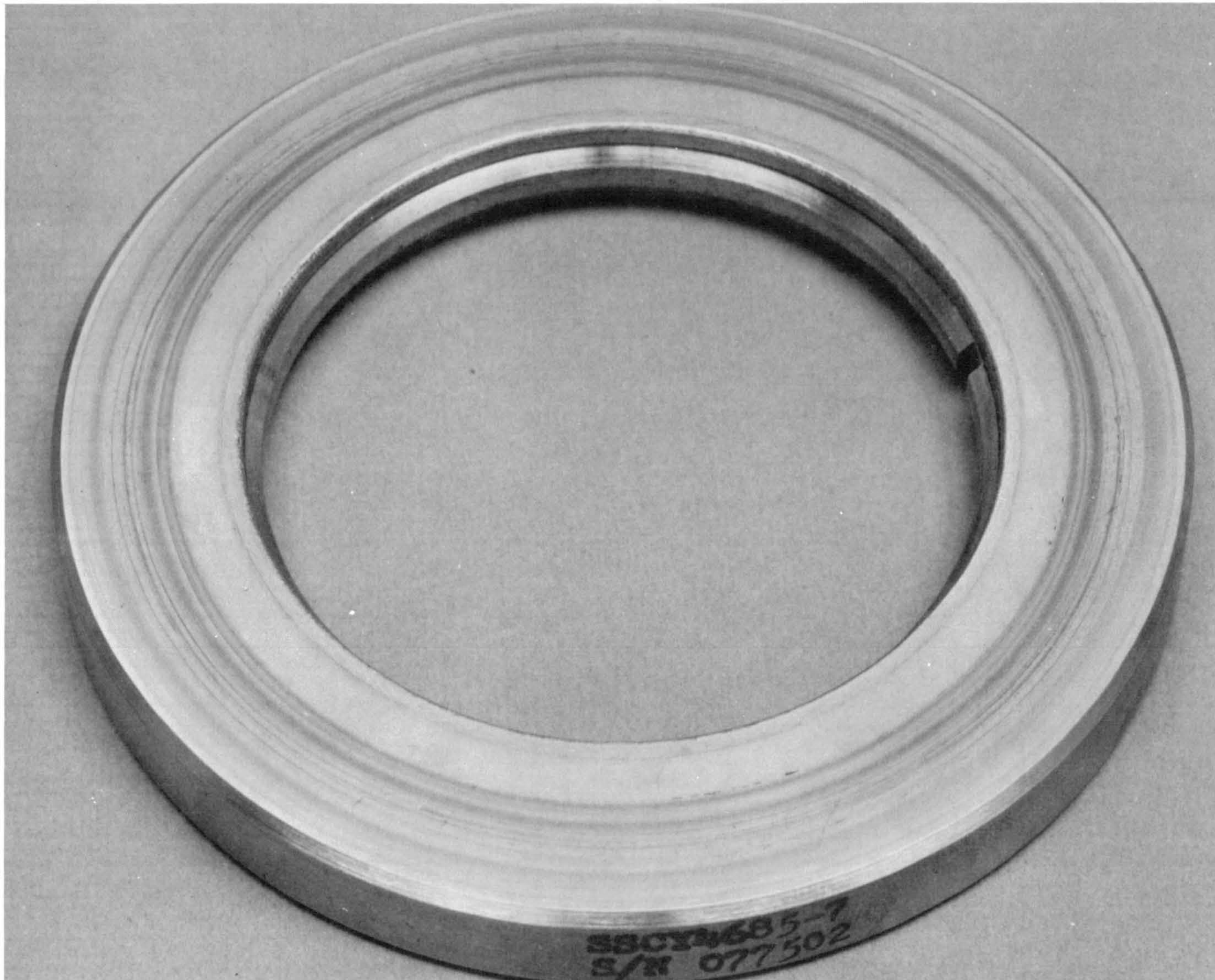


Figure 72. LOX Seal Mating Ring CF 851226, S/N 02, Posttest 295, Build 20
After 10 Hours

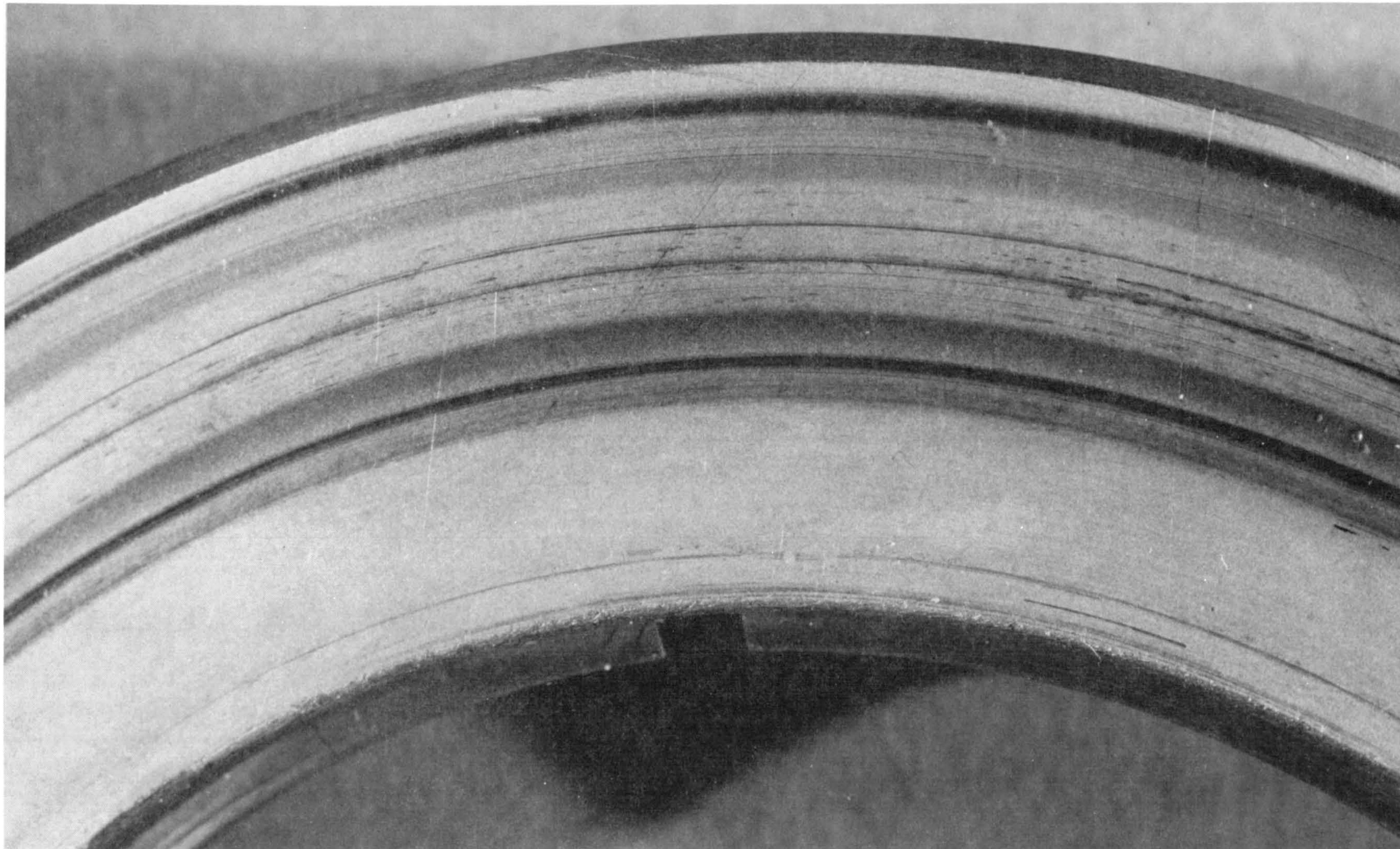


Figure 73. LOX Seal Mating Ring CF851226, S/N 02, Posttest 295, Build 20 After 10 Hours

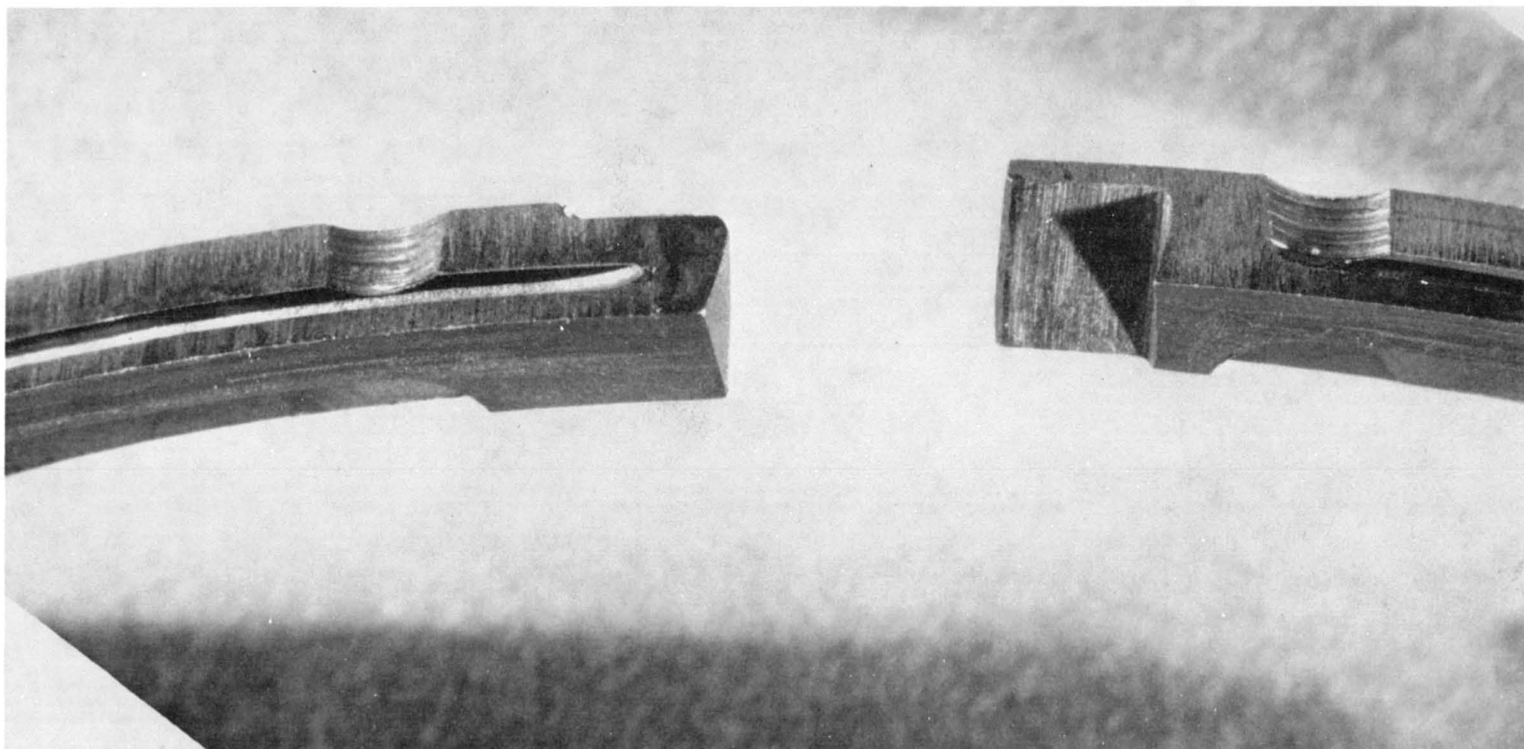


Figure 74. LOX Seal Piston Ring CF850816-005, S/N 01 (Vespel SP21), Posttest 295, Build 20 After 10 Hours

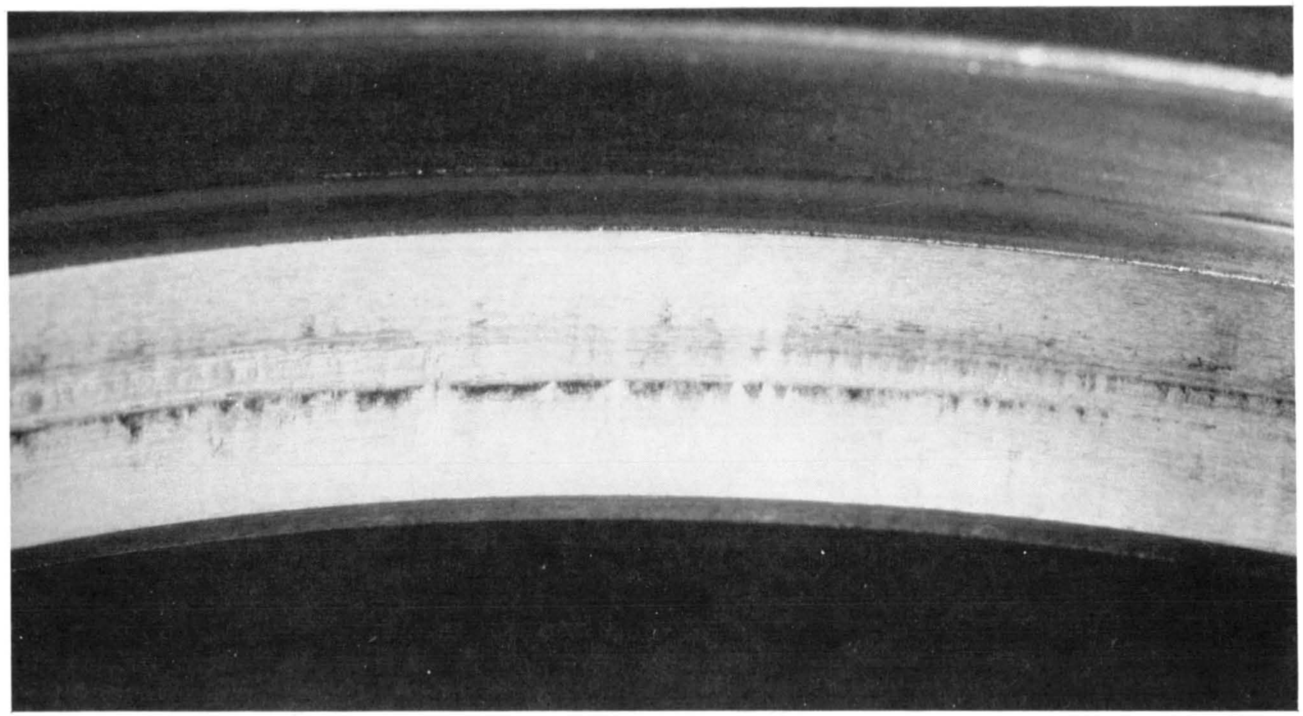


Figure 75. LOX Seal Carrier Ring CD851298, S/N 04, Piston Ring Sealing Surface, Posttest 295, Build 20 After 10 Hours

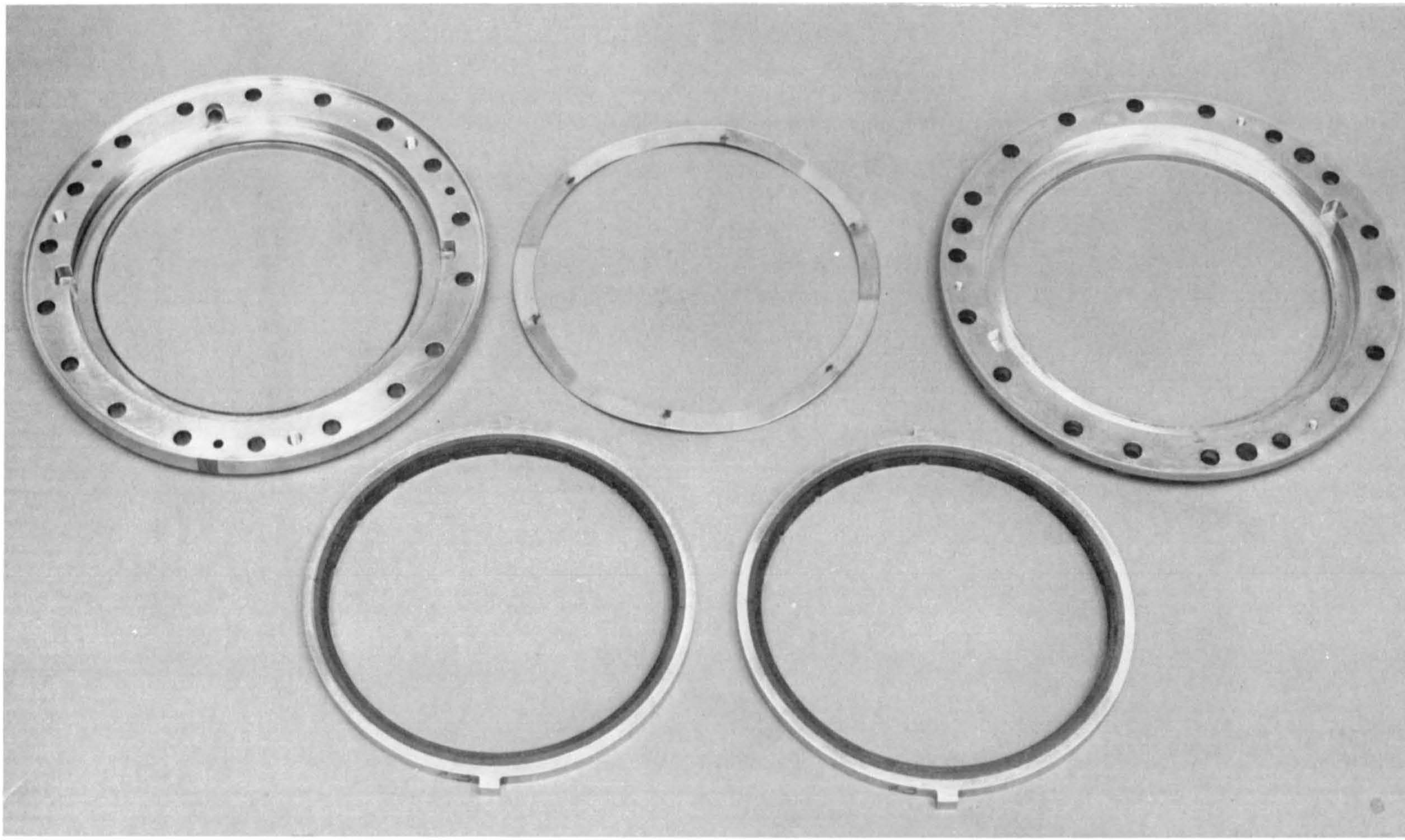
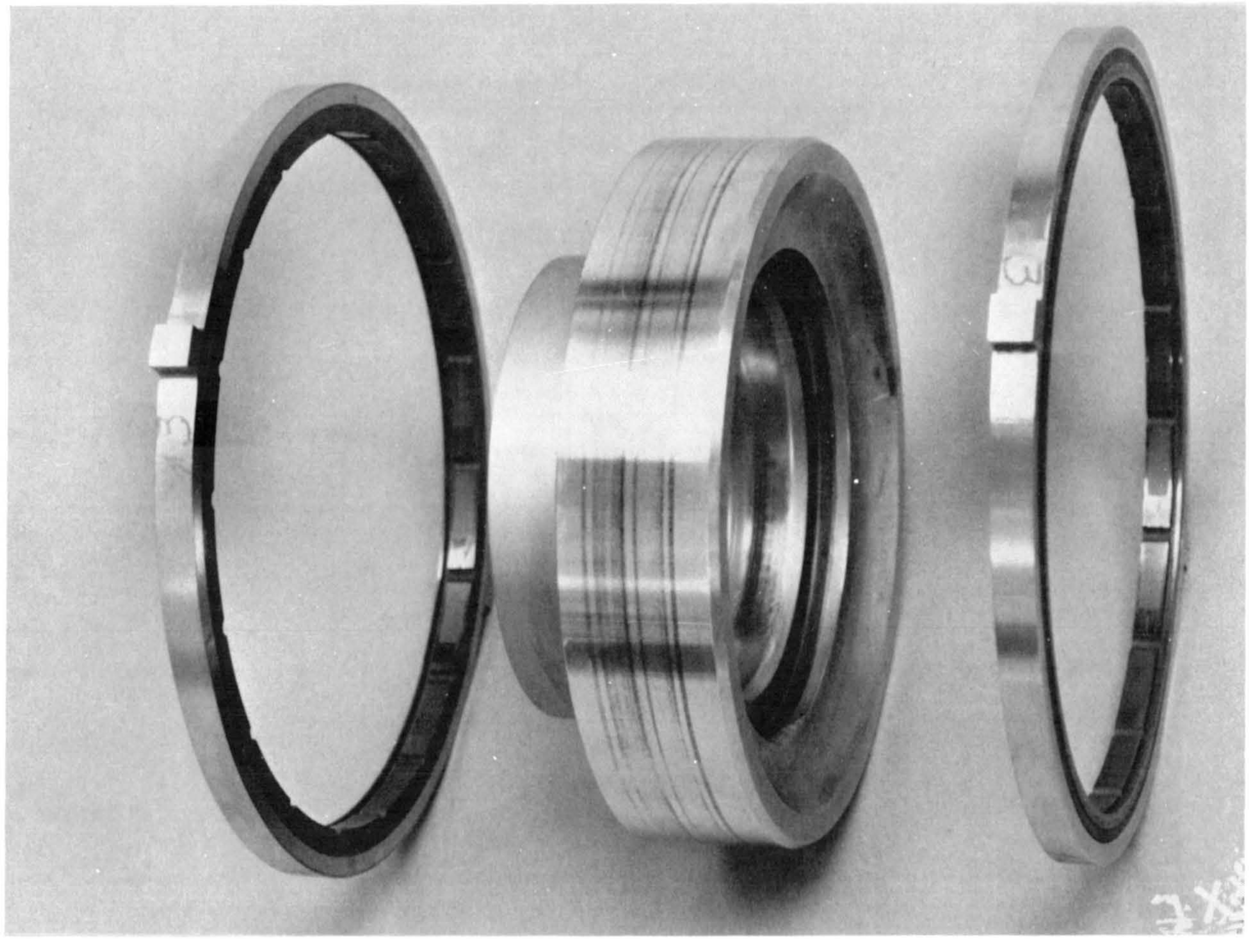


Figure 76. Helium Seal Assembly 99RS006215, S/N 03, Posttest 295, Build 20
After 9.6 Hours



LOX SIDE TURBINE SIDE

Figure 77. Helium Seal 99RS006215, S/N 03, and Mating Ring RS0010476X, S/N 001, Posttest 295, Build 20 After 9.6 Hours

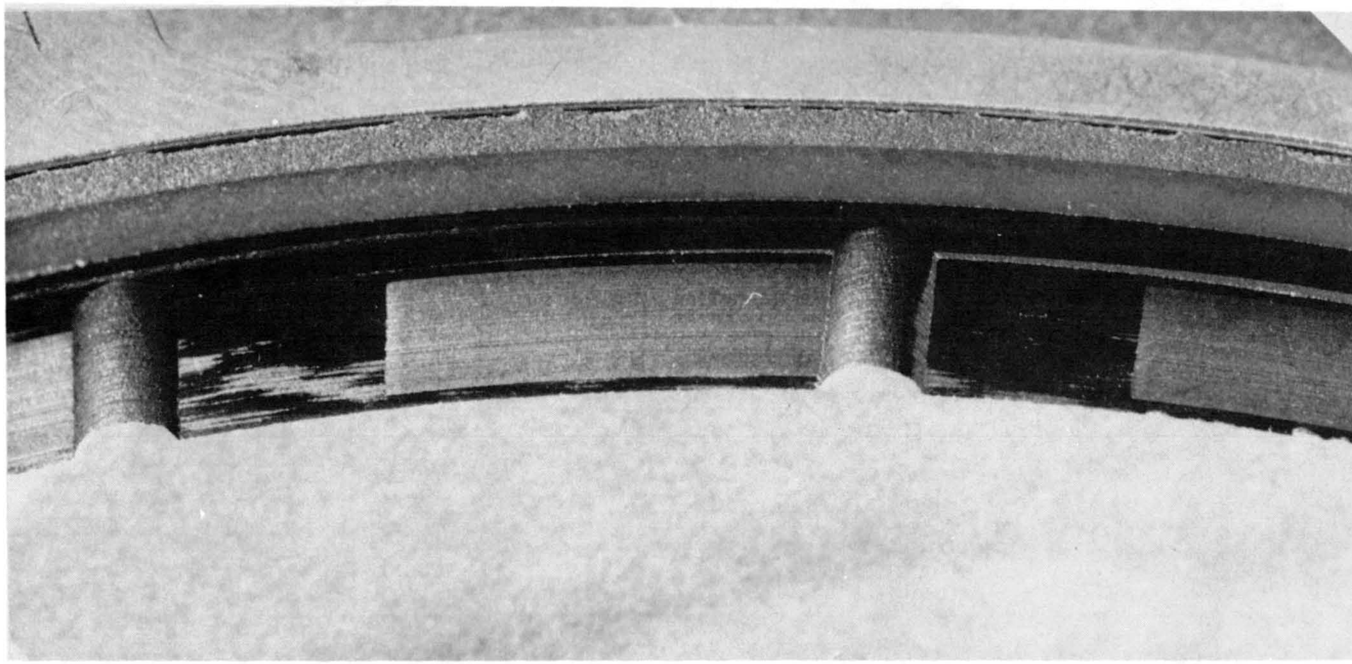


Figure 78. Helium Seal Typical LOX Side Carbon Ring 99RS006215, S/N 03, Posttest 295, Build 20 After 9.6 Hours

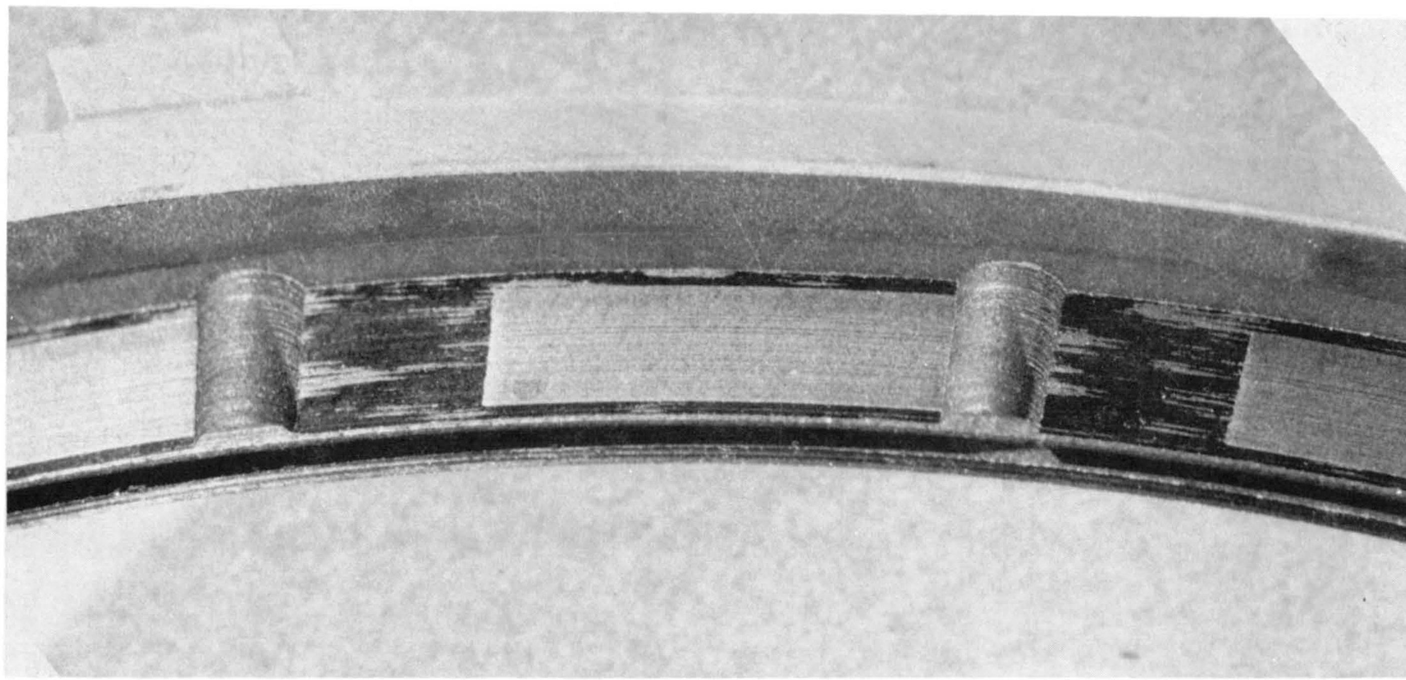


Figure 79. Helium Seal Typical Turbine Side Carbon Ring 99RS006215, S/N 03, Posttest 295, Build 20 After 9.6 Hours

A total of 52 tests for 3.94 hours was performed. The tester was removed for inspection prior to the planned 5 hours due to intermittent high vibration and abnormal noise during the post test torque check. Twenty-one tests were cut due to exceeding the 10 g peak-to-peak redline. Since all other parameters indicated satisfactory operation, the g-level redline was increased to 20 g on test 334. The vibration level varied from 6 g peak to peak to 20 g peak to peak on the remaining tests.

The acceleration teats were accomplished by pressurizing the drive turbine to accelerate the tester to approximately 32,000 rpm within 2 seconds. The LOX seal pressure was increased from approximately 20 psig to 400 psig during the same time period by opening a motorized valve between the facility LOX pump discharge and the LOX seal cavity.

The LOX seal leakage at 2758 kPa (400 psig) was 0.045 to 0.059 m^3/s (96 to 126 SCFM). The leakage is in the same range as the previous seal and indicates satisfactory performance.

The helium seal leakage at 345 kPa (50 psig) purge pressure was 0.019 to 0.022 m^3/s (41 to 48 SCFM) and was generally higher after the initial tests, indicating wear.

<u>Build 21 Disassembly</u>

Inspection revealed the LOX side helium seal ring had lost clearance to the mating ring and worn a groove approximately 0.0076 to 0.0100 cm (0.003 to 0.004 in.) deep into the chrome plated surface (Fig. 80). The LOX side carbon seal ring was worn 0,0038 cm (0.0015 in.) diametral and scored from rubbing contact. The LOX side lift pads were worn completely off. The turbine side mating ring surface was scored and the carbon was worn 0.0033 cm (0.0013 in.) diametral.

The high tester vibration and abnormal noise posttest apparently were caused by the failed helium seal.

The helium seal ring diametral clearance was 0.0150 cm (0.0059 in.) pretest compared to 0.0193 cm (0.0076 in.) on the previous successful seals. The lower seal clearance apparently is insufficient to provide for the clearance decrease due to thermal contractions and centrifugal growth. A new mating ring was reworked to provide 0.0190 to 0.0203 cm (0.0075 to 0.0080 in.) diametral clearance on the next build.

The LOX seal and mating ring were in good condition. The carbon was polished with no measurable wear. The mating ring surface had a light carbon deposit with circumferental marks and three small sysmetrical dark spots (Fig. 81). The dark spots apparently result from rubbing contact during transient operation due to a resonant frequency deflection of the mating ring. The spots are not considered a problem unless wear occurs.

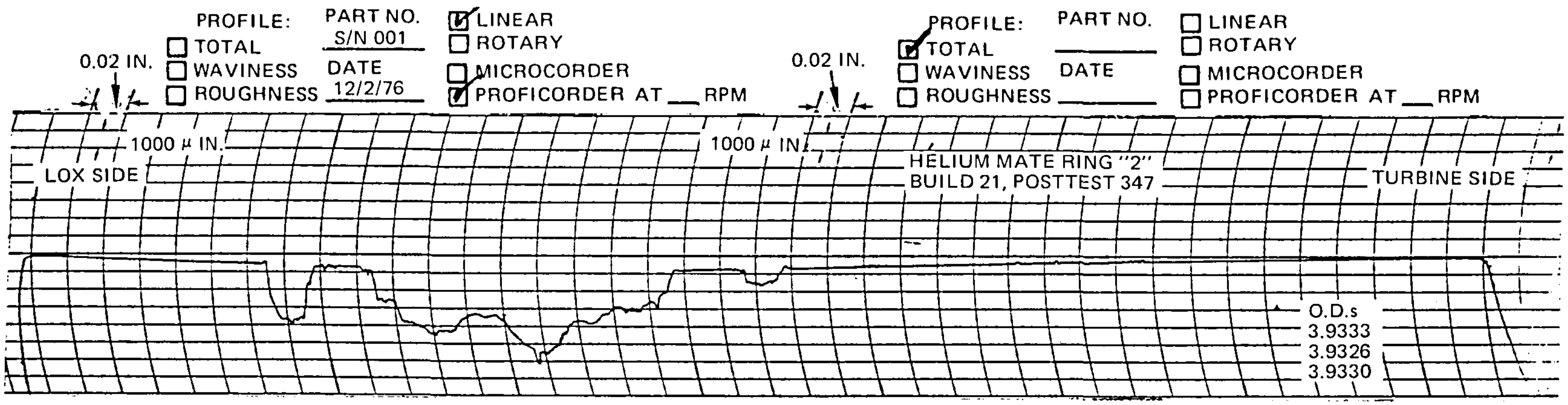


Figure 80. Surface Profile Trace of Helium Seal Mating Ring RS010476X, S/N 001-1, Posttest 347, Build 21

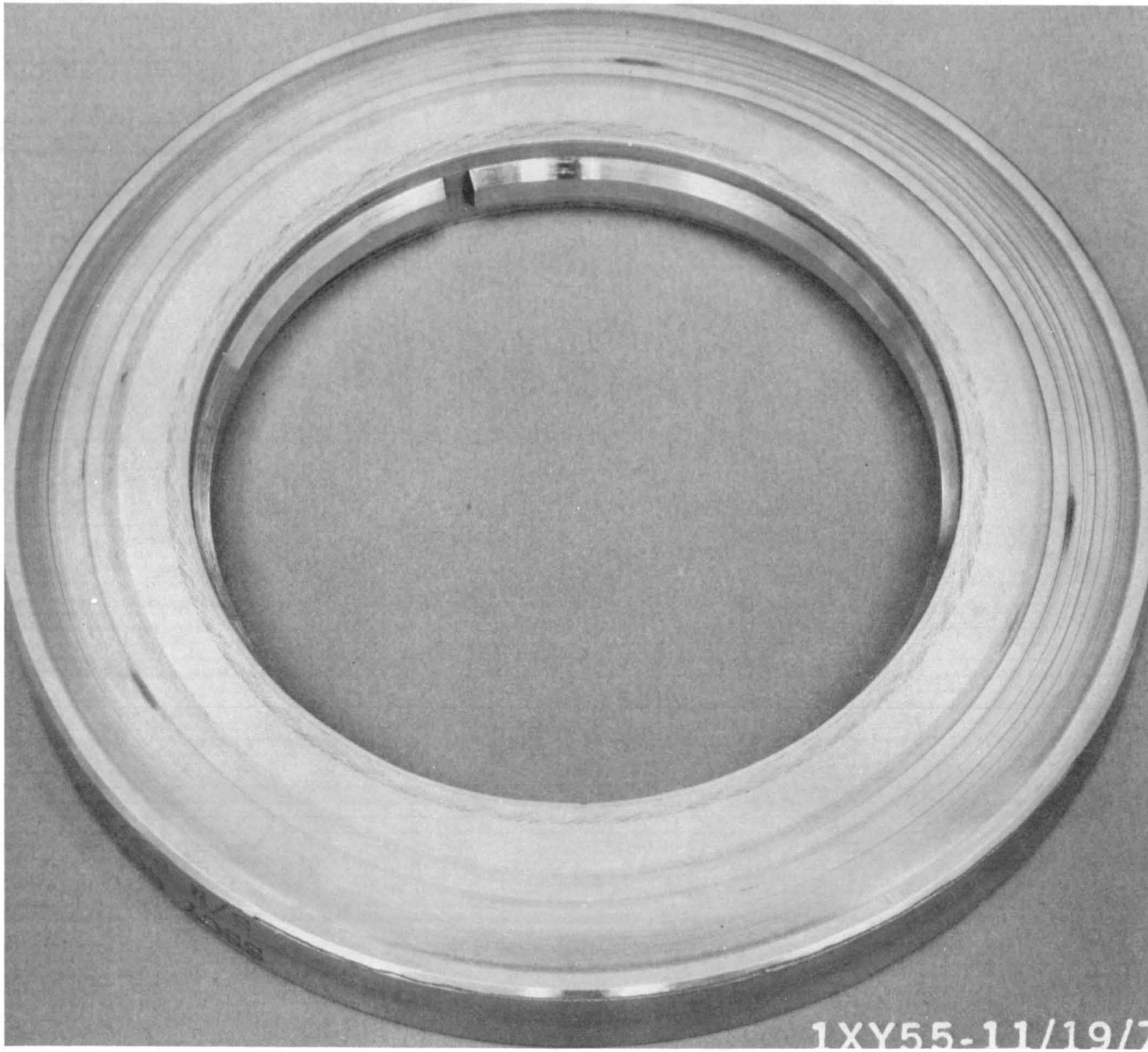


Figure 81. LOX Seal Mating Ring CF851226, S/N 05, Posttest 347, Build 21 After 3.94 Hours

Build 22 Assembly

The tester was reassembled with the same LOX seal and mating ring without rework.

A new floating ring Rayleigh Step pad helium seal was installed with a new Z shaped mating ring which had been reworked by grinding the outside diameter and replating to increase the seal ring clearance. The diametral clearance was increased from 0,0152 to 0.0203 cm (0.0060 to 0.0080 in.) due to the wear which occurred on Build 21.

The rotating assembly was rebalanced with the new helium mating ring. A new seal end thrust bearing was installed. The same cover end bearing was reinstalled.

Tests 348 - 417

The test objective was 50 acceleration tests to 32,000 rpm in 10 seconds or less with a simultaneous LOX seal pressure increase from 138 to 2758 kPa (20 to 400 psig) for a total time of 5 hours.

A total of 70 tests for 5.23 hours was performed to complete the test objective. Stable data were obtained on all but seven of the tests. The LOX seal leakage varied from 0.050 to 0.032 m^3/s (107 to 69 SCFM) at approximately 2758 kPa (400 psig) and generally decreased during the test series, indicating excellent seal performance. The leakage was generally less than on Build 21 when the seal was new.

The helium seal leakage at 345 kPa (50 psig) purge pressure was steady at approximately 0.020 to 0.021 m^3/s (44 to 46 SCFM). The leakage did not change during the test series, indicating no wear or deterioration.

Build 22 Disassembly

Inspection revealed both seals to be in good condition. The LOX seal carbon was polished with no measurable v?ar. The mating ring had a light carbon deposit with circumferential marks and appeared the same as pretest 348. The three small symmetrical dark spots which were present post test 347, appeared to smooth out and were nearly gone.

The helium seal with the seal ring clearance increased to 0.0203 cm (0.0080 in.) diametral was in good condition with no significant wear. The mating ring had a carbon deposit from rubbing contact which was heavier on the LOX side.

The seal ring diametral clearance was the same post test as pretest. The increased clearance was apparently sufficient to provide for the clearance decrease due thermal contraction and centrifugal growth which caused the failure on Build 21.

Build 23 Assembly

The tester was reassembled with the same LOX and helium seal hardware without rework, except the LOX seal carbon was lapped and the helium seal mating ring was cleaned.

The tester bearings were replaced with slightly used bearings.

Tests 418 - 490

The test objective was 60 acceleration tests from 0 to 32,000 rpm in 10 seconds or less with a simultaneous LOX seal pressure increase from 138 to 2758 kPa (20 to 400 psig). The scheduled test duration was 6 minutes each for 6 hours total.

A total of 73 tests for 6.11 hours was performed to complete the test objective. This 6 hours increased the total time on the Phase III seal hardware to 15.28 hours, completing the Phase III objective.

The LOX seal leakage varied from 0.054 to 0.042'a3/s (117 to 90 SCFM) at approximately 2758 kPa (400 psig) sealed pressures and generally decreased during the test series. The leakage was similar to Build 21 when the seal was new.

The helium seal leakage at 345 kPa (50 psig) purge pressure was steady from 0.019 to 0.022 m^3/s (42 to 48 SCFM). The leakage did not change during the test series, indicating no wear or deterioration.

Build 23 Disassembly

Inspection revealed both seals to be in good condition. The LOX seal mating ring is shown in Fig. 82 and 83. The mating ring surface had a light contact pattern with four symmetrical spots in the area near the center of the lift pads. Profile measurements (Fig. 84) indicated the maximum height of the spot near the antirotation slot was 0.00038 cm (0.000150 in.) The carbon ring was worn on the surface of the lift pads by the mating ring high spots as shown in Fig. 85 and 86. Profile measurements (Fig. 87) indicated the wear depth was 0.00063 cm (0.000250 in.). The LOX seal carbon face wear was 0.00025 cm (0.0001 in.). Static leakage posttest increased 22% compared with pretest.

The helium seal hardware was in good condition as shown in Fig. 88 through 91. The mating ring had a carbon deposit from rubbing contact which was heavier on the LOX side. The LOX side carbon ring lift pad recesses were reduced 0.00025 cm (0.0001 in.) due to wear. The turbine side carbon ring indicated no wear.

PHASE IV RAYLEIGH STEP LOX CHECKOUT TEST

Build 1 Assembly

The tester was assembled with new Phase IV LOX and helium seal hardware. The LOX seal consists of a Phase III type Rayleigh Step hydrodynamic carbon P692

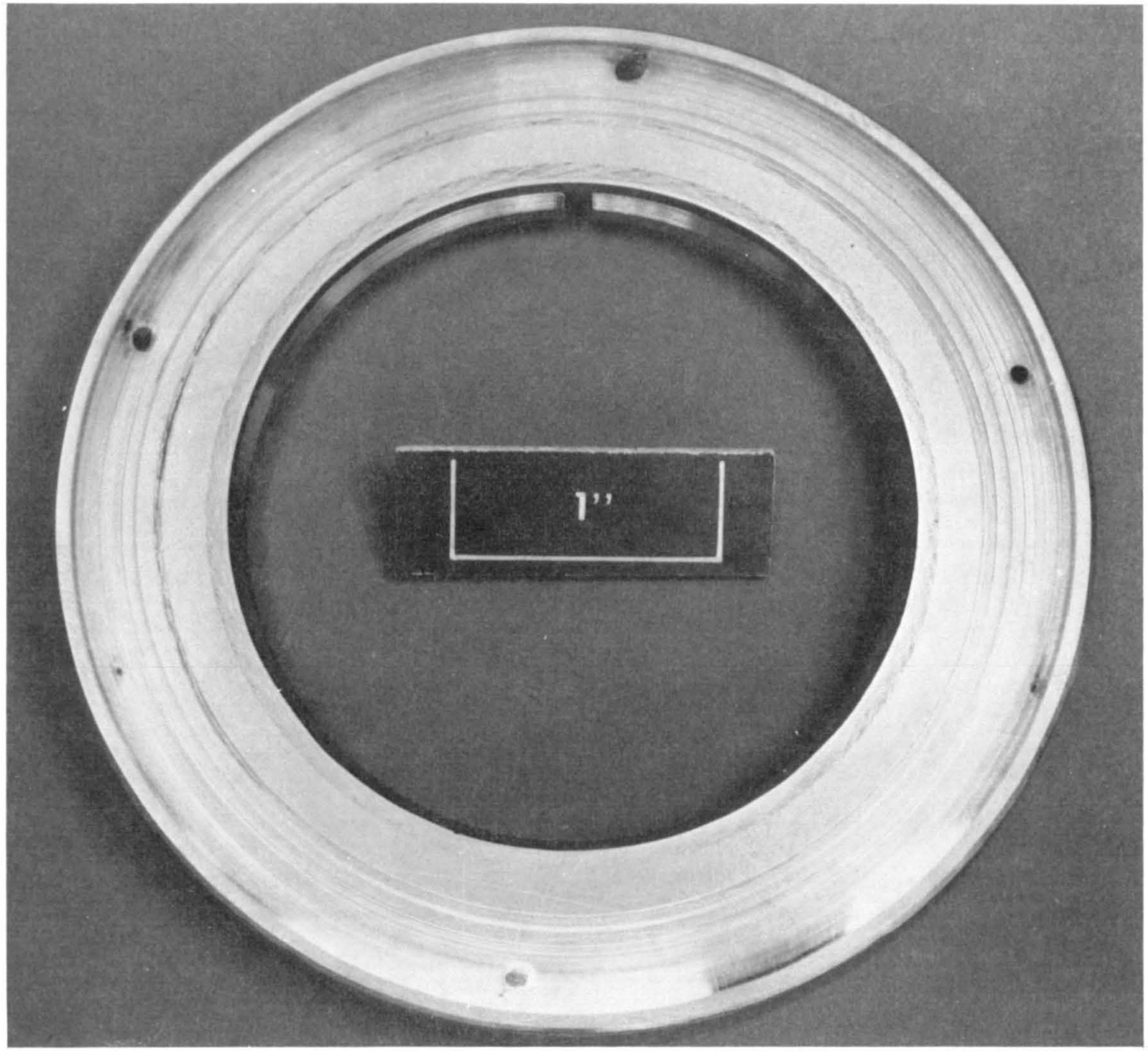


Figure 82. LOX Seal Mate Ring CF851226, S/N 05, Posttest 490, Build 23 After 15.28 Hours

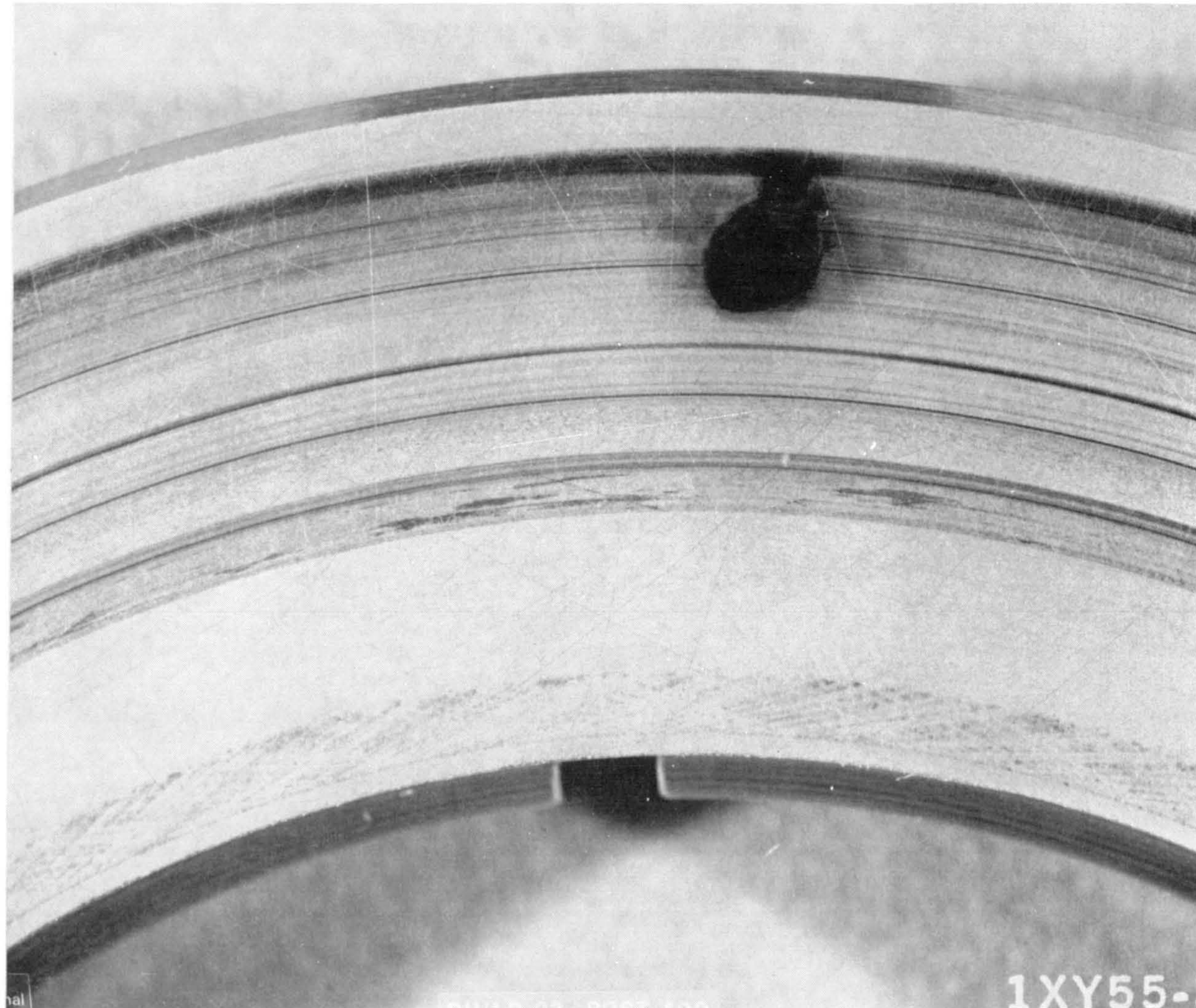


Figure 83. LOX Mate Ring CF851226, S/N 05, Posttest 490, Build 23 After 15.28 Hours

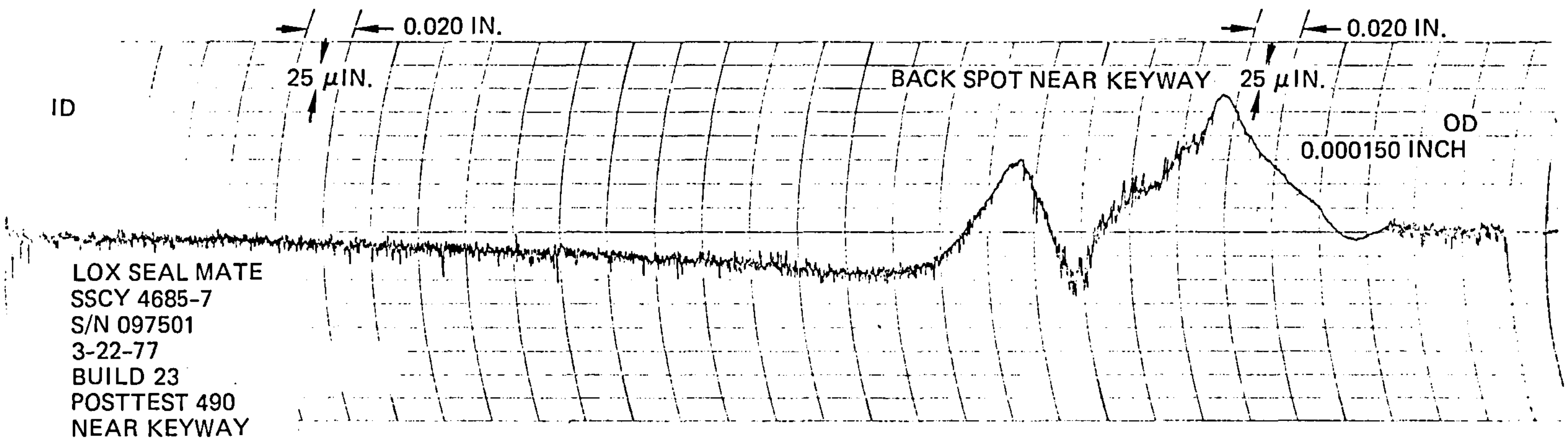


Figure 84. Surface Profile Trace at High Spot on LOX Mate Ring CF851226, S/N 05, Posttest 490, Build 23 After 15.28 Hours

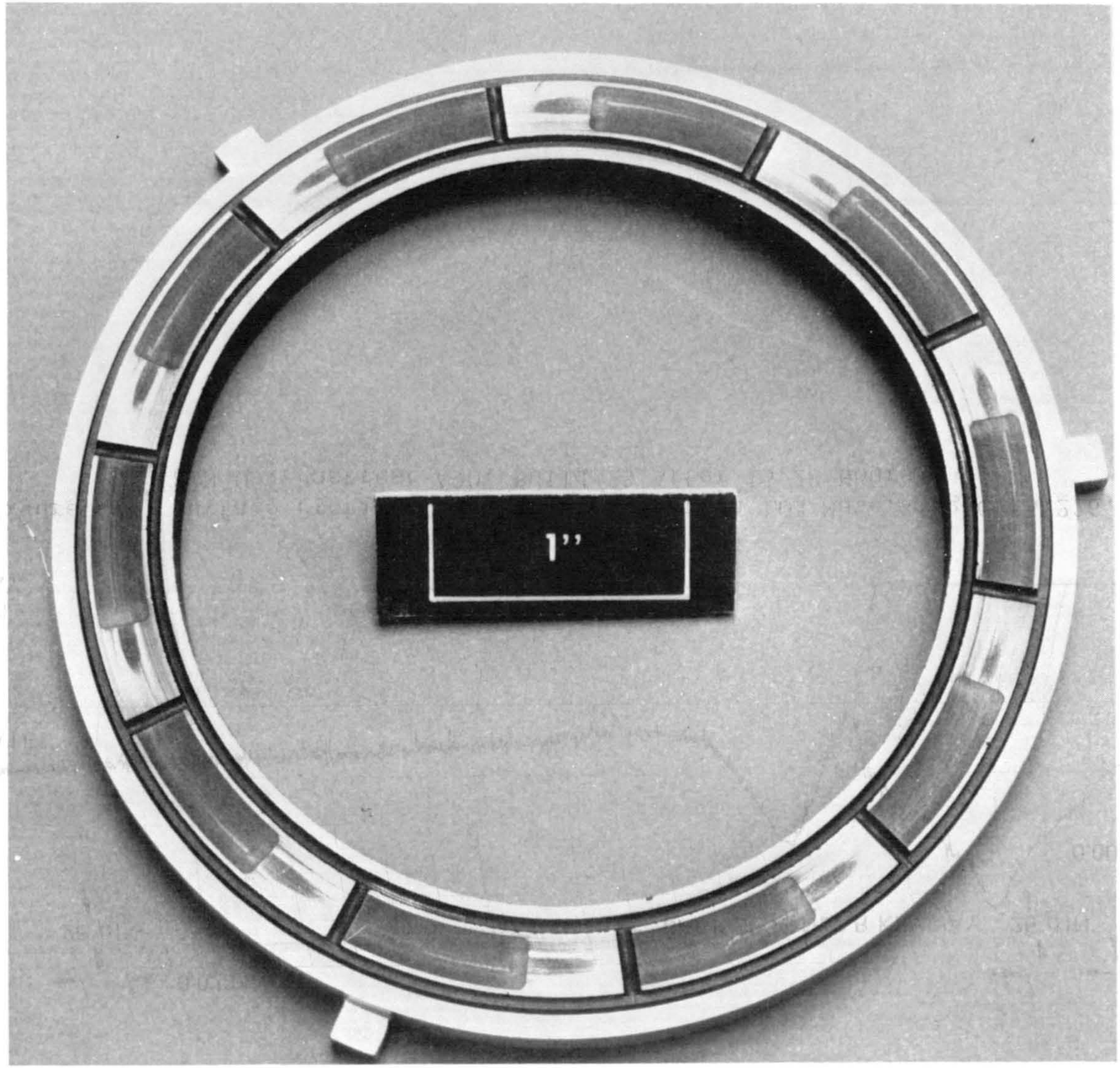


Figure 85. LOX Seal Carbon Ring CF851218-1, S/N 02 (Phase III P692 Carbon), Posttest 490, Build 23 After 15.28 Hours

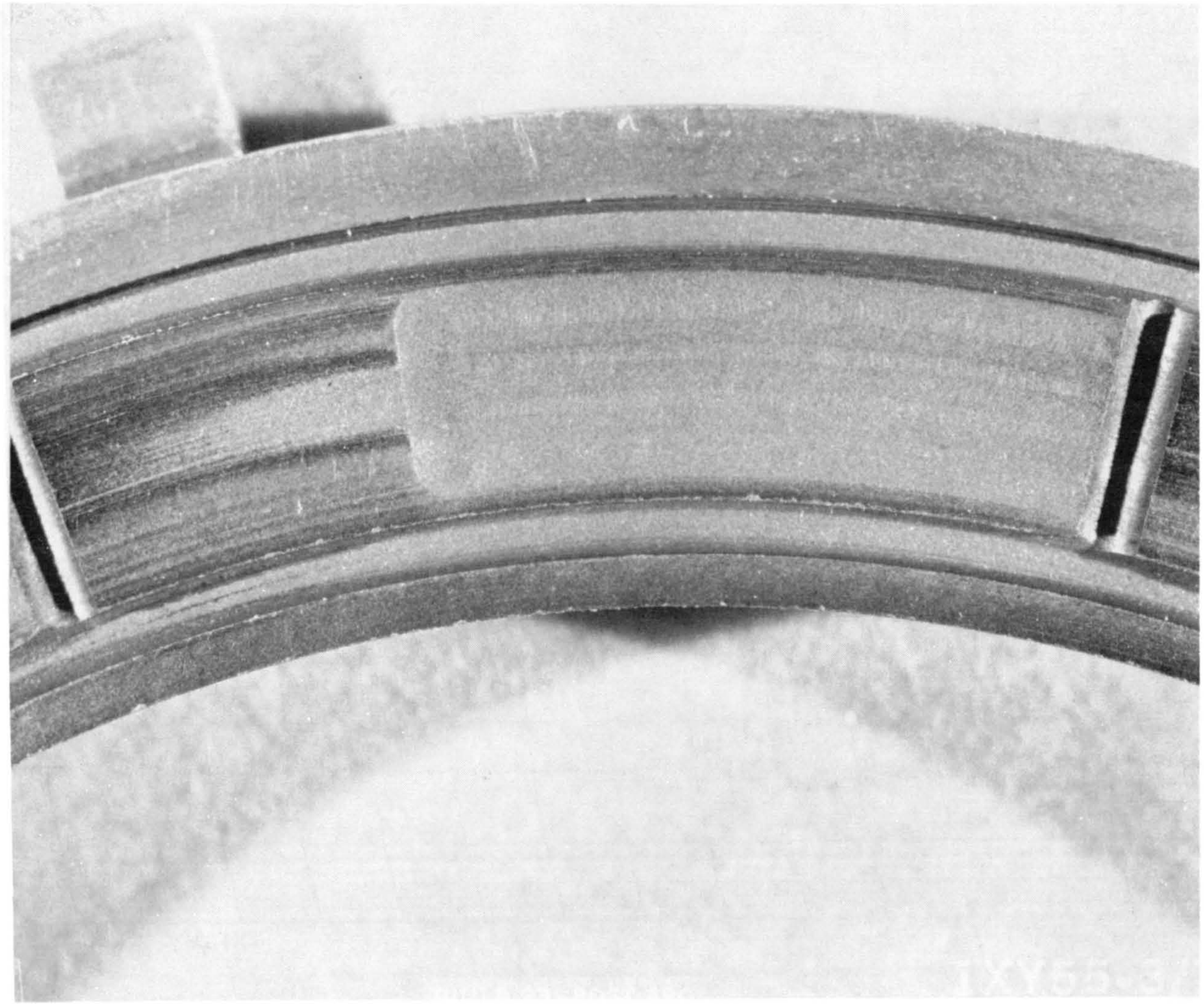


Figure 86. LOX Seal Carbon Ring CF851218-1, S/N 03, Typical Lift Pad, Posttest 490, Build 23 After 15.28 Hours

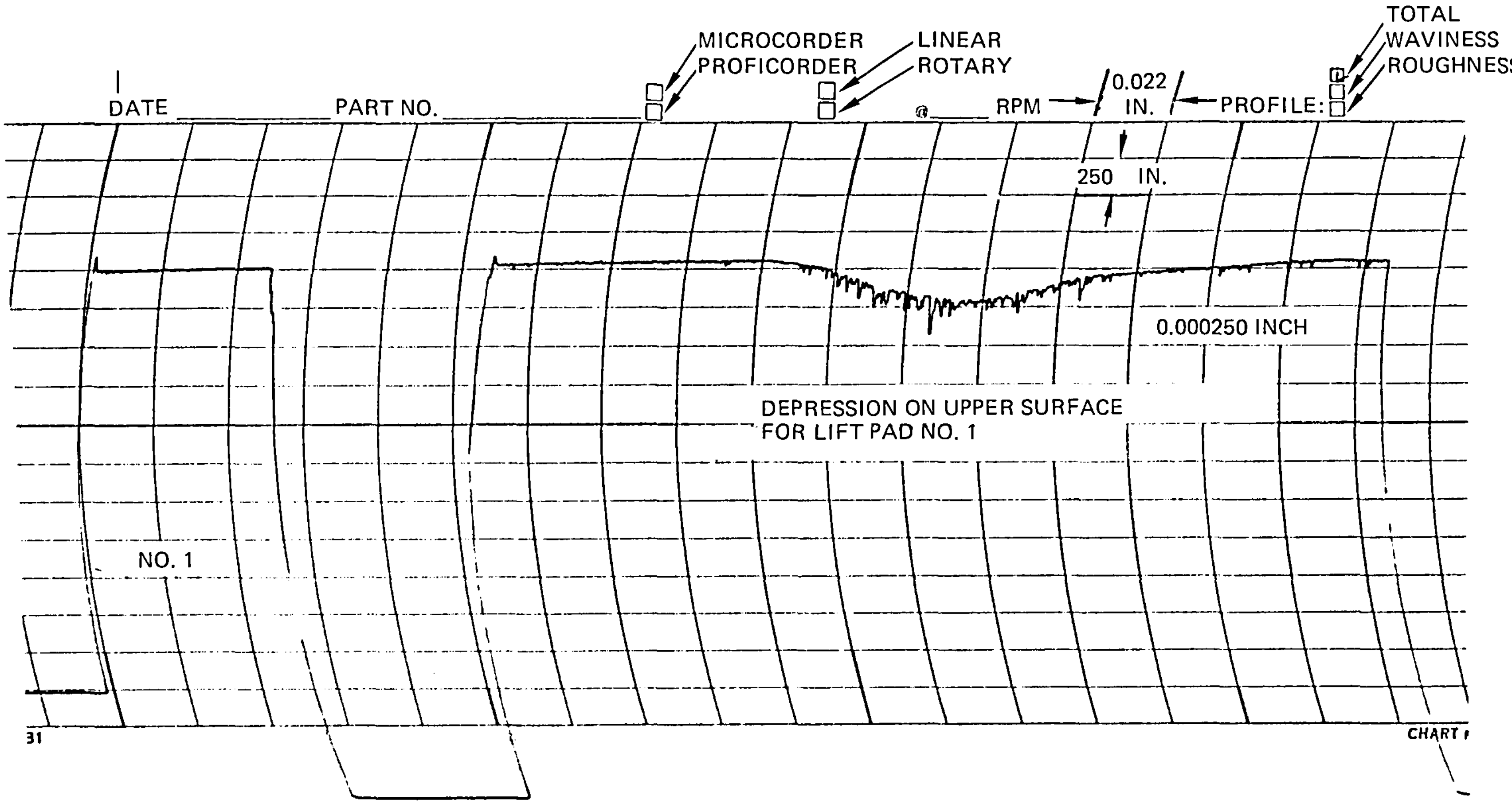
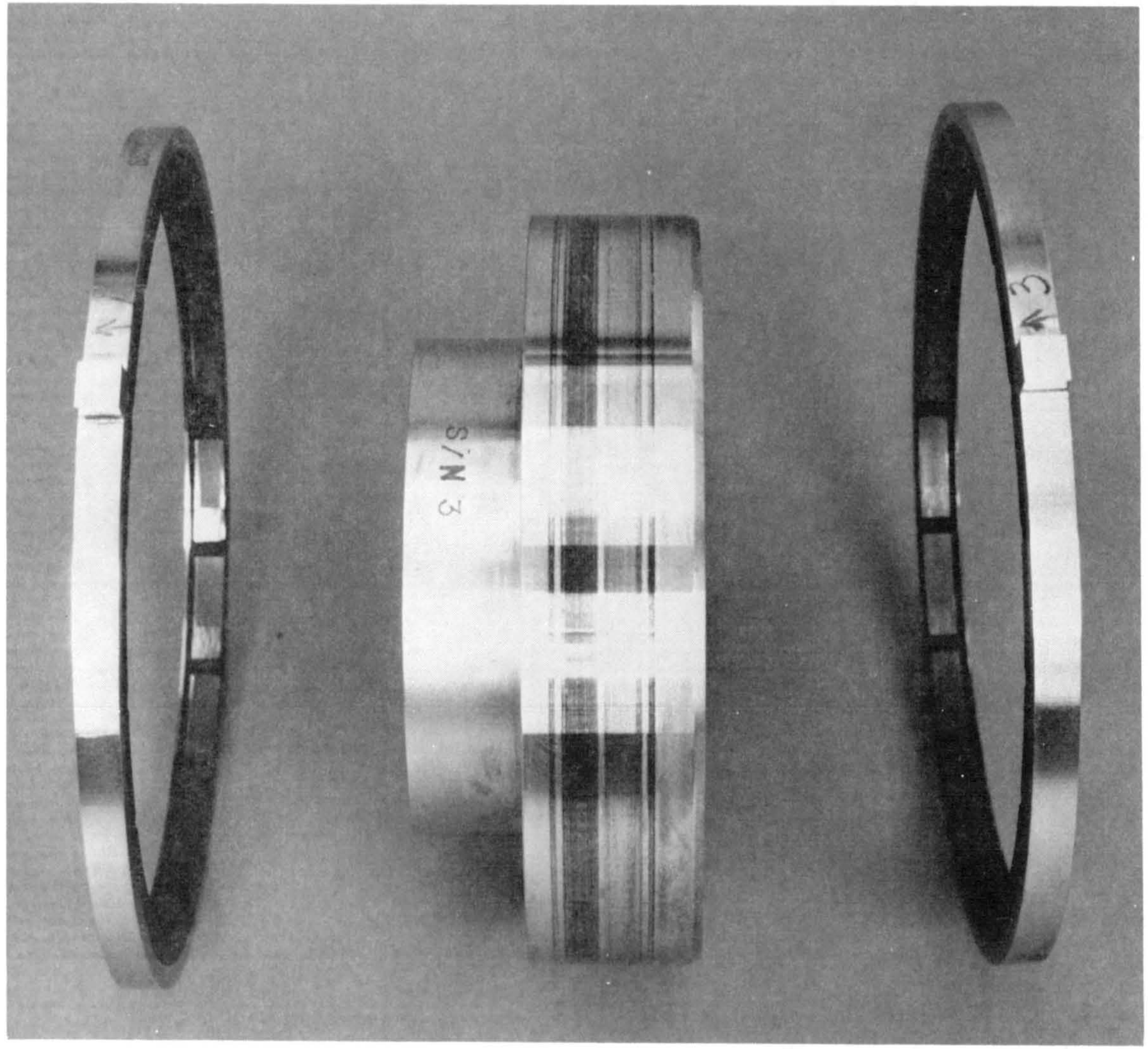
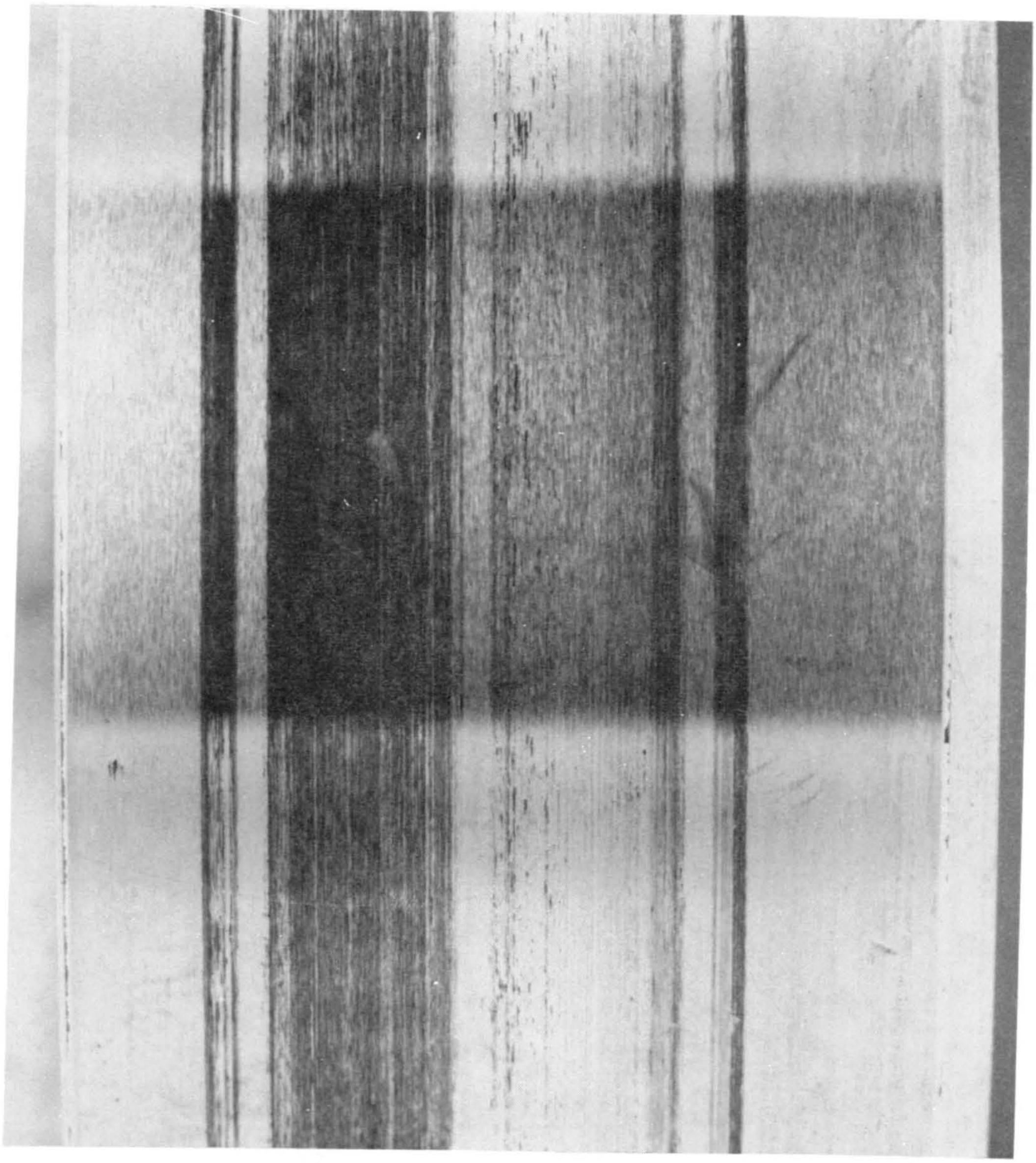


Figure 87. Surface Profile at Wear Spot, Lox Seal Carbon Ring CF851218-1, S/N 02, Posttest 490, After 15.28 Hours, Build 23



LOX SIDE TURBINE SIDE

Figure 88. Helium Seal 99RS006215, S/N 04, and Mating Ring RS010476X, S/N 003, Posttest 490, Build 23 After 11.34 Hours



LOX SIDE TURBINE SIDE

Figure 89. Helium Mating Ring RS010476X, S/N 003, Posttest 490, Build 23 After 11.34 Hours

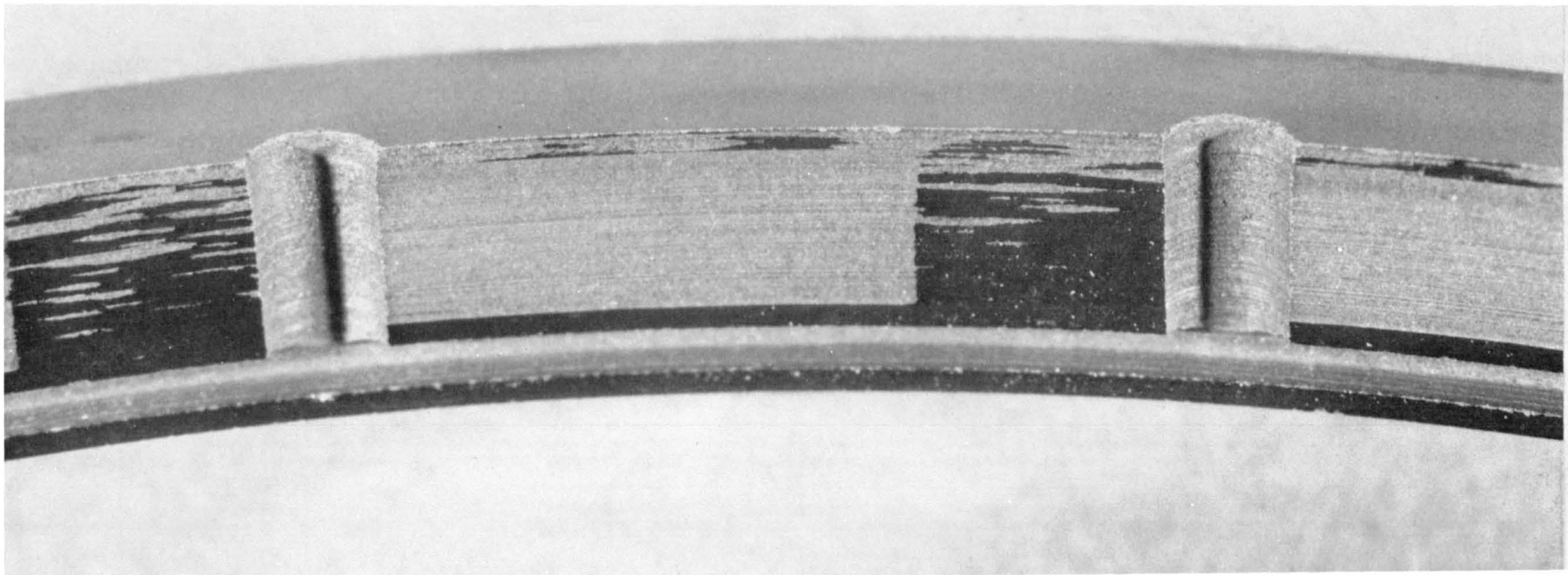


Figure 90. Helium Seal Typical LOX Side Carbon Ring 99RS006215, S/N 04, Posttest 490, Build 23 After 11.34 Hours

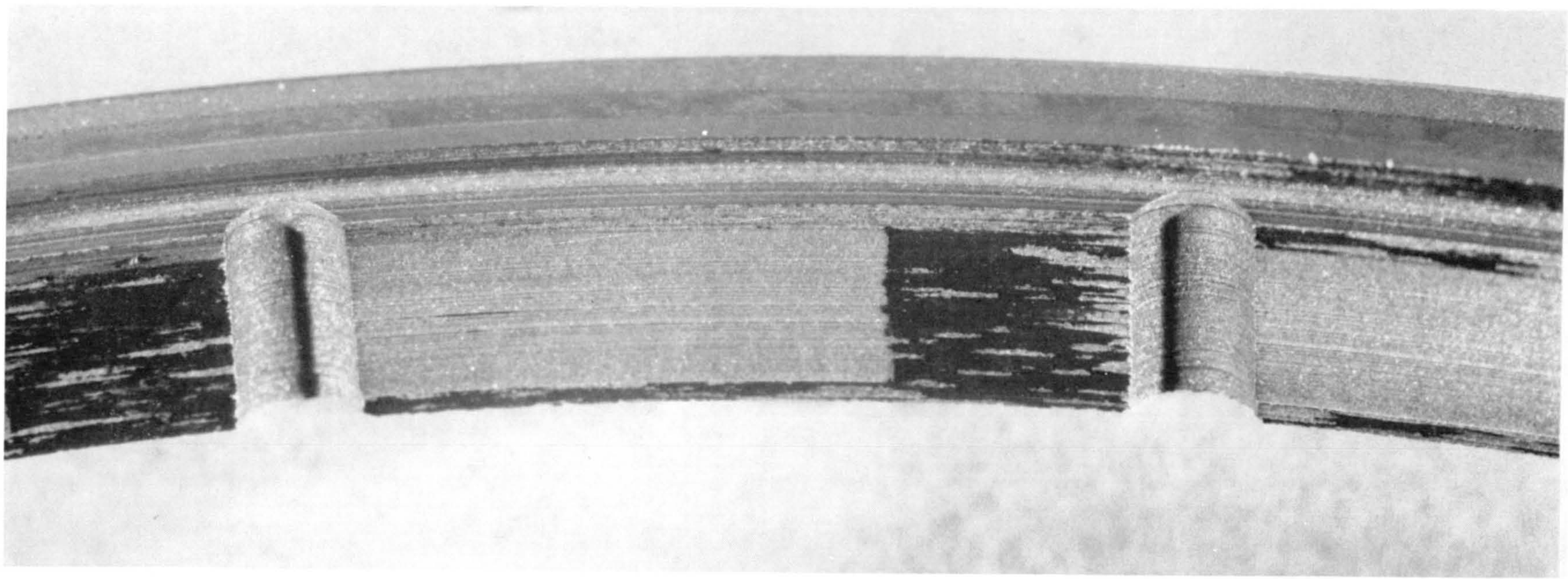


Figure 91. Helium Seal, Typical Turbine Side Carbon Ring 99RS006215, S/N 04, Posttest 490, Build 23 After 11.34 Hours

seal ring with a segmented Vespel SP211 secondary sealing element. The three-segment seal replaces the split piston ring used on Phase III for more effective sealing.

A typical profile trace of the LOX seal Rayleigh Step lift pads is shown on Fig. 92. The recess pad depth was approximately 0.0023 cm (0.0009 in.). The carbon ring and mating ring were flat within one helium light band. The flatness did not change significantly with the mating ring installed. The seal was installed with 0.1295 cm (0.051 in.) compression using eight springs with an installed load of 54.3 N (12.2 lb.).

The Phase IV helium purged intermediate seal has six spring loaded carbon G84 segments on the LOX and turbine sides. The seal is run on a Z-shaped Inconel 903 mating ring to reduce distortion. A typical profile trace across the Rayleigh Step lift pad is shown on Fig. 93 for the turbine side and on Fig. 94 for the LOX side.

Tests 1 - 10

The test objective was to perform four Liquid Oxygen Checkout tests of 15 minutes duration each at 30,000 rpm with LOX seal pressures of 1034, 1724, 2413 and 2758 kPa (150, 250, 350 and 400 psia) and helium seal pressures of 345 and 689 kPa (50 and 100 psia).

A total of 10 tests for 52.3 minutes was performed to complete the test objective. Stable data were obtained for each test point. The LOX seal leakage varied from 0.042 m^3/s (91.4 SCFM) at 931 kPa (135 psia) to 0.052 m^3/s (110.8 SCFM) at 2620 kPa (380 psia). The helium seal leakage varied from 0.0017 m^3/s (3.62 SCFM) at 358 kPa (52 psia) to 0.0059 m^3/s (12.74 SCFM) at 731 kPa (106 psia).

Build 1 Disassembly

Inspection revealed the seals to be in excellent condition. The LOX seal carbon face was polished with 0.0001 inch wear (Fig. 95). The LOX mating ring had a light polished contact pattern at the dam, the pad outer land and the pad inner land. The LOX mating ring surface profile trace (Fig. 96) indicated no measurable wear. The segmented Vespel secondary seal was in excellent condition with a uniform polished contact pattern. The posttest static leakage was less than when the seal was installed new, indicating that the face sealing dam and the secondary seal condition improved during the test.

The helium seal carbon segments were polished with a uniform contact pattern. The LOX side segments were worn evenly across the dam and pads 0.0005 cm (0.0002 in.) (Fig. 97). The turbine side segments were worn with a slight taper from 0.0005 cm (0.0002 in.) on the inner land to 0.0010 cm (0.0004 in.) on the outer land and 0.0007 cm (0.0003 in.) on the dam (Fig. 98). The mating ring had a uniform contact pattern with a light carbon deposit. The surface profile trace (Fig. 99) indicated no measurable wear. The posttest static leakage was approximately the same as pretest, indicating no deterioration during the testing.

The seal hardware condition is shown on Fig. 100 through 104.

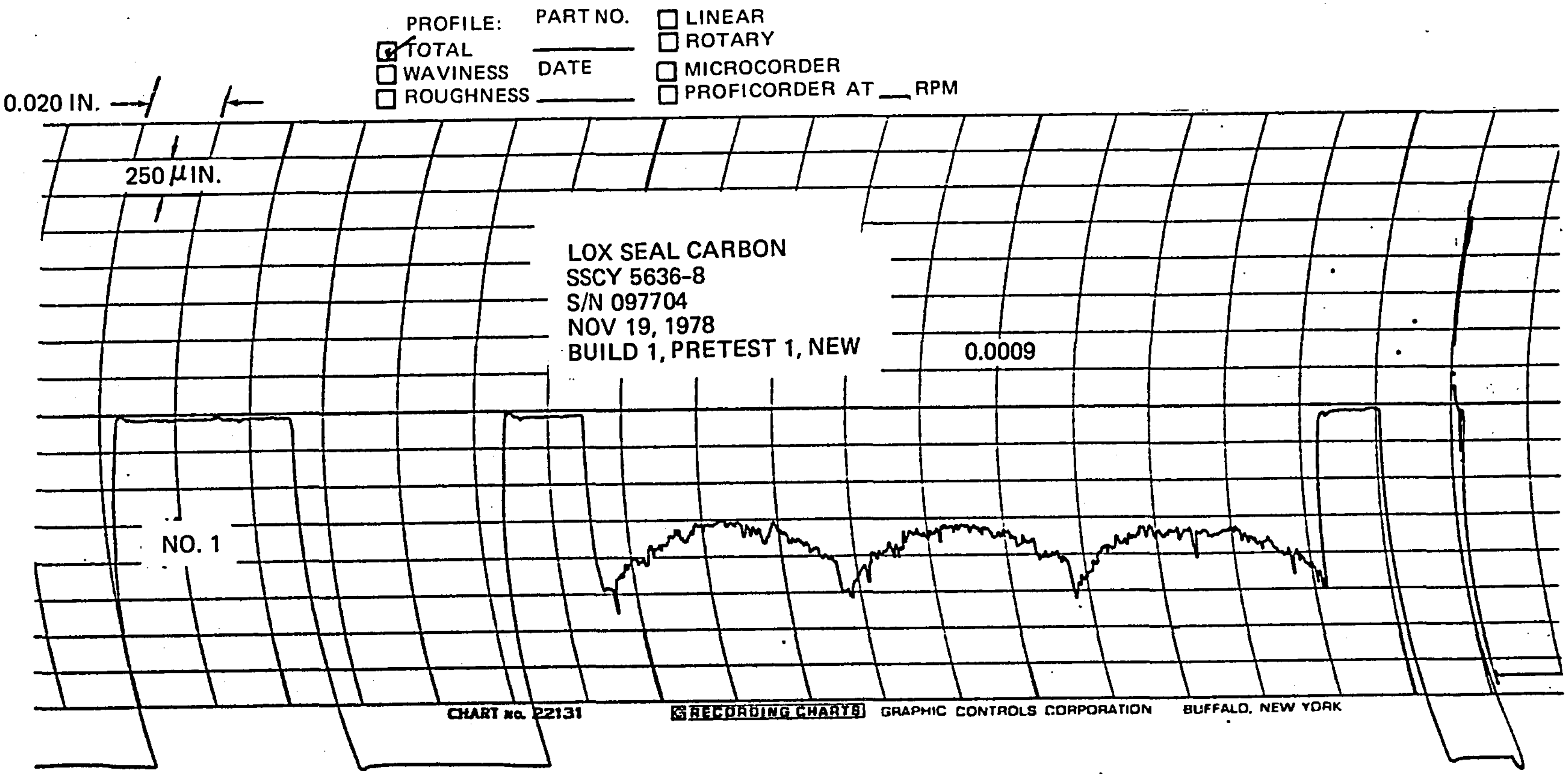


Figure 92. Typical Surface Profile Trace LOX Seal Face Position 1 P/N SSCY5636-8 (New), S/N 097704, Pretest 1, Build 1

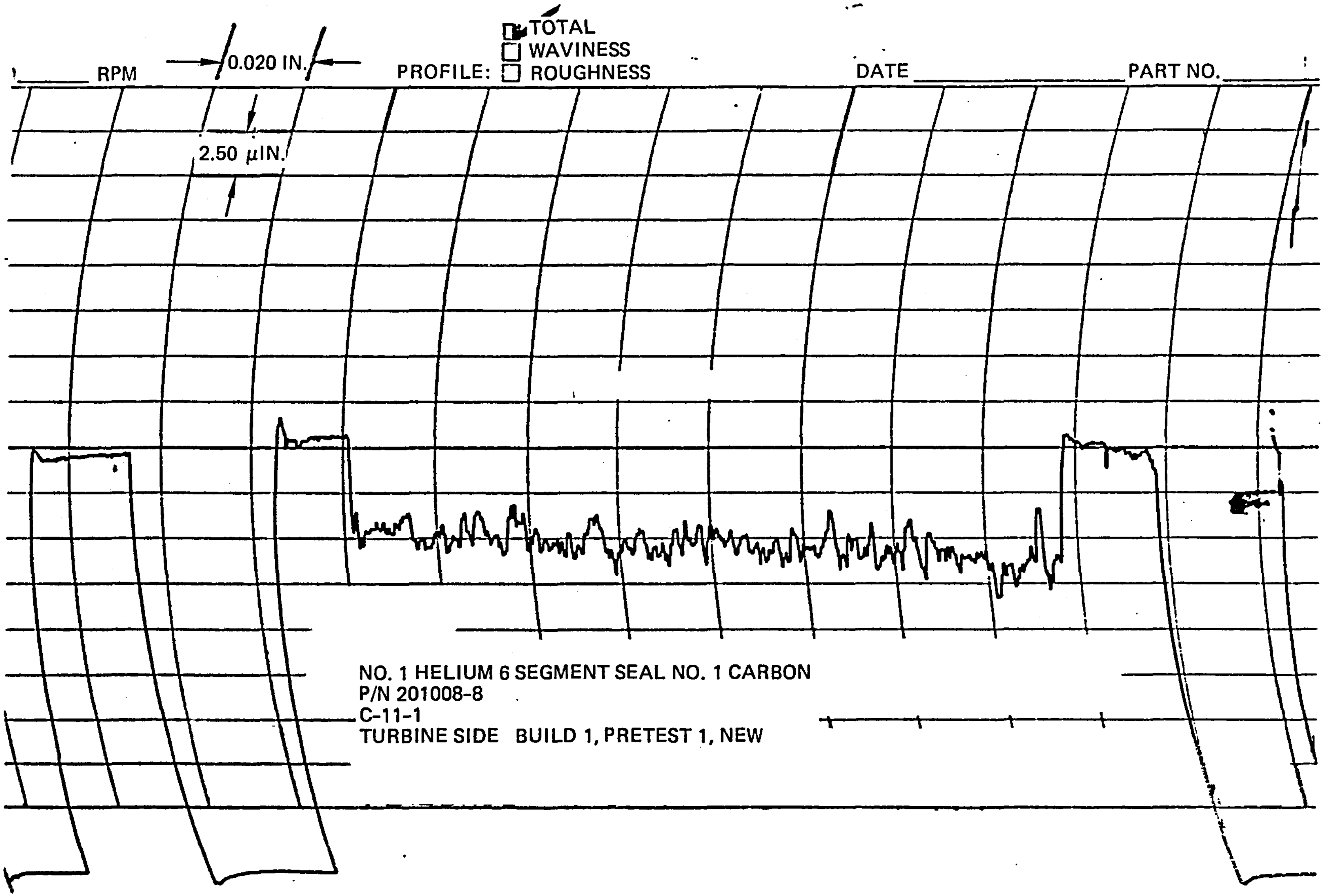


Figure 93. Typical Surface Profile Trace of Turbine Side Helium Seal Segment C-11-1 (New), Pretest 1, Build 1

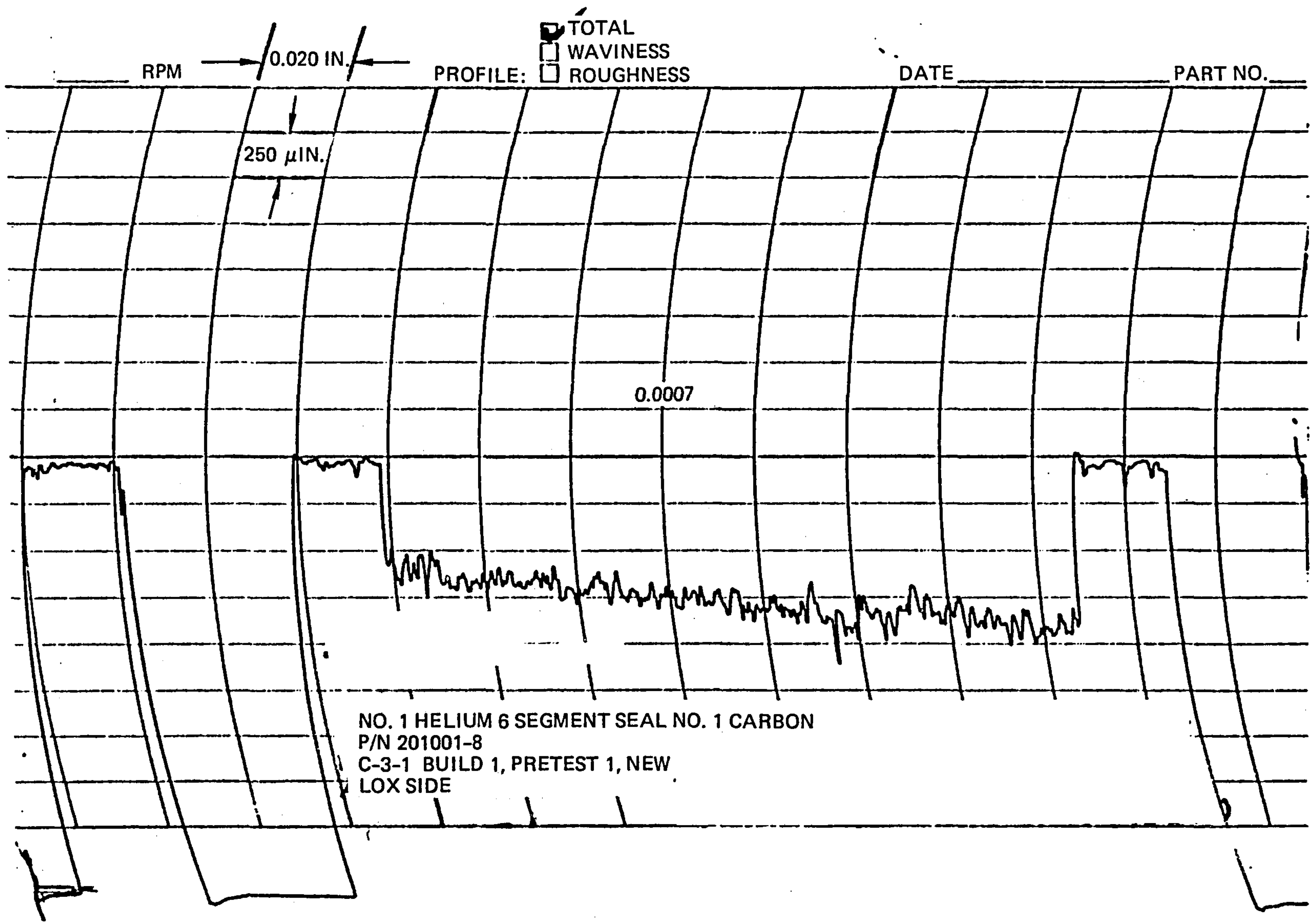


Figure 94. Typical Surface Profile Trace of LOX Side Helium Seal Segment C-3-1 (New), Pretest 1, Build 1

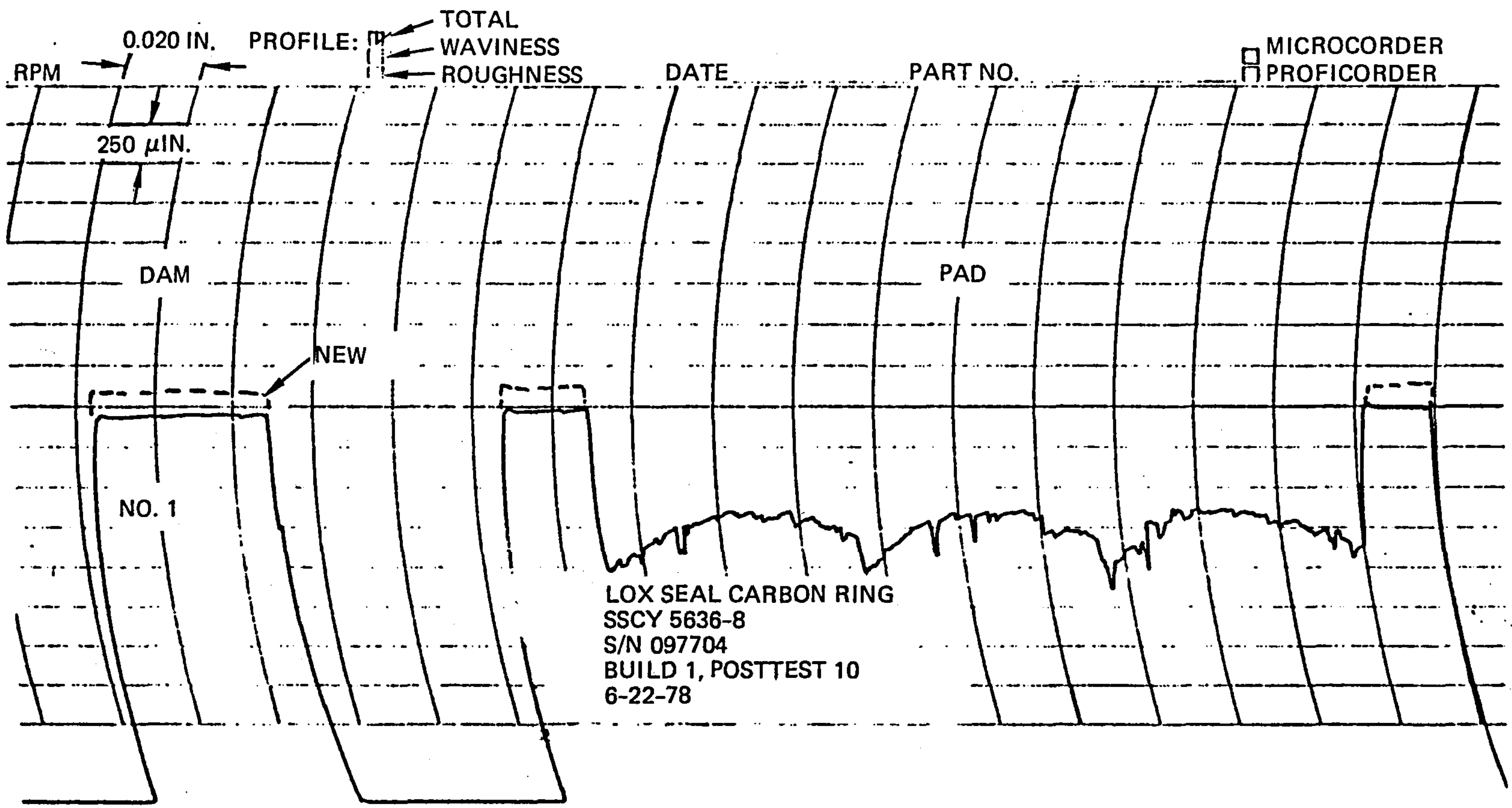


Figure 95. Typical Surface Profile Trace LOX Seal Face Position 1 P/N SSCY5636-8, S/N 097704, Posttest 10, Build 1

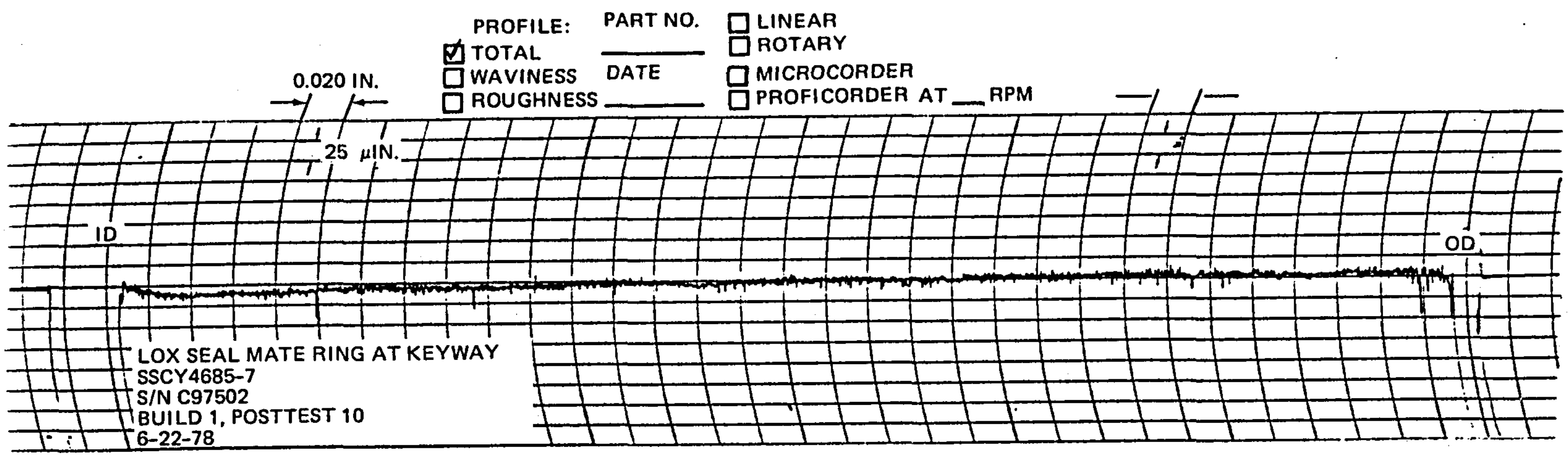


Figure 96. Surface Profile Trace LOX Mating Ring P/N SSCY4685-7, S/N C97502, Posttest 10, Build 1

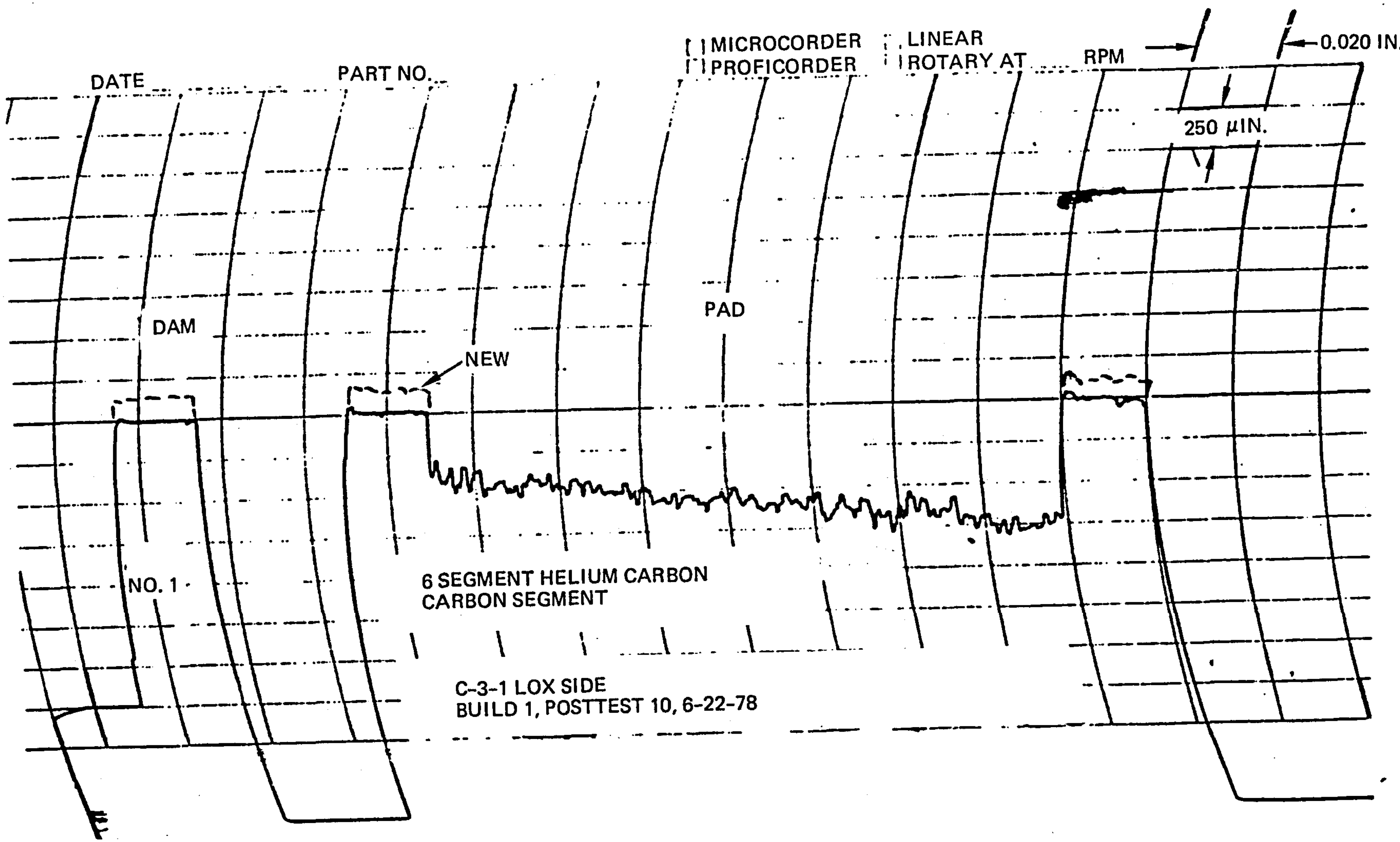


Figure 97. Surface Profile Trace of LOX Side Helium Seal Segment C-3-1, Posttest 10, Build 1

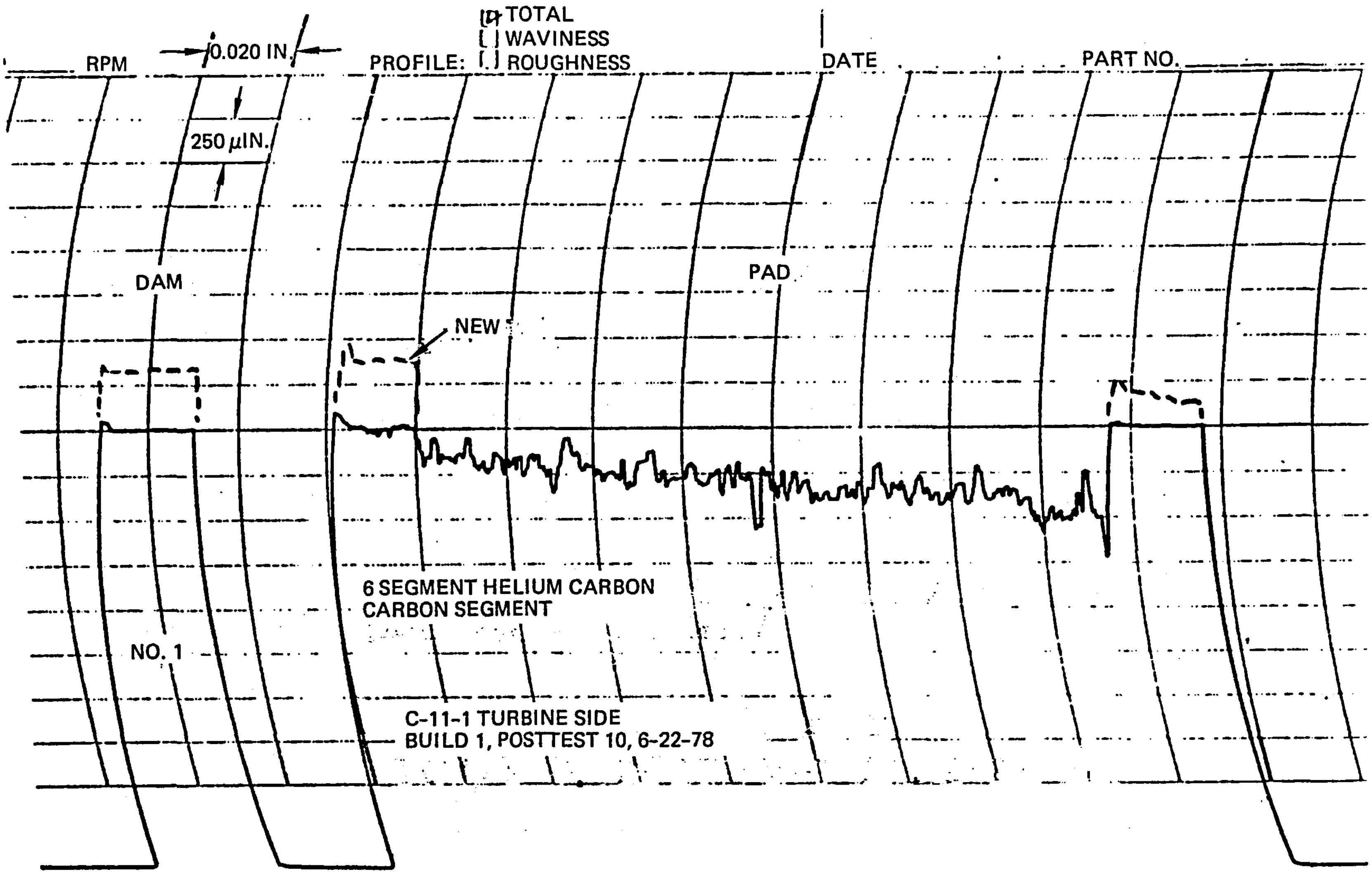


Figure 98. Surface Profile Trace of Turbine Side Helium Seal Segment C-11-1, Posttest 10, Build 1

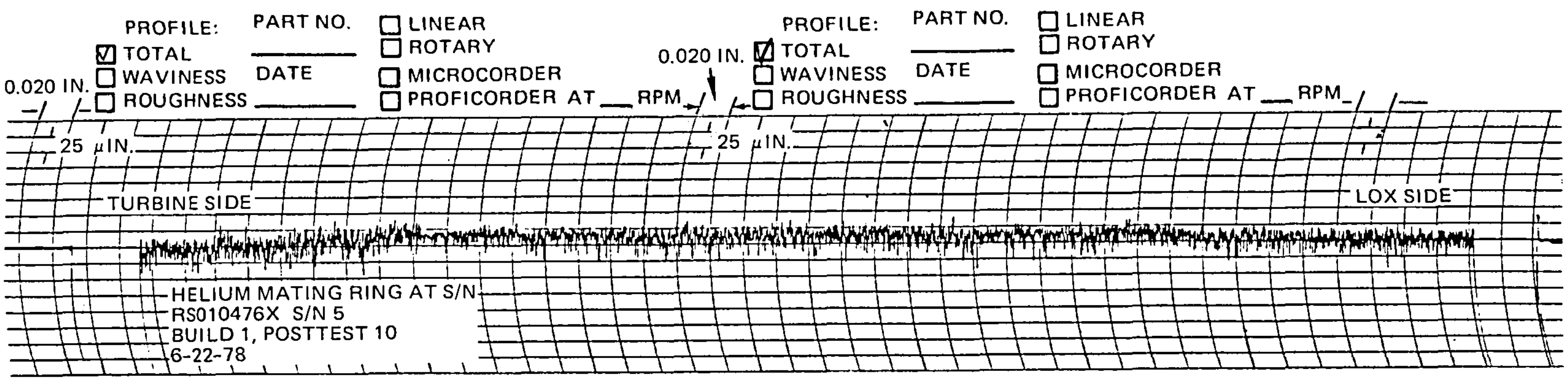
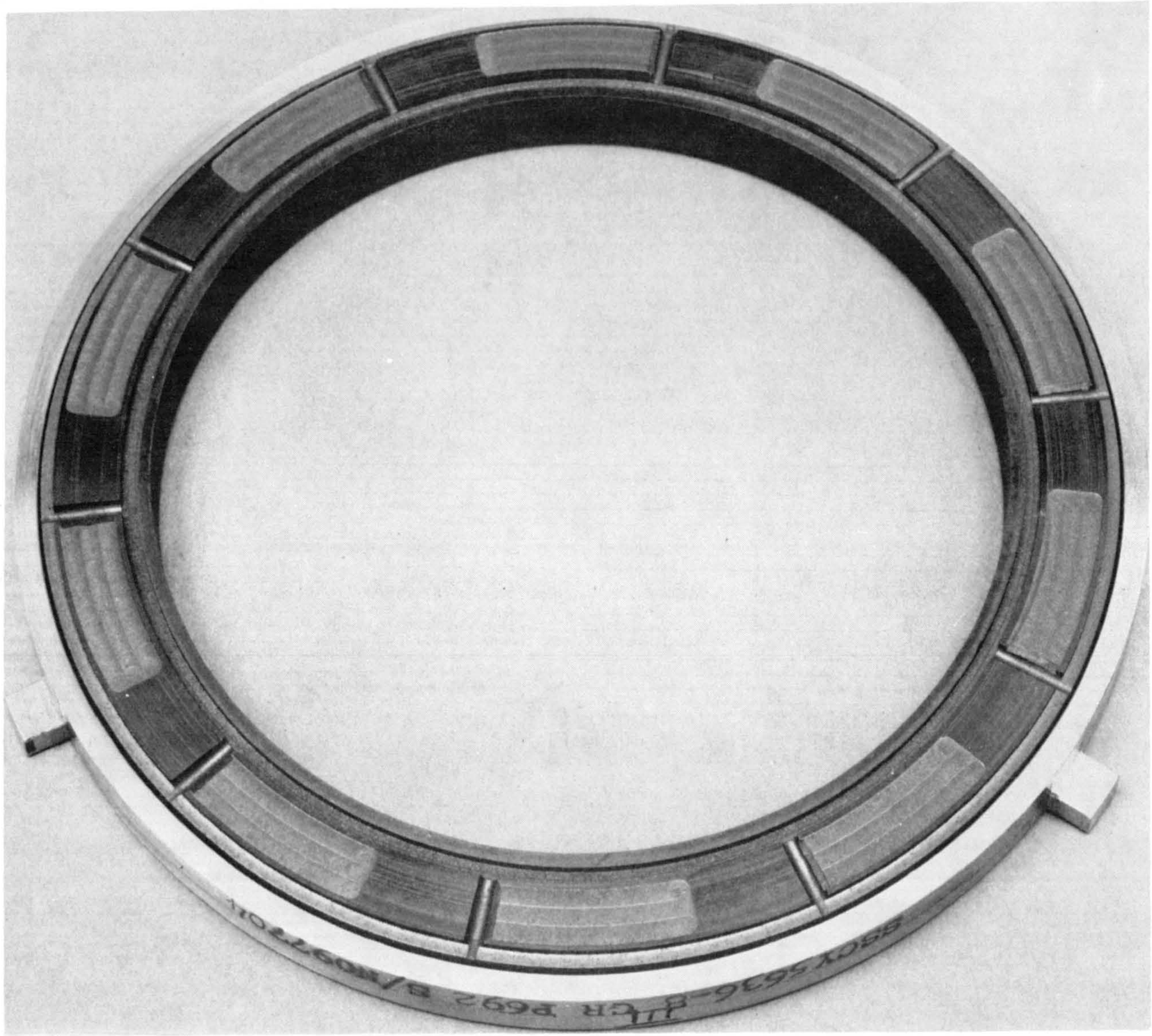
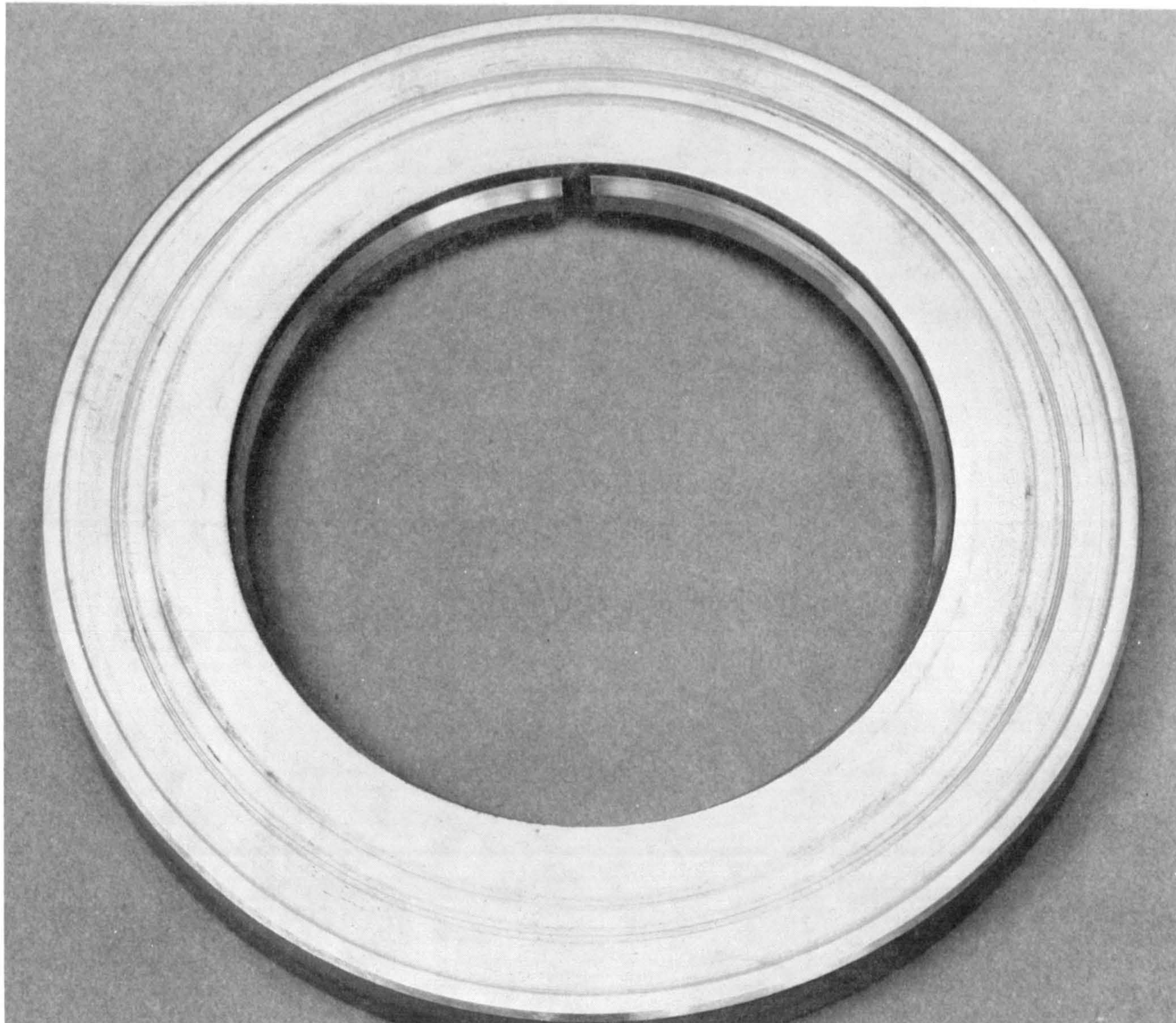


Figure 99. Surface Profile Trace Helium Mating Ring RS010476X, S/N 5, Posttest 10, Build 1



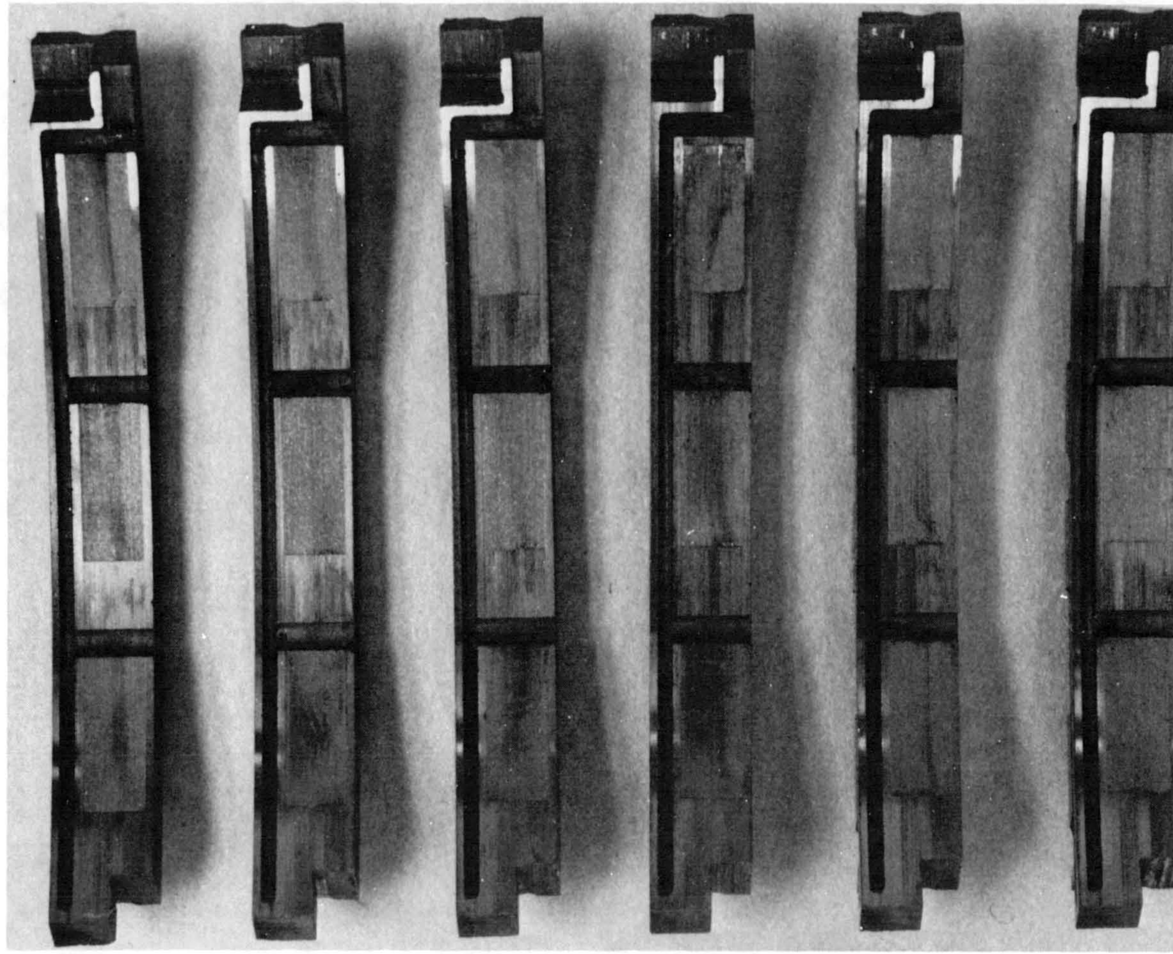
IXY55-6/21/78-CIF

Figure 100. LOX Seal Carbon Ring SSCY5636-8, S/N 04, Posttest 10, Build 1



1XY55-6/21/78-C1G

Figure 101. LOX Mating Ring SSCY4685-7, S/N 02, Posttest 10, Build 1



6 5 4 3 2 1

Figure 102. Helium Seal LOX Side Carbon Segments P/N 201001, S/N C3, Posttest 10, Build 1

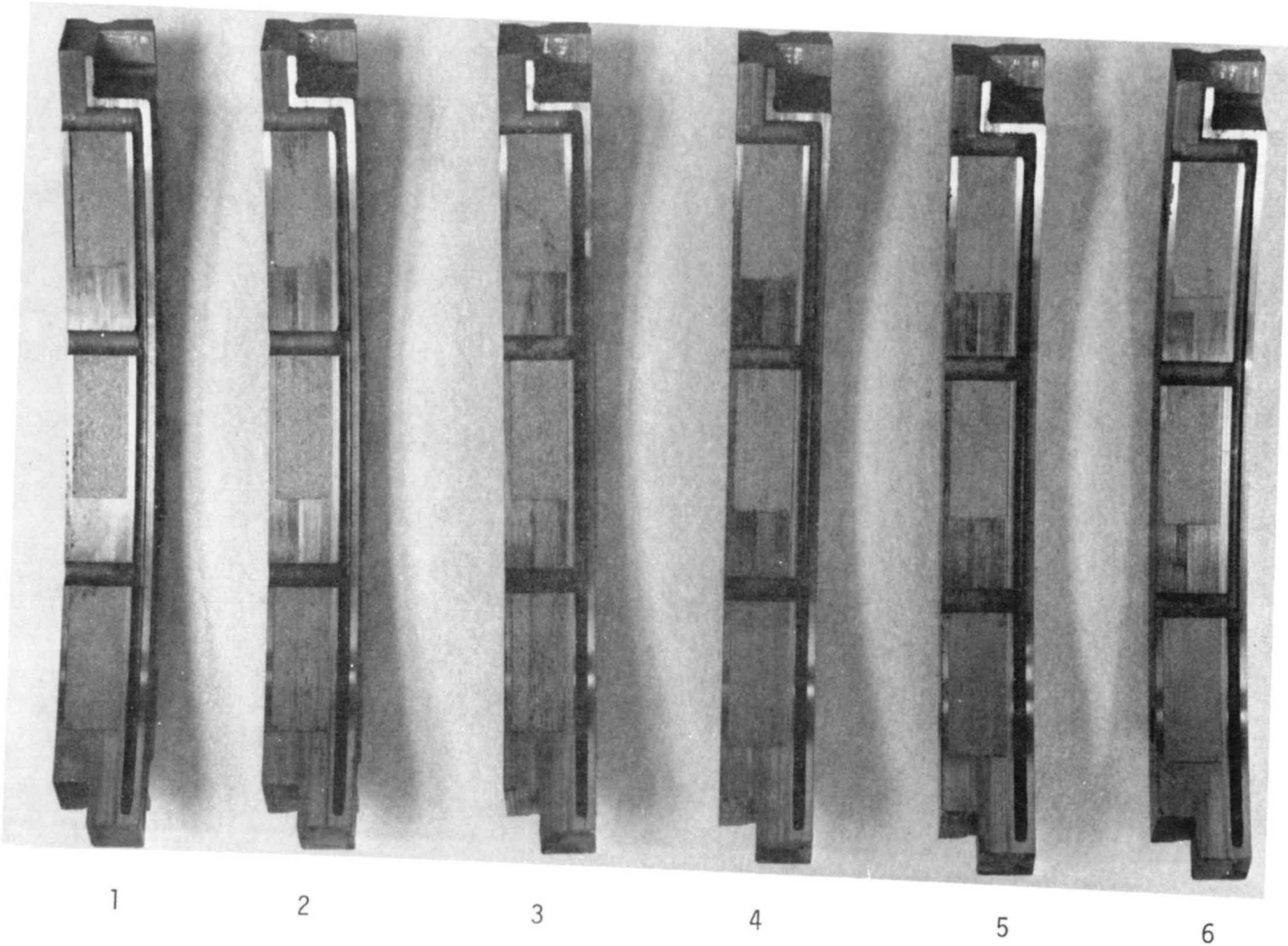


Figure 103. Helium Seal Turbine Side Carbon Segments P/N 201001, S/N C11, Posttest 10, Build 1

Figure 104. Helium Mating Ring RS010476X, S/N 5, Posttest 10, Build 1

PHASE IV RAYLEIGH STEP LOX ACCELERATION TEST

Build 2 Assembly

The tester was reassembled using the same seal hardware without rework. A new static spring seal was installed with the LOX mating ring due to the previous seal being too short to properly load the ring. A recheck of the mating ring installed flatness indicated that the flatness increased from 1 to 2 HLB in the free position to 4 to 5 HLB installed.

Tests 11 - 77

The test objective was 50 tests of 6 minutes duration each for a total time of 5 hours at a LOX seal pressure of 2758 kPa (400 psia) and helium seal pressure of 345 kPa (50 psia). The tester was accelerated to 30,000 rpm in approximately 10 seconds with a simultaneously LOX seal pressure rise from 138 to 2758 kPa (20 to 400 psia).

A total of 67 tests for 299.6 minutes was performed to complete the test objective. The first 18 tests were performed with helium seal pressures of 565 to 696 kPa (82 to 101 psig) to evaluate the capability of higher pressure operation in anticipation of future use on the Space Shuttle oxidizer turbopump.

The helium seal performance was satisfactory at the higher pressures with leakage rates from 0.0019 to 0.0028 m^3/s (4 to 6 SCFM); however, the facility drive turbine starting torque was marginal due to the higher friction drag of the helium seal at the increased pressure level.

The helium pressure was reduced to the original requirement of 345 kPa (50 psia) because of speed control problems. The helium seal leakage rate at 241 kPa (35 psig) was approximately 0.0014 to 0.0023 m^3/s (3 to 5 SCFM).

The LOX seal performance was satisfactory with the leakage varying from approximately 0.051 to 0.060 m^3/s (110 to 130 SCFM) at 2758 kPa (400 psig) LOX pressure.

Build 2 Disassembly

Inspection after 67 tests and 5 hours revealed the seals to be in excellent condition with no significant additional wear since the initial one hour checkout test. The LOX seal carbon face was polished with light circumferential scratches and no measurable wear. The LOX mating ring had a light polished pattern at the dam, the pad inner land and the pad outer land. The surface profile trace indicated 0.000025 cm (0.00001 in.) wear at the outer land, no wear at the inner land and 0.000012 cm (0.000005 in.) wear at the dam outside diameters. The posttest static leakage was approximatly the same as pretest, indicating no deterioration during the 5-hour test.

The helium seal carbon segments were polished with uniform contact and no significant additional wear since the initial 1-hour checkout test. The mating ring had a uniform contact pattern with a light carbon deposit. The contact pattern appeared the same as pretest. The surface profile trace indicated no measurable wear. The posttest static leakage after the 5-hour test was approximately the same as the posttest leakage after the initial 1-hour test.

Build 3 Assembly

The tester was reassembled using the same hardware without rework.

The tester bearings were inspected in place on the shaft and found to be in satisfactory condition. The same bearings were reinstalled.

Tests 78 - 133

The test objective was 50 tests of 6 minutes duration each, for a total of 5 hours to complete the 10 hour requirement at a LOX seal pressure of 2758 kPa (400 psia) and helium seal pressure of 345 kPa (50 psia). The tester was accelerated to 30,000 rpm in approximately 10 seconds with a simultaneous LOX seal pressure rise from 138 to 2758 kPa (20 to 400 psia).

A total of 56 tests for 302.8 minutes were performed to complete the test objective. The performance of both seals was consistently satisfactory.

The LOX seal leakage averaged approximately 0.079 m^3/s (170 SCFM) with a variation from 0.070 to 0.084 m^3/s (150 to 180 SCFM) at 2482 to 2723 kPa (360 to 395 psig). The leakage during the last 5 hours of testing was very consistent, indicating no deterioration in seal performance (Fig. 105).

The helium seal leakage varied from 0.0019 to 0.0037 m^3/s (4 to 8 SCFM) at 345 kPa (50 psia) with an increasing trend between 7 and 9 hours of testing. The leakage leveled off at 0.0033 to 0.0037 m^3/s (7 to 8 SCFM) during the last 2 hours of testing (Fig. 106).

Build 3 Disassembly

Inspection after 56 tests and 5.05 hours (total 133 starts and 10.91 hours) revealed the seals to be in excellent condition with no additional wear since the inspection at 5.86 hours.

The LOX seal carbon face was polished with light circumferential scratches and no measurable wear (Fig. 107). The segmented Vespel SP211 secondary sealing element was in excellent condition with an even polished pattern on the Vespel and a uniform contact pattern on the pilot ring. There was no visible wear or deterioration on either the Vespel segments or the pilot ring surface. The LOX mating condition was the same as when inspected at 5.86 hours with a light polished pattern at the dam, pad inner land and pad outer land. The surface profile trace (Fig. 108) indicated that the wear at the dam outside diameter had not changed since the last inspection.

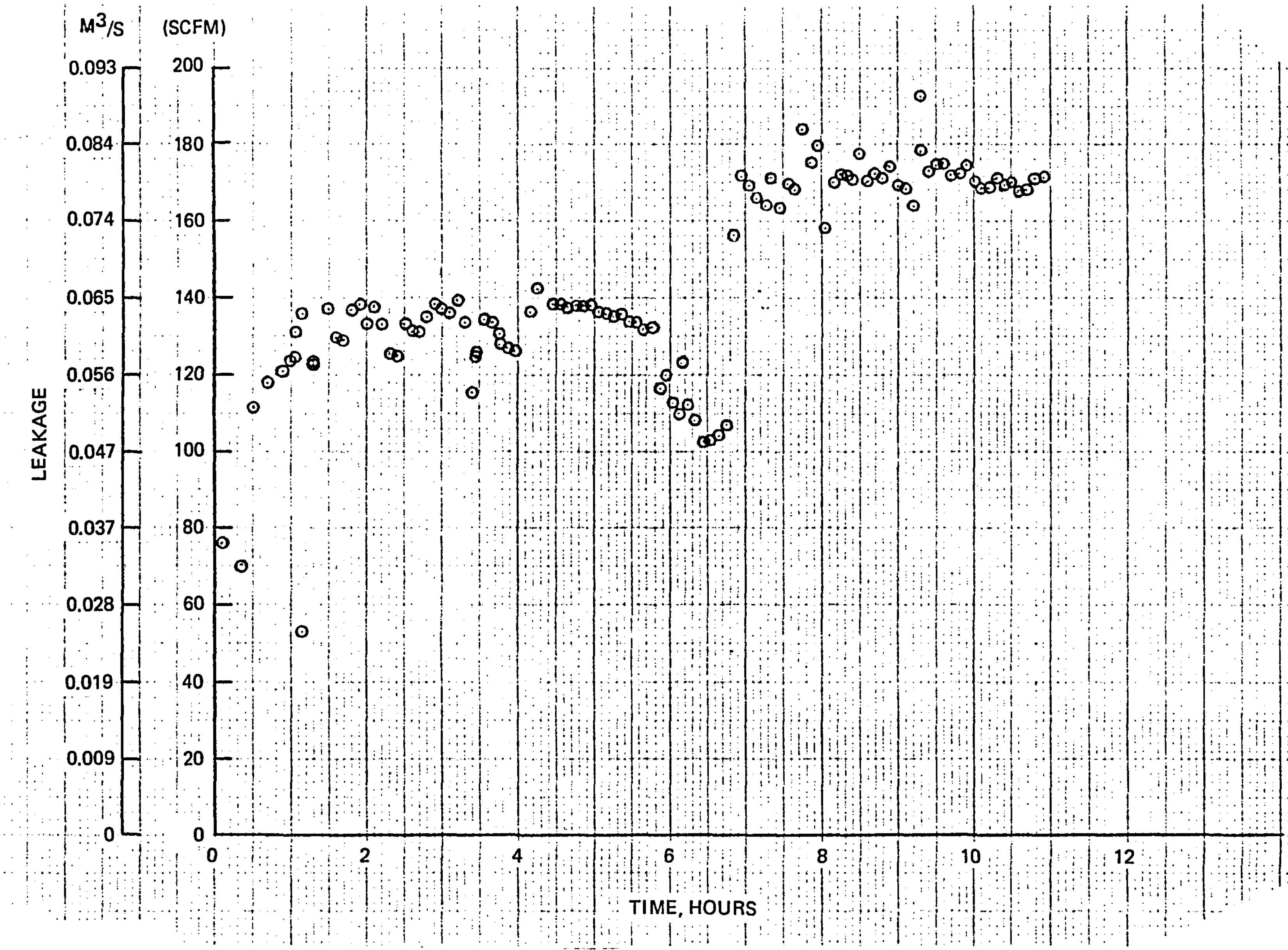


Figure 105. Phase IV Rayleigh Step LOX Seal Leakage

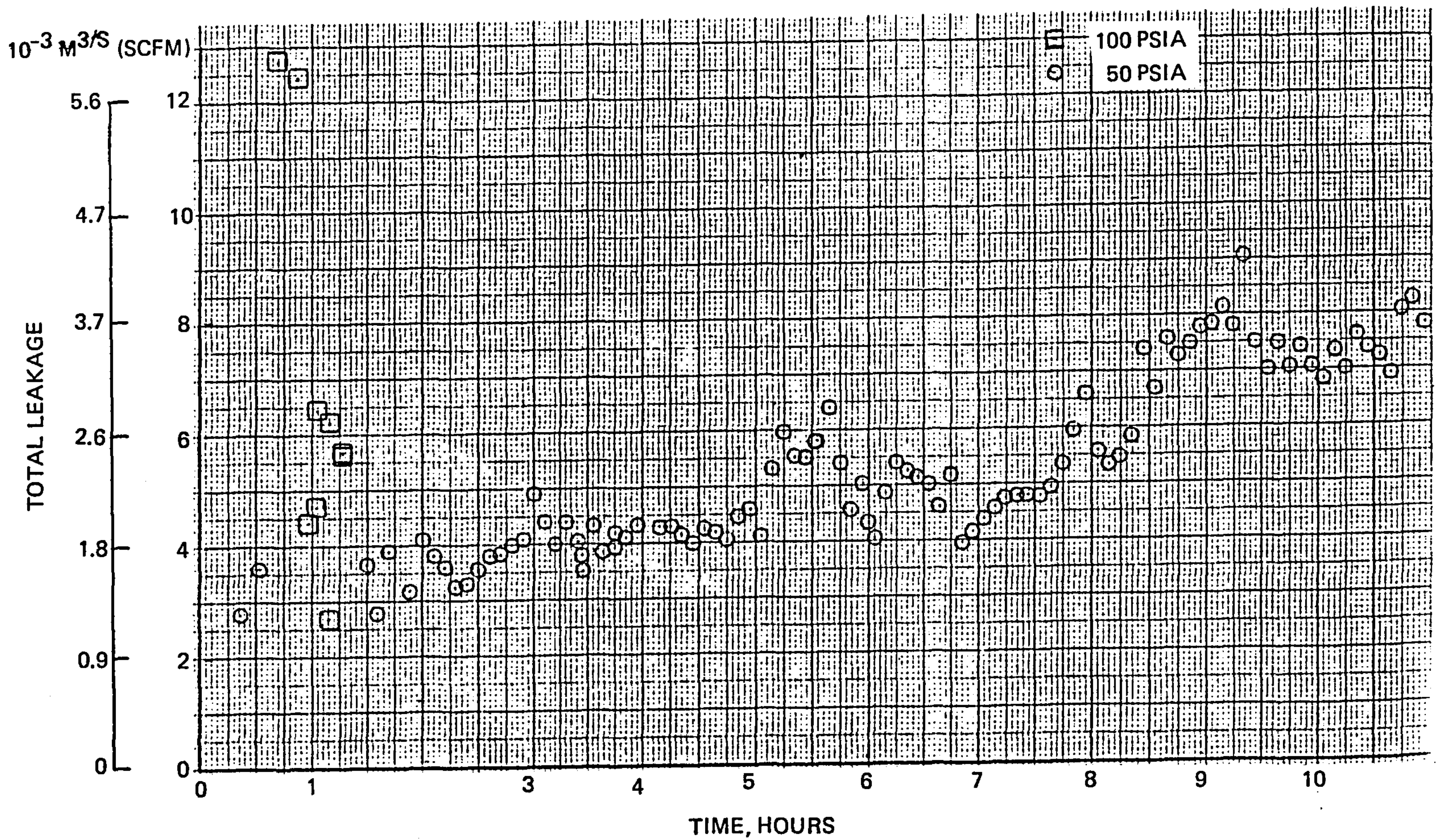


Figure 106. Phase IV Rayleigh Step Segmented Carbon Helium Seal Leakage

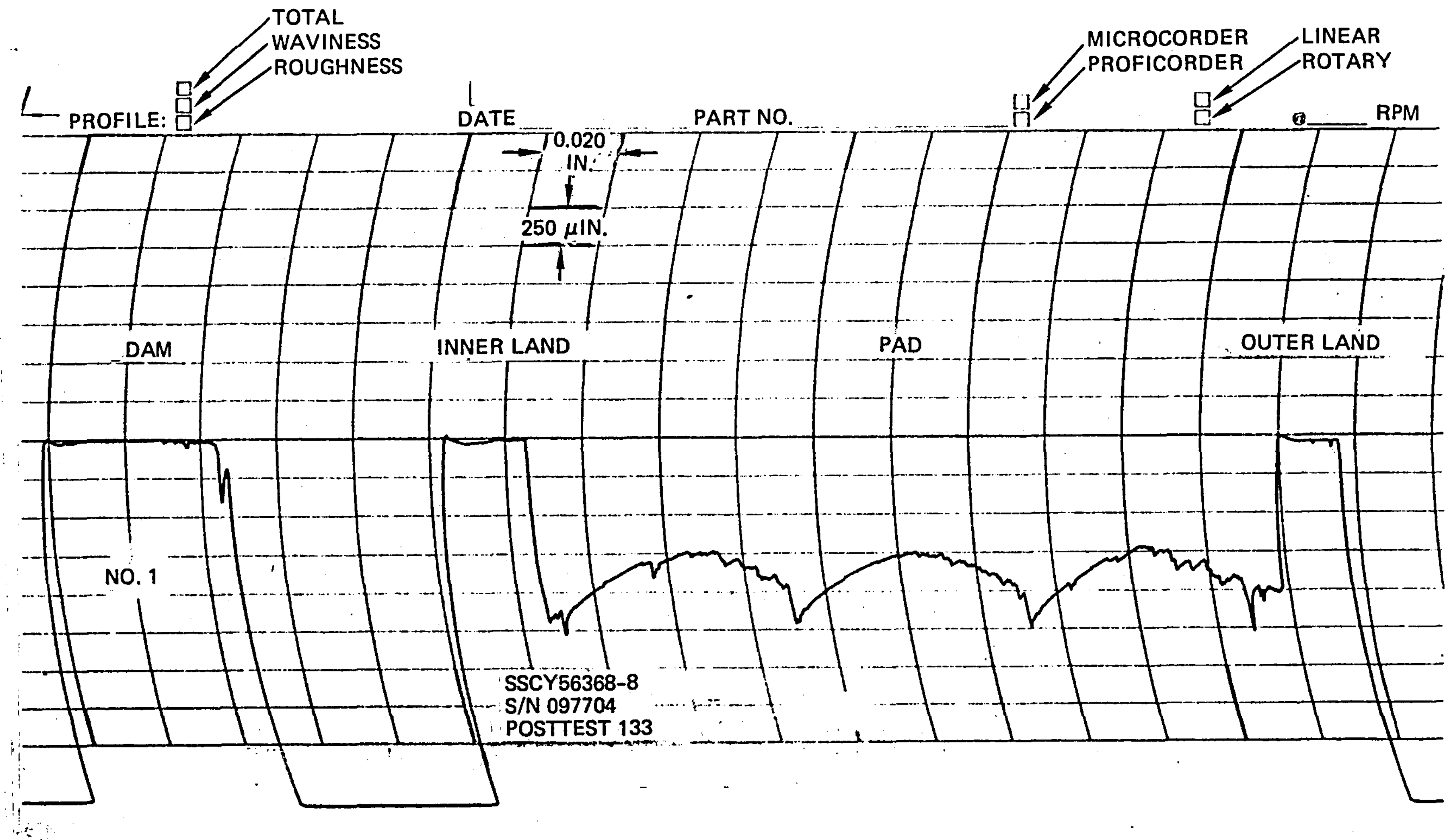


Figure 107. Typical Surface Profile Trace LOX Seal Face Position 1 P/N SSCY5636-8, S/N 097704, Posttest 133, Build 3 (10.91 Hours)

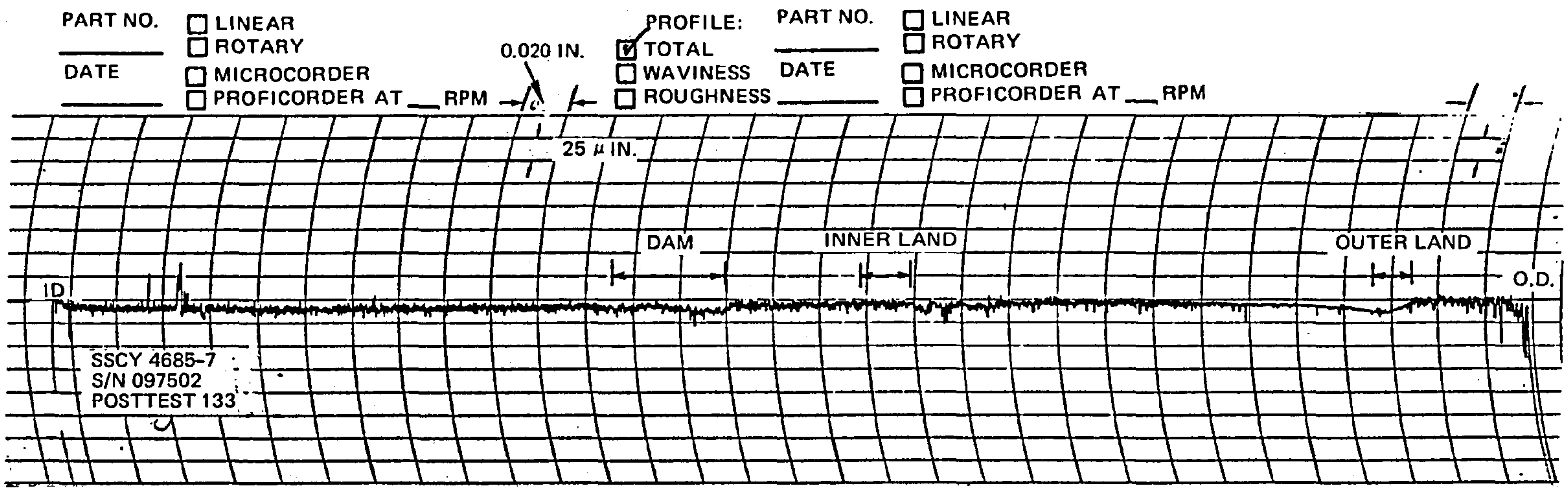


Figure 108. Surface Profile Trace LOX Mating Ring P/N SSCY4685-7, S/N 02, Posttest 133, Build 3 (10.91 Hours)

The helium seal carbon segments were polished with uniform contact and light circumferential scratches. The surface profile traces (Fig. 109 and 110) indicated no additional wear during the last 5 hours of testing. There has been no significant wear since the initial 52.3 minute checkout test. The mating ring had a uniform contact pattern with a light carbon deposit. The contact pattern has appeared the same since the first inspection. The surface profile trace (Fig. 111) indicated no measurable wear. The static leakage is approximately the same as new on the turbine side. The LOX side leakage at 345 kPa (50 psig) increased from 540 to 1080 cm^3/s (2000 to 4000 SCIM).

The seal hardware condition is shown in Fig. 112 through 116.

PHASE IV SPIRAL GROOVE LOX CHECKOUT TEST

Build 4 Assembly

The tester was assembled with a new Phase IV inward pumping spiral groove LOX seal and segmented carbon helium seal (refer to page 26 for description of seal concept). The Phase IV spiral groove LOX seal uses the Phase III housing and Vespel SP211 split piston ring. The P692 carbon sealing ring is the same as Phase III, except the sealing face is a plain flat surface. The spiral grooves are etched into the hard chrome plated surface of the rotating mating ring.

A typical profile trace of the carbon sealing face is shown in Fig. 117. The carbon surface was flat within 3 helium light bands .

A typical profile trace of the spiral groove mating ring surface is shown in Fig. 118. The spiral groove depth measured 0.00038 to 0.00050 cm (0.00015 to 0.00020 in.). The mating ring surface was flat within 3 to 4 HLB in the free position and within 2 HLB after installation in the tester. The mating ring axial runout was 0.0013 cm (0.0005 in.) total.

The LOX seal was installed with 0.20 cm (0.079 in.) compression using 14 equally spaced springs with an installed load of 59.2 N (13.3 lb). The static GN_2 leakage was 0.0023 m^3/s (5.0 SCFM) at 345 kPa (50 psig) and 0.010 m^3/s (21.5 SCFM) at 2068 kPa (300 psig).

Typical profile traces of the six-segment helium seal are shown in Fig. 119 for the turbine side and in Fig. 120 for the LOX side.

Tests 134 - 142

A total of 9 tests for 630 seconds was performed on a new Phase IV inward pumping spiral groove LOX seal and Rayleigh Step segmented carbon helium seal. The testing was terminated due to high vibration, erratic speed control and excessive LOX seal leakage.

The first test (134) was cut off at start by the automatic vibration redline of 20 g peak to peak. The next six tests (135 - 140) were cut off due to speed control problems. The tester did not start at the normal turbine pressure level and the speed was erratic, indicating a variation in seal drag torque. The LOX seal leakage typically spiked up at start of rotation and

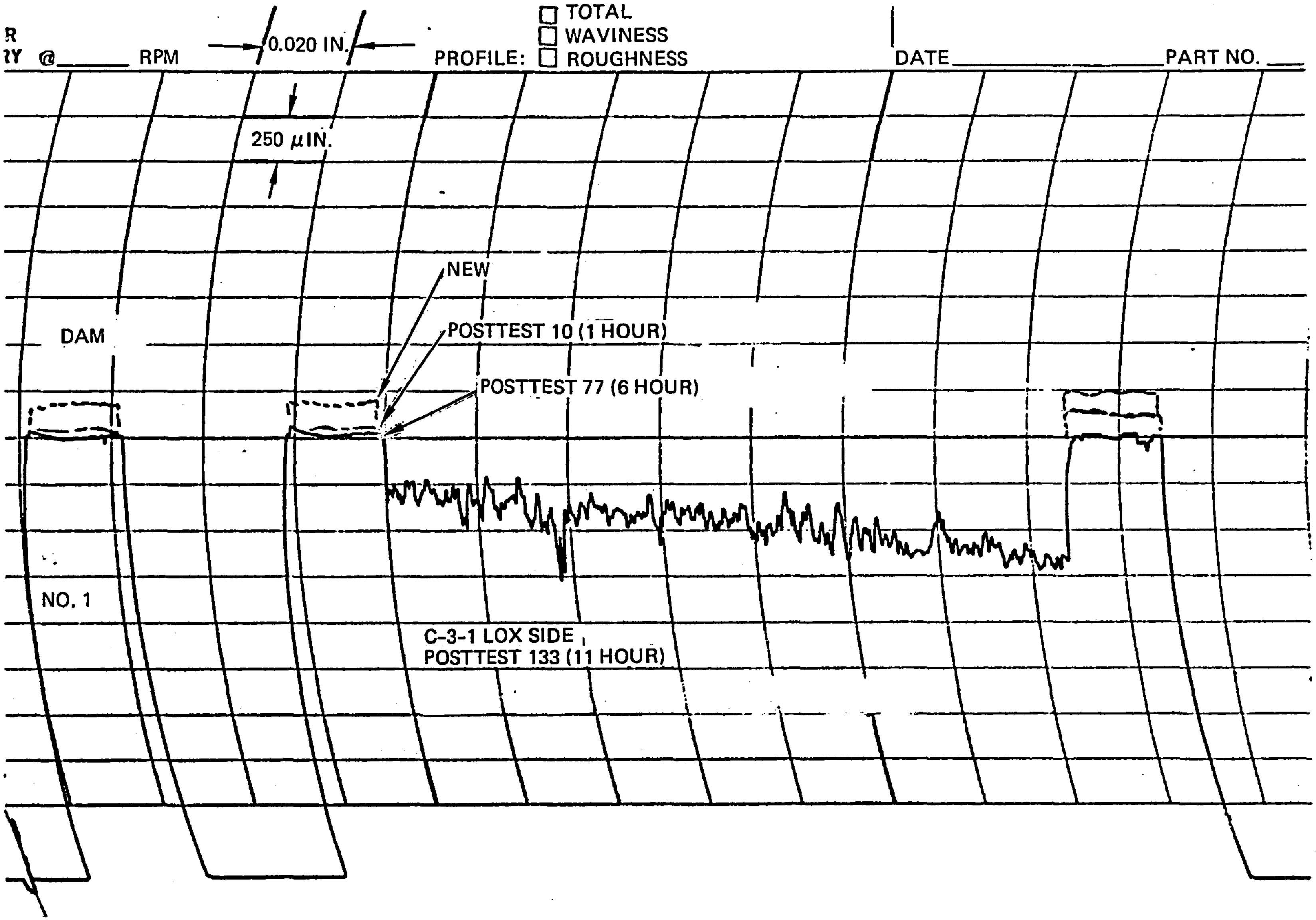


Figure 109. Surface Profile Trace of LOX Side Helium Seal Segment C-3-1, Posttest 133, Build 3 (10.91 Hours)

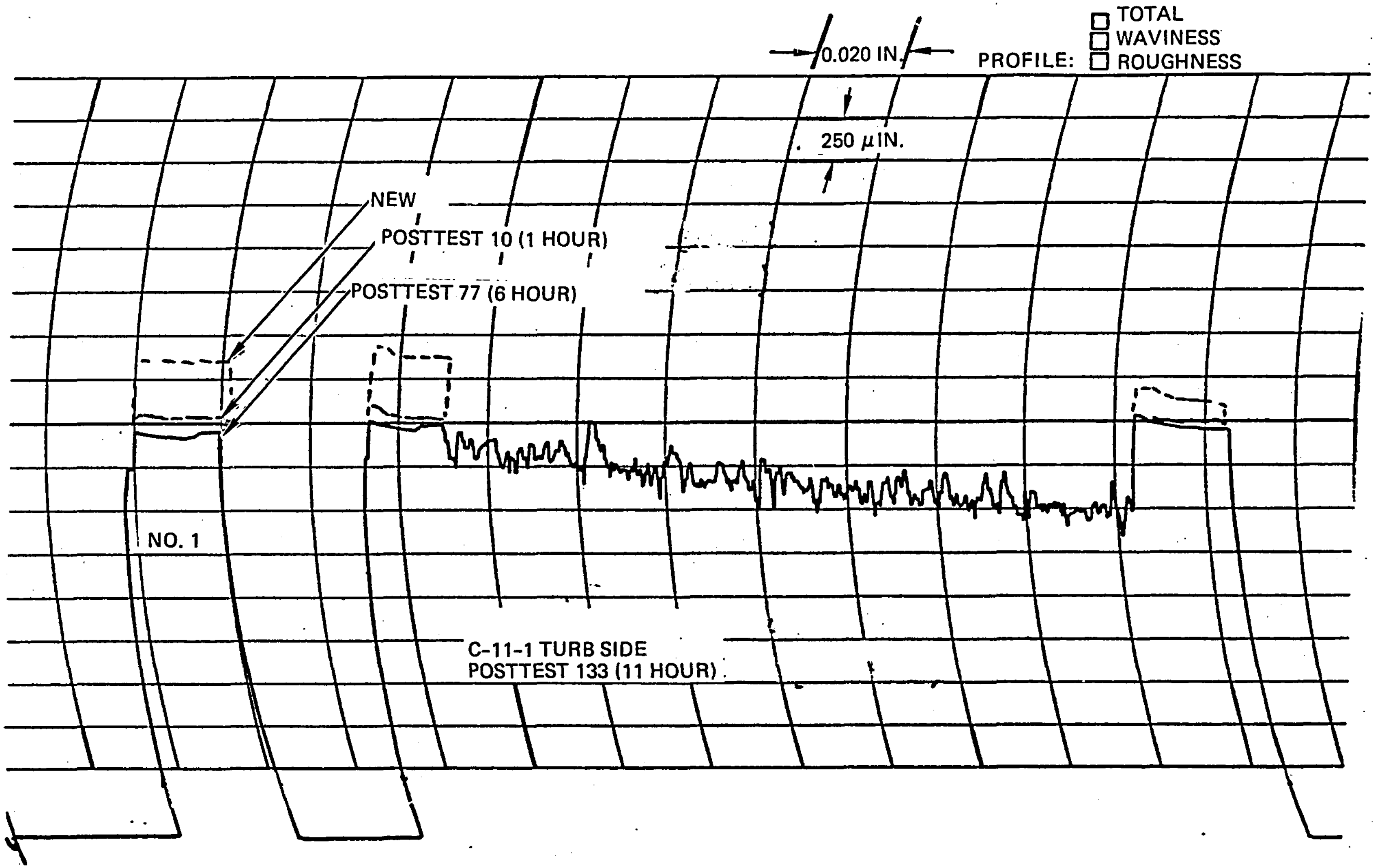


Figure 110. Surface Profile Trace of Turbine Side Helium Seal Segment C-11-1, Posttest 133, Build 3 (10.91 Hours)

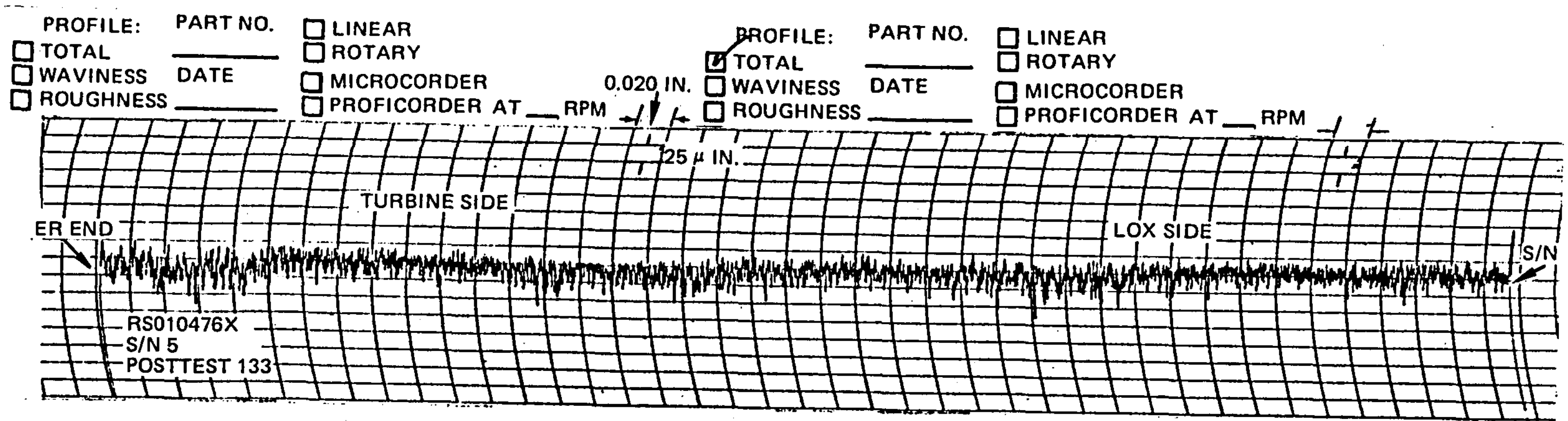


Figure 111. Surface Profile Trace Helium Mating Ring RS010476X, S/N 5, Posttest 133, Build 3 (10.91 Hours)

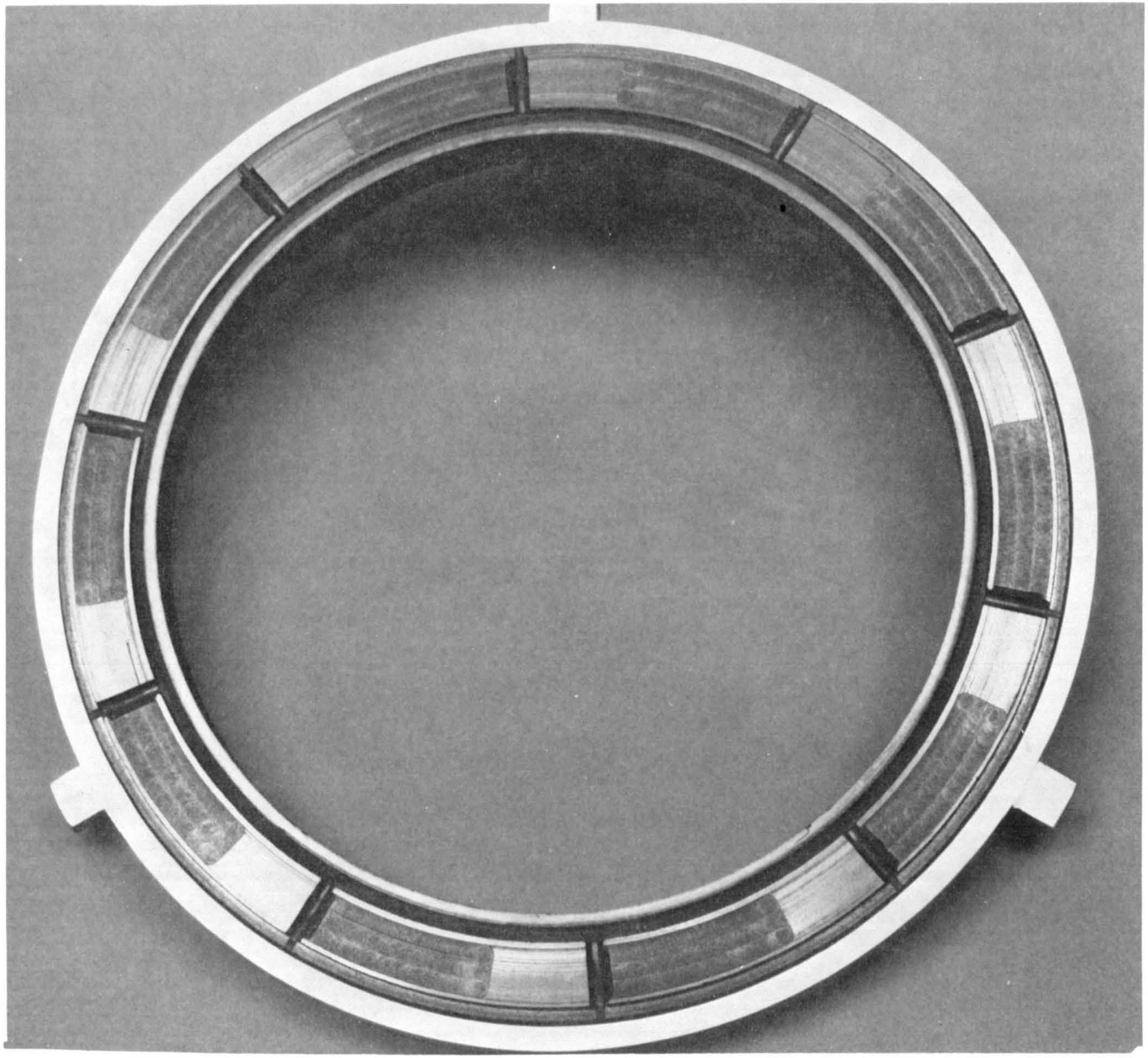


Figure 112. LOX Seal Carbon Ring SSCY5636-8, S/N 04, Posttest 133, Build 3 (10.91 Hours)

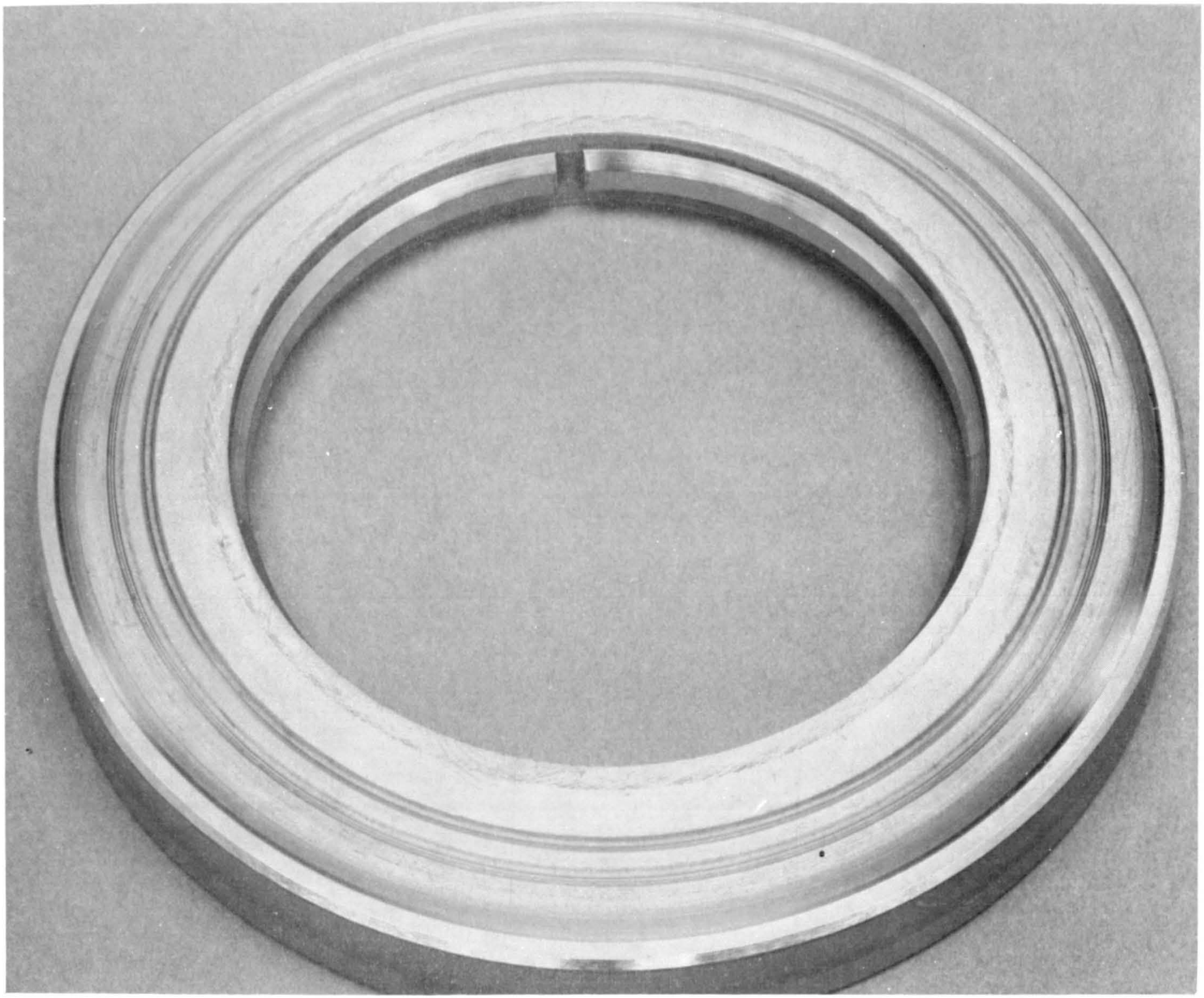


Figure 113. LOX Mating Ring SSCY4685-7, S/N 02, Posttest 133, Build 3 (10.91 Hours)

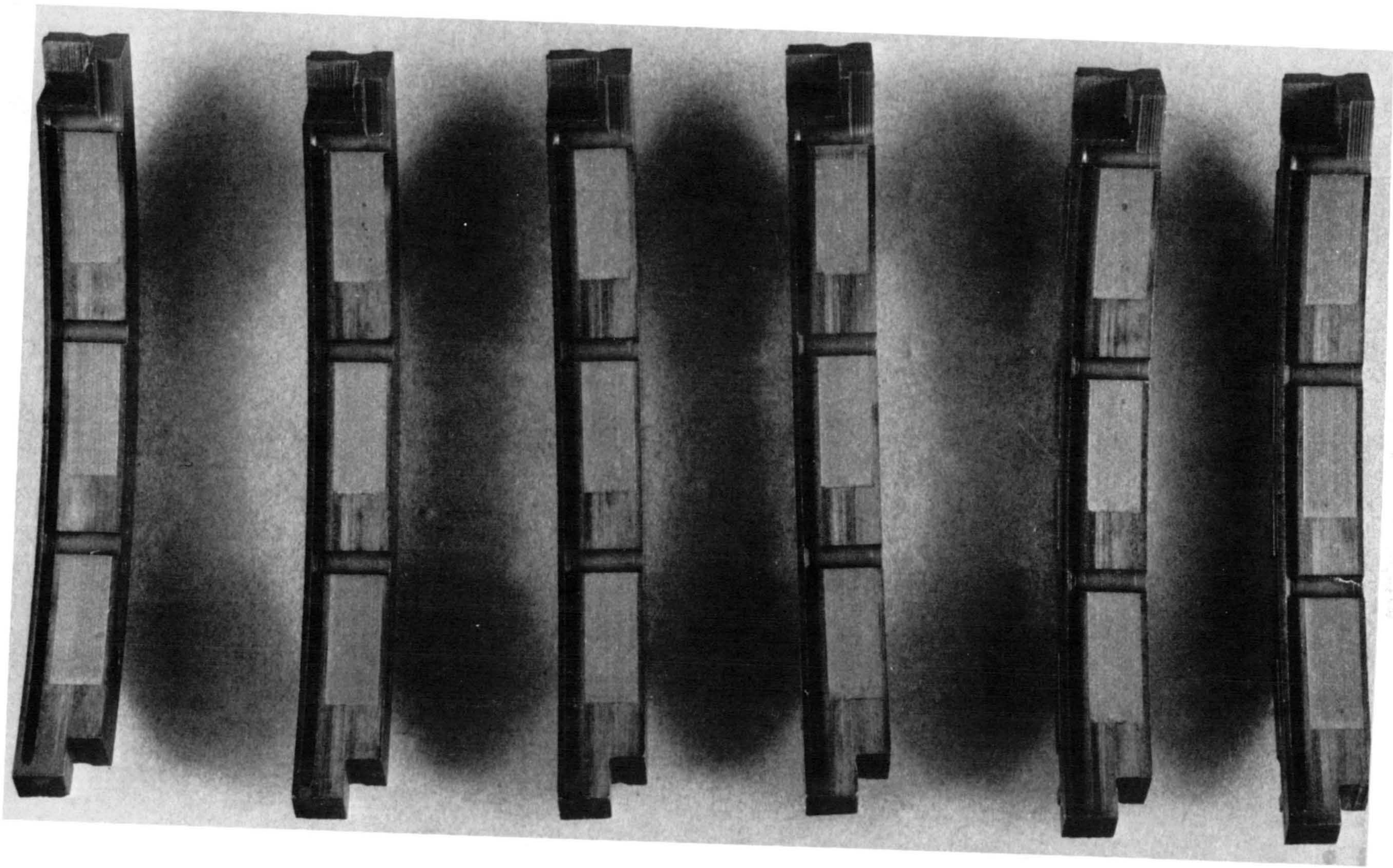


Figure 114. Helium Seal LOX Side Carbon Segments P/N 201001, S/N 3, Posttest 133, Build 3 (10.91 Hours) (Phase IV)

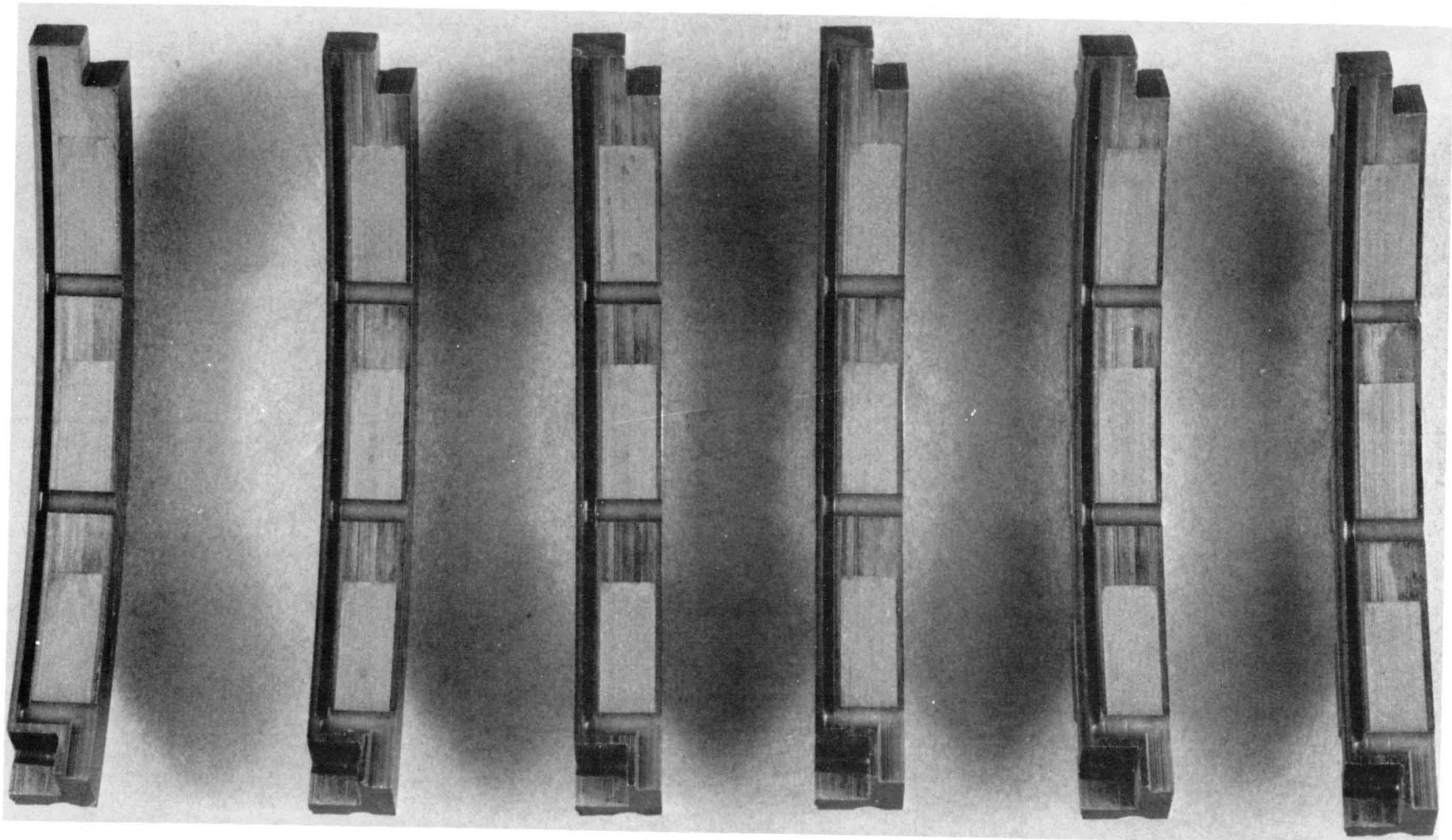


Figure 115. Helium Seal Turbine Side Carbon Segments P/N 201001, S/N C11, Posttest 133, Build 3 (10.91 Hours)

Figure 116. Helium Mating Ring RS010476X, S/N 5, Posttest 133, Build 3 (Phase IV)

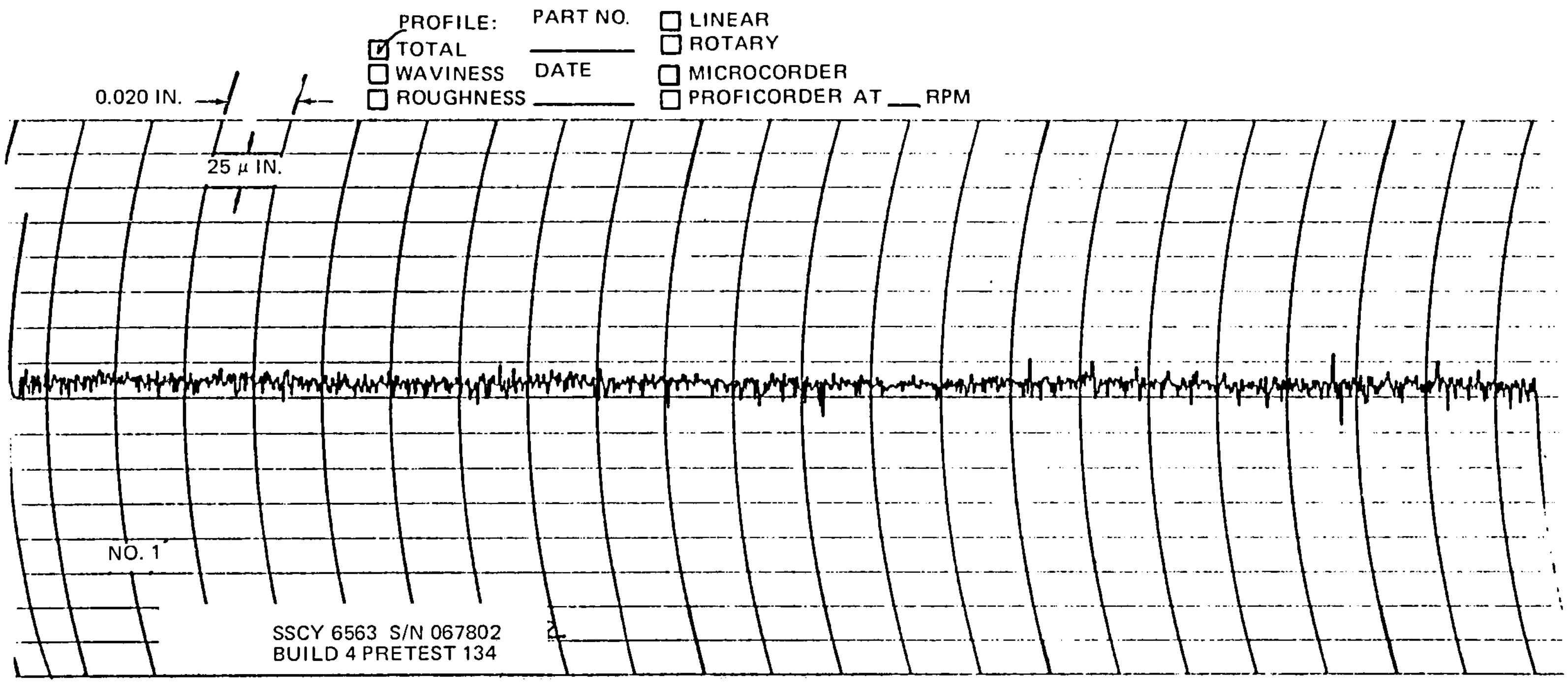


Figure 117. Typical Surface Profile Trace of Spiral Groove LOX Seal Carbon Seal Ring SSCY 6563, S/N 067802, Pretest 134, Build 4

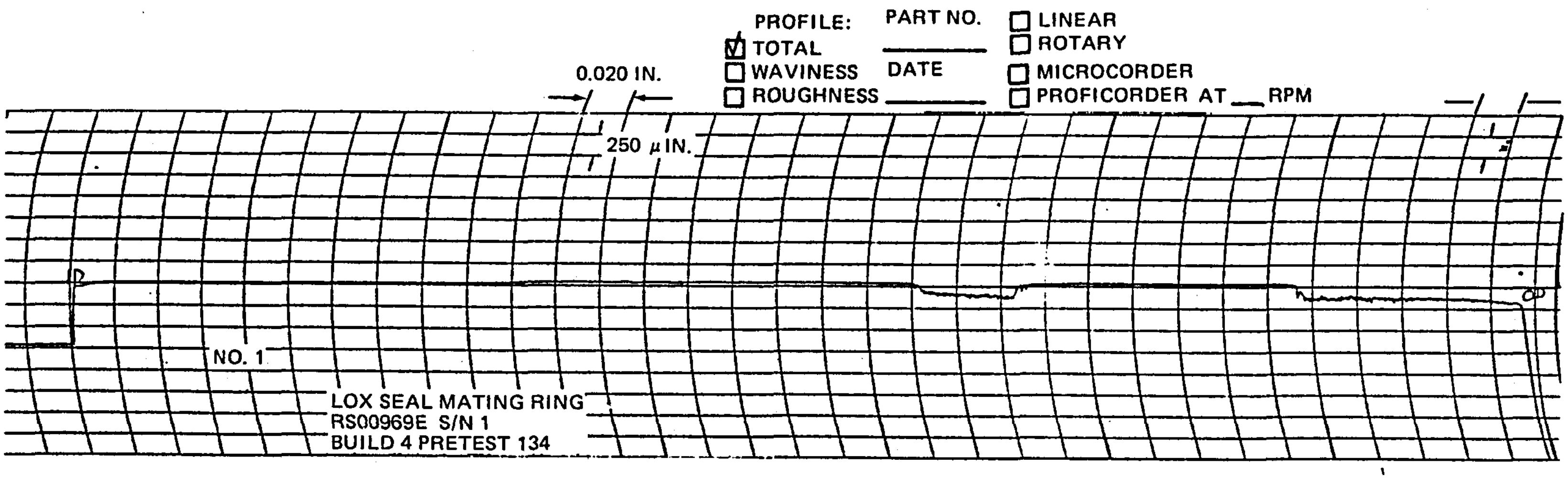


Figure 118. Typical Profile Trace of Spiral Groove LOX Seal Mating Ring RS009696E, S/N 1, Pretest 134, Build 4

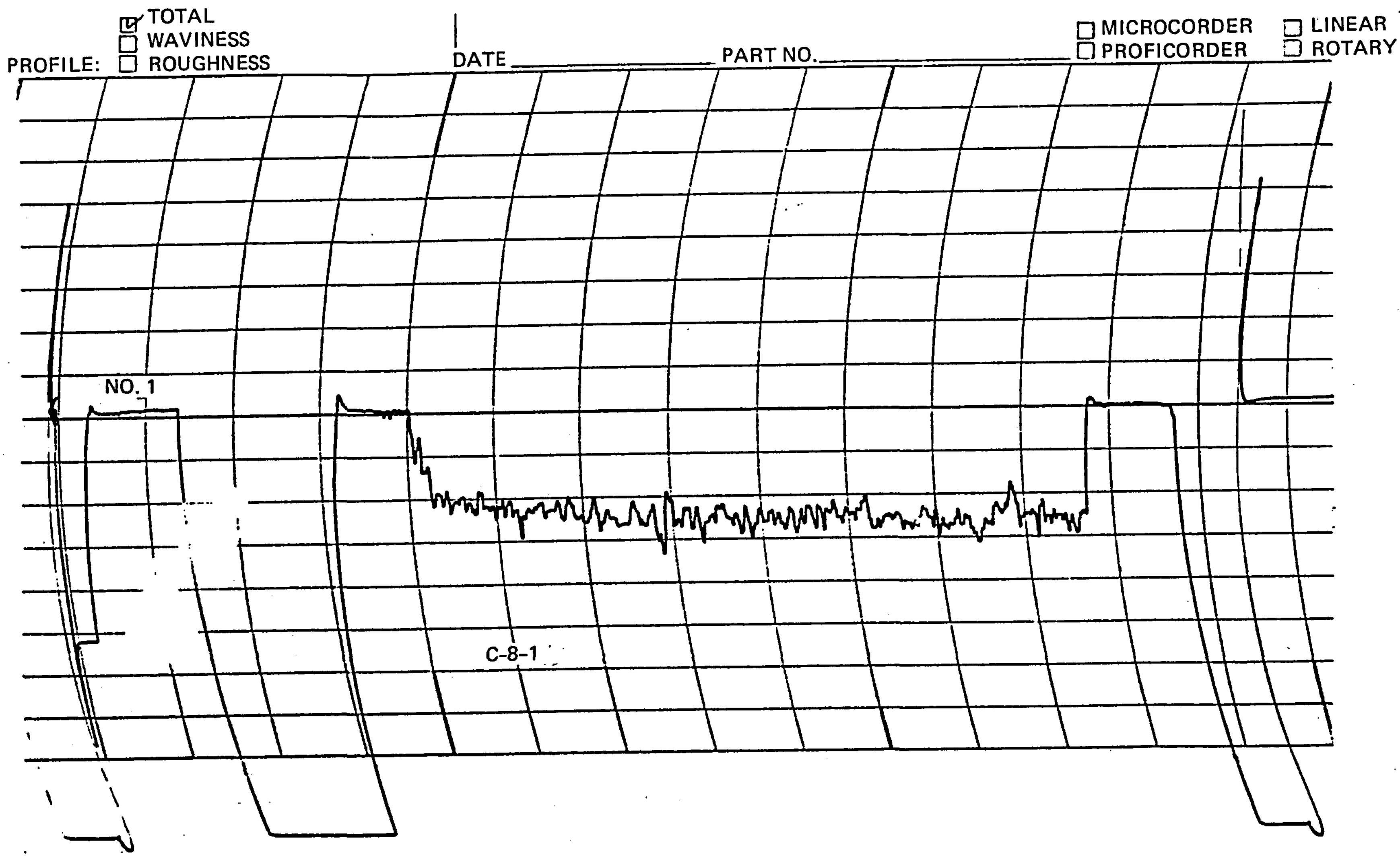


Figure 119. Typical Surface Profile Trace of LOX Side Helium Seal Segment C-8-1, Pretest 134, Build 4

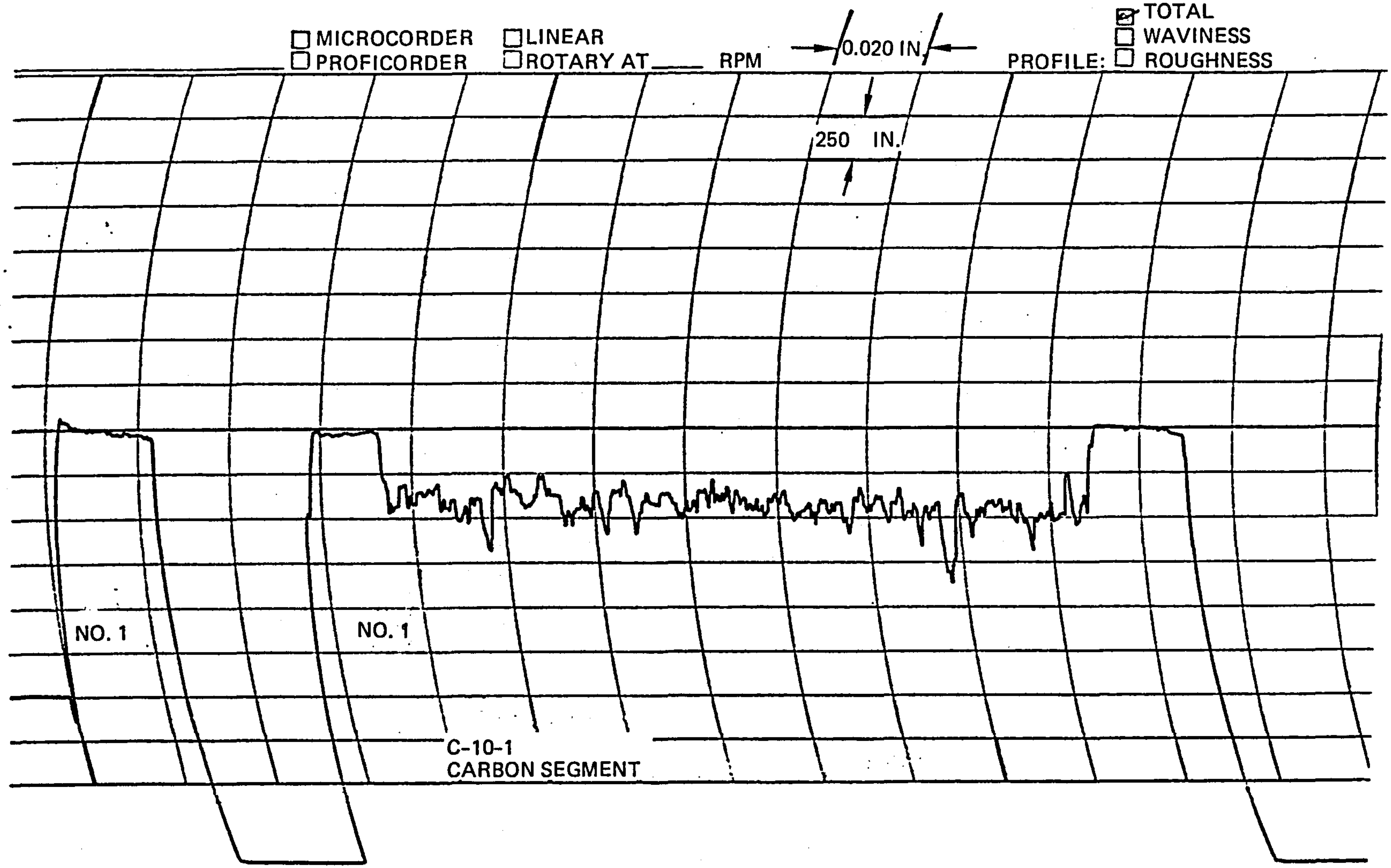


Figure 120. Typical Surface Profile Trace of Turbine Side Helium Seal Segment C-10-1, Pretest 134, Build 4

gradually decreased during each test. The LOX seal pressure level was also difficult to maintain, indicating excessive variation in LOX seal leakage.

Test 141 was run for 363 seconds; however, the speed was erratic with a variation of approximately 2000 rpm, indicating inconsistent seal drag torque. The LOX seal pressure gradually dropped from 2344 to 1448 kPa (340 to 210 psig) during the test, indicating deterioration of the LOX seal.

The final test 142 was cut off at 168 seconds due to indication of excessive LOX seal leakage. The leakage orifice differential pressure pegged out and the temperature at the orifice indicated liquid flow. Visual observation of the LOX seal drain indicated a full stream of liquid spraying out of the drain exit.

The maximum LOX seal pressure which could be obtained was 1138 kPa (165 psig). The LOX seal drain cavity pressure increased to 483 kPa (70 psig) and LOX was leaking through the helium purged intermediate seal and out of the turbine side drain.

<u>Build 4 Disassembly</u>

Disassembly inspection revealed the LOX seal spiral grooves to be completely worn off. The surface of the chrome plated Monel mating ring was worn 0.028 to 0.063 cm (0.011 to 0.025 in.) (Fig. 121). The carbon seal ring surface worn 0.102 to 0.152 cm (0.040 to 0.060 in.) with excessive pitting (Fig. 122). The carbon ring had slipped at the interference fit to the Invar retainer band and was cocked. The interference fit was apparently reduced by excessive heat from the heavy rubbing. The other components of the seal were in good condition.

The helium seal indicated heavy rubbing contact at one spot on the mating ring from excessive eccentric rotation. The remainder of the mating ring surface showed light rubbing contact. There was no measureable wear on the LOX side segments. The turbine side segment wear was 0.00025 to 0.00076 cm (0.0001 to 0.0003 in.). One LOX side segment was broken at two places, apparently from excessive eccentric motion of the shaft caused by heavy rubbing at the LOX seal. The turbine side segments were in good condition except for the wear. The data indicate that the helium seal damage was a result of the LOX seal failure.

Investigation of the Phase IV spiral groove LOX seal failure indicated that the heavy face rubbing was caused by marginal force balance. The original design was biased toward the minimum operating gap to minimize leakage. Operation apparently reduced the face gap sufficient to cause rubbing contact.

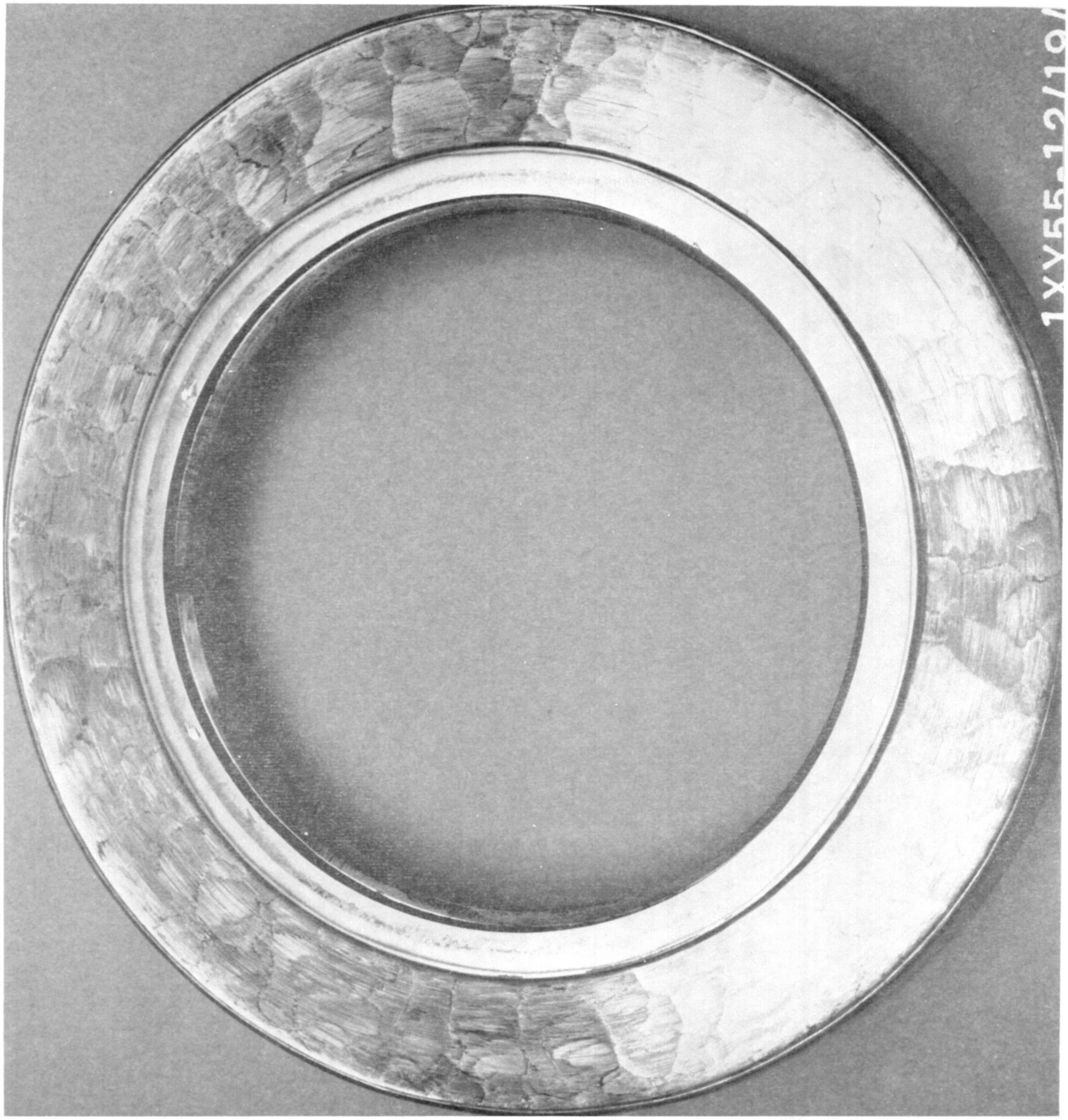


Figure 121. Spiral Groove LOX Seal Mating Ring RS009696E (C28-2500-015), S/N 01, Posttest 142, Build 4

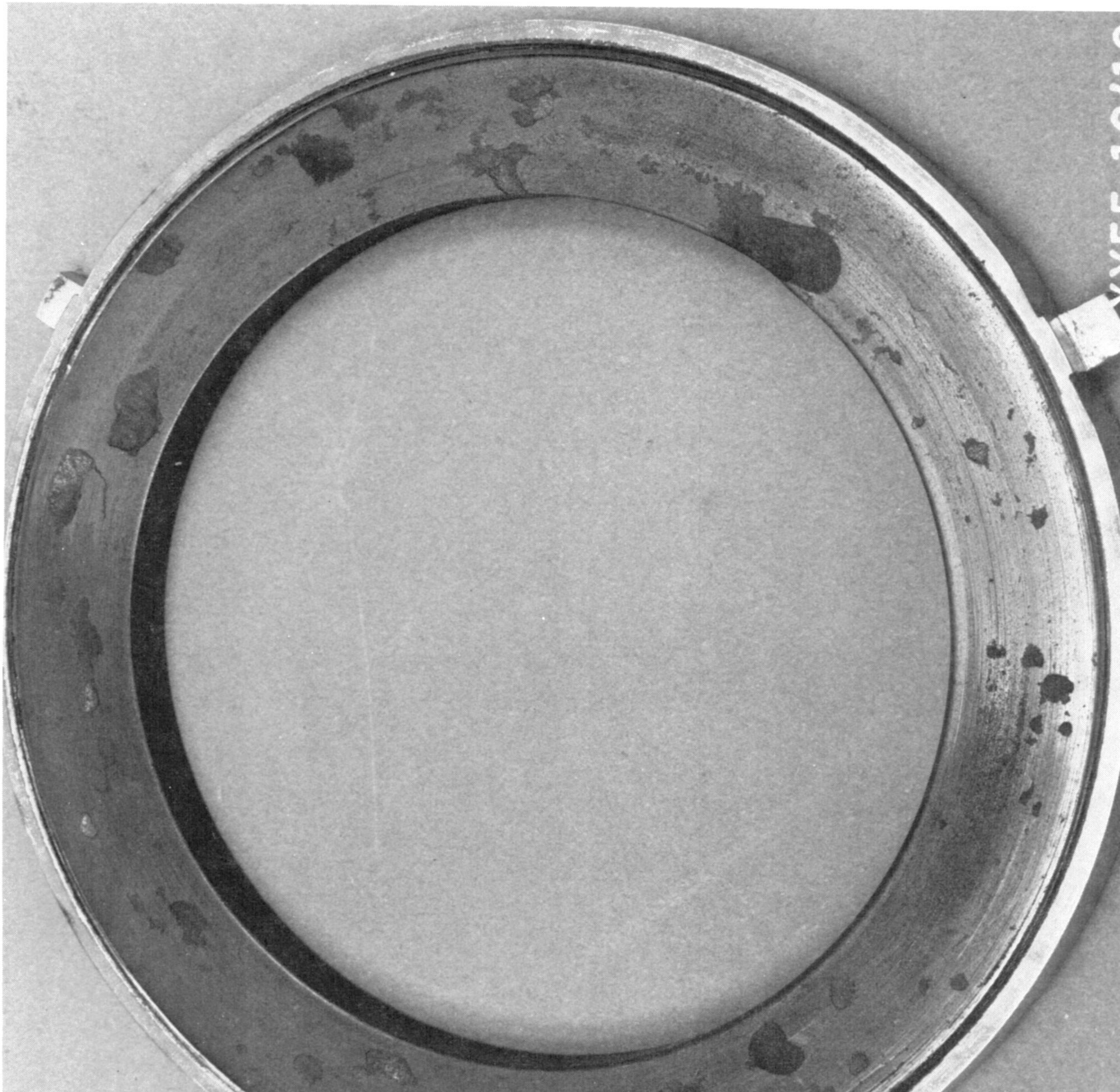


Figure 122. Spiral Groove LOX Seal Carbon Seal Ring SSCY 6563-1, S/N 01, Posttest 142, Build 4

The force balance was revised by reducing the inside diameter of the carbon sealing face from 7.302 to 7.023 cm (2.875 to 2.765 in.). The smaller face ID will increase the opening force and allow the seal to operate at a larger face gap to minimize rubbing contact.

The remaining three original seal rings, part number SSCY 6563-1, were returned to Stein Seal Company for replacement of the carbon ring. The original Invar 36 FM retainer band was used with a new smaller ID carbon ring to make the new Mod I seal ring assembly, part number SSCY 6888-1.

Build 5 Assembly

The tester was assembled with a new Mod I inward pumping spiral groove LOX seal and a new six segment carbon helium seal.

Tests 143 - 145

Pretest 143 when the LOX seal was initially pressurized the leakage was excessive. The tester turning torque increased from 2.26 J (20 in.-lb) at 0 LOX pressure to 15.2 J (135 in.-lb) at 2413 kPa (350 psig), indicating that the seal was being loaded closed by the pressure.

Test 143 was started at a LOX seal pressure of 965 kPa (140 psig). At start, the drain pressure and the leakage orifice pressure increased, indicating increased leakage. The test was cut after 2 seconds due to the vibration level exceeding the redline of 20 g peak to peak. At cutoff with the LOX seal pressure steady at 1034 kPa (150 psig), the drain pressure and leakage orifice pressure dropped to near zero, indicating lower leakage than pretest.

Test 144 started with the LOX seal pressure at 965 kPa (140 psig). The drain pressure spiked up at start and dropped back to near zero at cutoff. The leakage orifice temperatures dipped slightly at start and returned at cutoff. The test was cut off at 3 seconds due to high vibration.

Test 145 also started with the LOX seal pressure at 965 kPa (140 psig). The drain pressure and temperature were similar to test 143, except at cutoff they were erratic, indicating seal damage.

Posttest 145, the LOX seal leakage was excessive with the LOX pouring out of the drain and outboard slave seal. The tester turning torque with the LOX seal pressurized to 862 kPa (125 psig) was erratic and high.

Build 5 Disassembly

Disassembly inspection revealed the spiral groove LOX seal to be rubbed and worn. The spiral grooves were worn off the mating ring surface (Fig. 123). The carbon seal ring surface was worn 0.0010 to 0.0056 cm (0.0004 to 0.0022 in.) (Fig. 124). The other components of the seal were in good condition.

The helium seal was in excellent condition, except the LOX segment dam was broken at installation. The carbon was polished with no measureable wear. The mating ring surface had a light contact pattern with no visible wear.

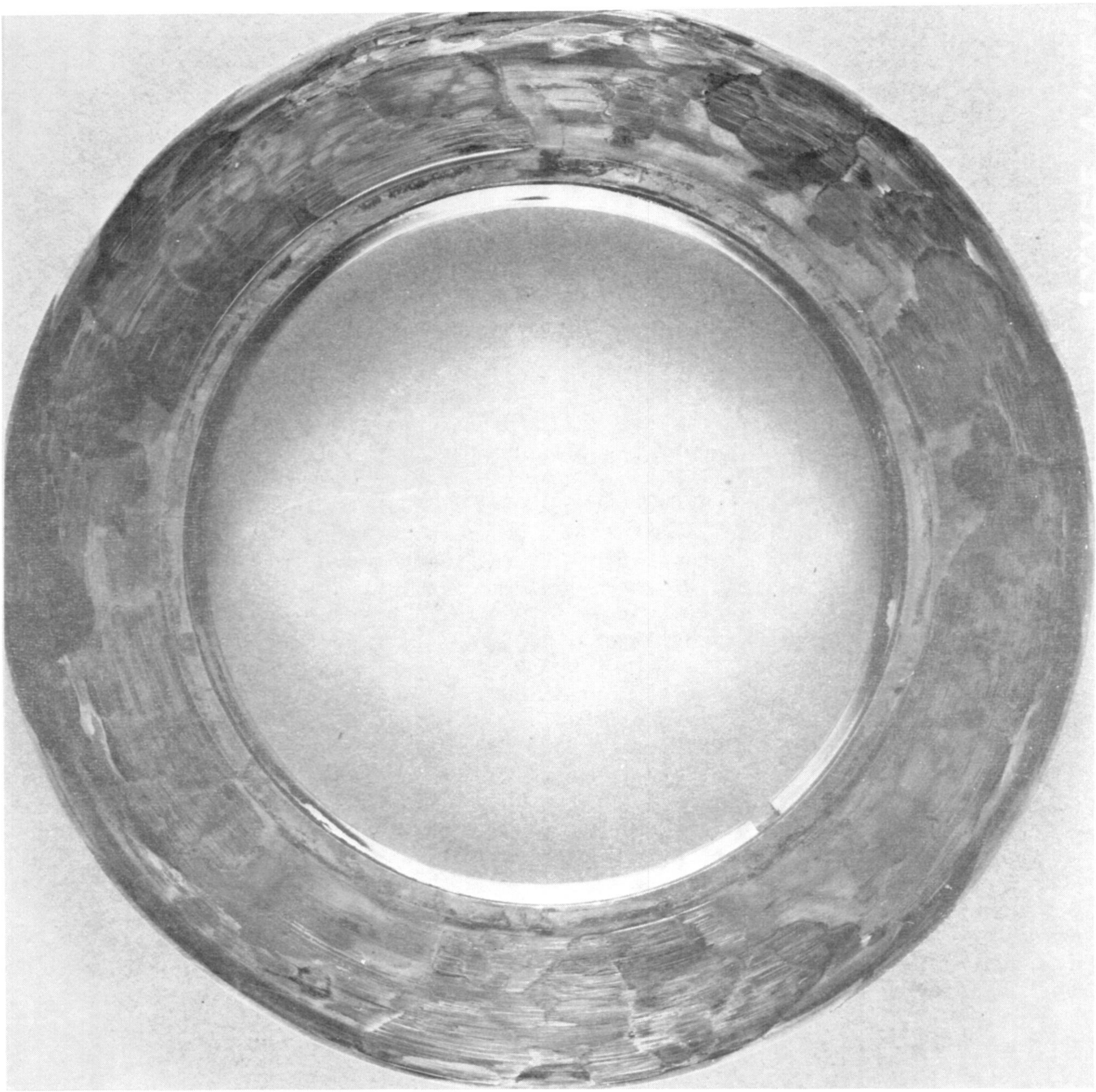


Figure 123. Spiral Groove LOX Seal Mating Ring RS009696E (C28-2500-015), S/N 02, Posttest 145, Build 5

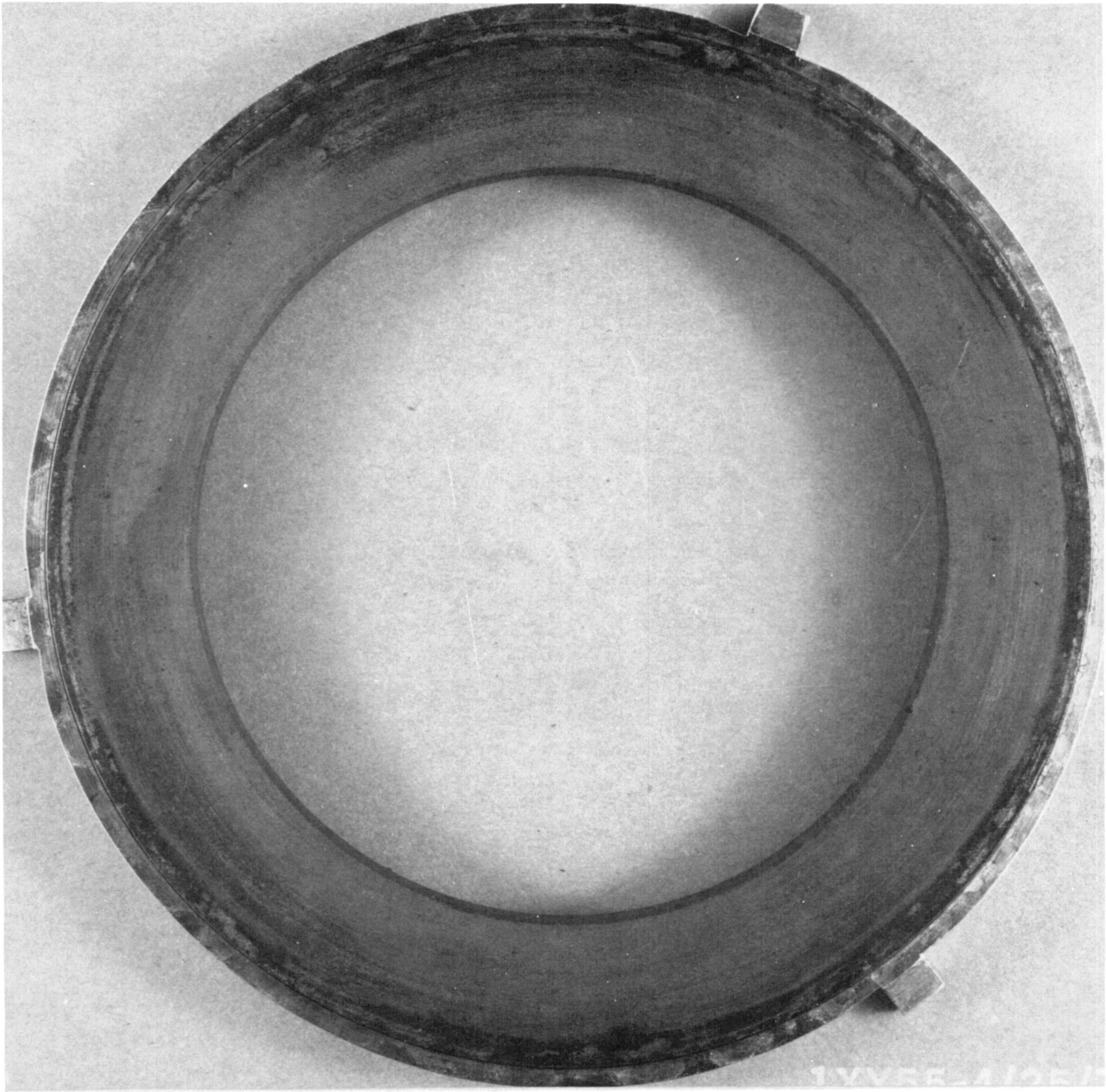


Figure 124. Spiral Groove LOX Seal Carbon Seal Ring SSCY 6888-1, S/N 01, Posttest 145, Build 5

Design review indicated that the wide sealing dam concept used by Crane on the more recent spiral groove designs may not be satisfactory for cryogenic fluids due to excessive force variation caused by vaporization of the fluid across the sealing interface. The spiral groove design was revised to be similar to the narrow dam concept used on the successful small high-speed LOX seal program. The spiral groove inside diameter was changed from 8.412 to 7.671 cm (3.312 to 3.020 in.). The spiral groove depth was changed from 0.0005 to 0.0010 cm (0.0002 to 0.0004 in.) for improved lift at the larger operating gap.

The existing spiral groove mating rings were reworked by Crane Packing Company to incorporate the revised design.

Build 6 Assembly

The tester was assembled with a new Mod II spiral groove LOX seal mating ring which was reworked by Crane Packing Company to incorporate the narrow dam concept.

A new carbon seal ring with decreased inside diameter (same as Build 5) was installed. A new piston ring and pilot ring was installed. The housing was the same as Build 5.

The LOX seal static leakage at assembly indicated a significant improvement compared to the previous wide dam spiral groove seal.

A typical profile trace of the spiral groove mating ring surface is shown in Fig. 125. The spiral groove depth measured 0.0010 cm (0.00040 in.).

The same Rayleigh Step segmented carbon helium and mating ring that was used on Build 5 was installed.

Tests 146 - 169

The test objective was to perform four tests of 15 minutes duration each with liquid oxygen at pressure increments of 1034, 1724, 2413 and 2758 kPa (150, 250, 350, and 400 psia) at 30,000 rpm.

The 1034 kPa (150 psia) tests were completed with a total of 23 starts and 1235 seconds. The 1724 kPa (250 psia) test was terminated due to a sudden increase in LOX seal drain pressure and leakage.

The spiral groove LOX seal performance at 1034 kPa (150 psig) was satisfactory with low leakage. The measured leakage varied from 0.005 to 0.020 m^3/s (11 to 44 scfm) at LOX pressures from 552 to 1103 kPa (80 to 160 psig). The drain temperature at the leakage orifice also indicated low leakage with ambient temperature gas at the drain exit. The data indicate satisfactory functioning of the seal.

The LOX seal performance at 1724 kPa (250 psia) was satisfactory with steady operation and low leakage prior to the sudden increase in leakage and drain pressure. The prefailure conditions indicated that both seals were functioning properly.

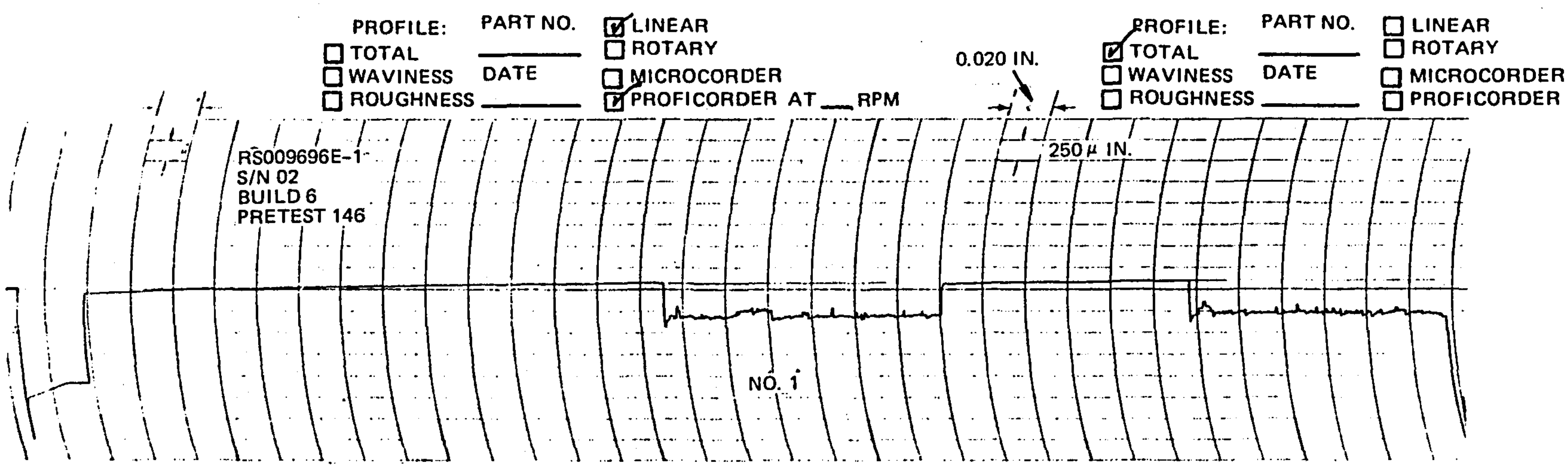


Figure 125. Typical Surface Profile Trace of Spiral Groove Mating Ring P/N RS009696E-1 (New), S/N 02

Build 6 Disassembly

Disassembly inspection revealed the spiral groove LOX seal to be rubbed and worn. The spiral groove mating ring surface was worn 0.0034 cm (0.0005 in.) (Fig. 126 and 127). The carbon seal ring surface was worn 0.083 to 0.132 cm (0.121 to 0.0192 in.). The other components of the seal were in good condition.

The helium seal was in good condition, except the LOX segment dam which was chipped during a previous installation. The carbon was polished with 0.0007 to 0.0021 cm (0.0001 to 0.0003 in.) wear. The mating ring surface had a light contact pattern.

Analysis of the Phase IV Crane inward pumping spiral groove LOX seal indicates that reducing the sealing dam width, optimizing the groove to land ratio and revising the angle of the spiral will increase the face gap and leakage rate, decrease the power loss and maintain adequate film stiffness. The increased face gap will reduce rubbing contact. The increased leakage will improve cooling of the seal ring and mating ring. The lower power loss will result in less heat generation at the seal face. The lower heat generation and improved cooling will minimize thermal distortion of the sealing faces.

Build 7 Assembly

The tester was assembled with a new spiral groove LOX seal mating ring which was reworked by Crane Packing Company to incorporate a reduced sealing dam width, revised angle of the spiral groove, and an optimized groove to land ratio. The spiral groove depth measured 0.0018 cm (0.0007 in.). The spiral groove diameter was 7.569 cm (2.980 in.).

A new carbon ring was installed. The housing, pilot ring, and piston ring were the same hardware used in Build 6. The helium seal assembly and mating ring were the same as Build 6.

Tests 170 - 176

The test objective was to perform four tests of 15 minutes duration each with liquid oxygen at pressure increments of 1034, 1724, 2413 and 2758 kPa (150, 250, 350 and 400 psia) at 30,000 rpm. The 1034, 1724 and 2413 kPa (150, 250 and 350 psi) tests were completed. Two tests at 1034 kPa (150 psia) for 904 seconds were performed. The first test was cut off prematurely due to a speed control problem. The second 1034 kPa (150 psia) test was of successful programmed duration with steady-state operation. Three starts at 2586 kPa (375 psia) for 14 seconds were then made. The first two tests were prematurely cut off due to speed control problems. The third start at 2586 kPa (375 psia) resulted in an explosion and subsequent fire.

The LOX seal performance at 1034 kPa (150 psig) was satisfactory with low leakage. The measured leakage during the steady-state duration run was 0.011 m^3/s (24 SCFM). The drain temperature at the leakage orifice also indicated low leakage with slightly less than ambient temperature gas at the drain exit. The data indicate satisfactory function of the seal during steady-state operation.

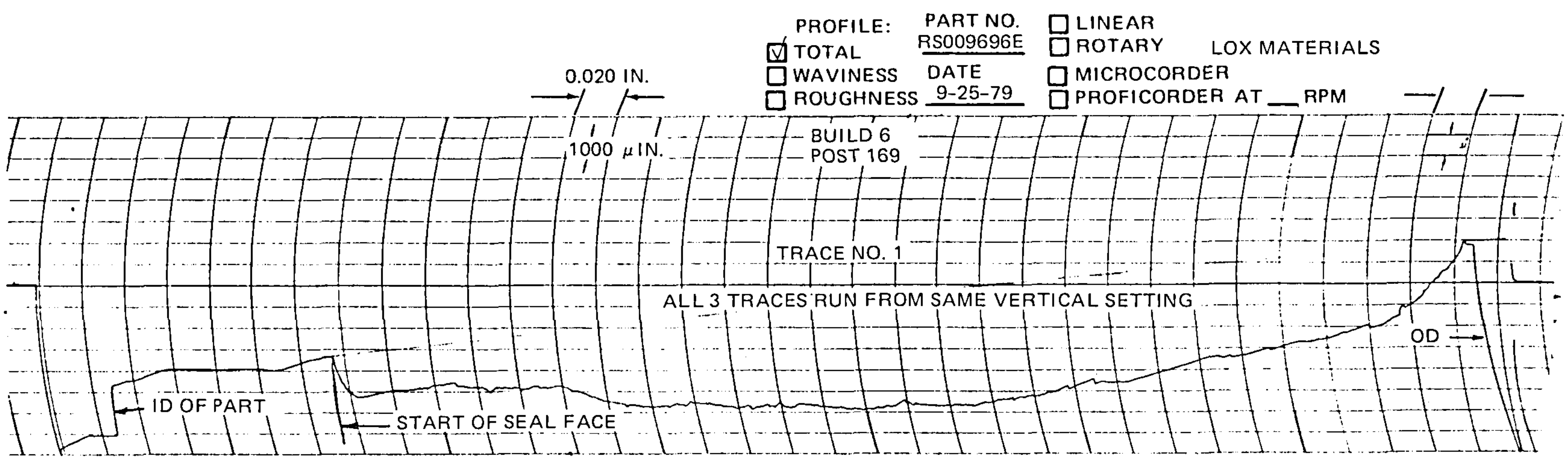


Figure 126. Typical Surface Profile Trace of Spiral Groove Mating Ring
P/N RS009696E-1, S/N 031, Posttest 169, Build 6

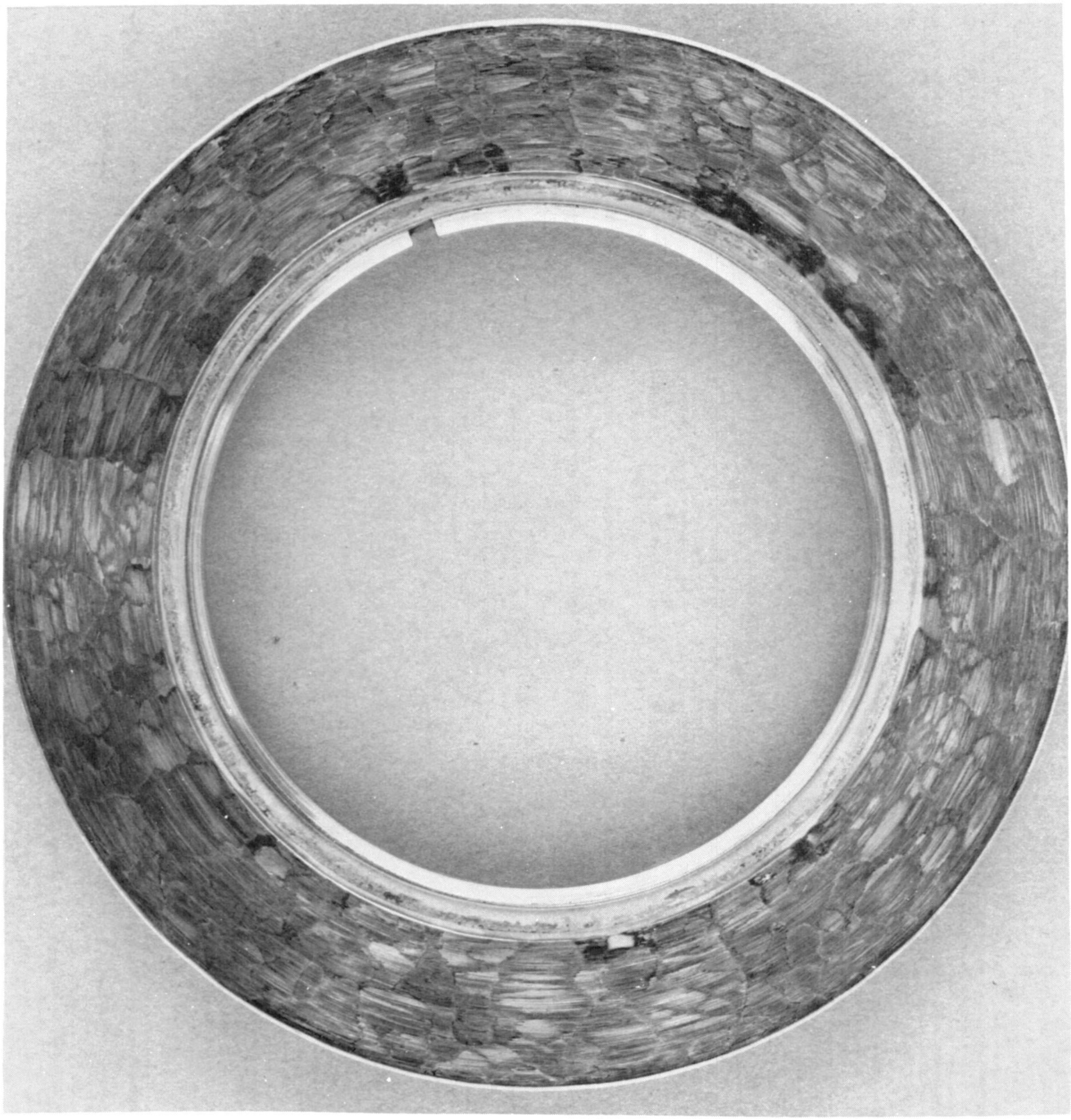


Figure 127. Spiral Groove LOX Seal Mating Ring RS009696E-1
(C28-2500-015), S/N 03, Posttest 169, Build 6

The leakage was excessive prior to start, increased at start, decreased after 100 seconds and held steady for the remainder of the test.

The LOX seal also performed well at 1724 and 2413 kPa (250 and 350 psig). The measured steady-state leakage at 1724 kPa (250 psig) was 0.009 m^3/s (20 SCFM). Ambient temperature gas at the leakage orifice indicated low leakage. At a LOX pressure 2344 kPa (340 psig), the measured leakage was 0.011 m^3/s. The data indicate satisfactory function of the seal during steady-state operation. The pretest 172 static leakage was excessive. The leakage increased at start, then decreased after 20 seconds and stablized at the lower level. The pretest 173 static leakage was satisfactory. The leakage increased at start, then decreased and stablized after 10 seconds.

The first two starts at 2586 kPa (375 psig) showed the LOX seal to be performing satisfactorily. The measured leakage varied from 0.013 to 0.016 m^3/s (28 to 34 SCFM). The drain temperature at the orifice indicated low leakage with ambient temperature gas at the drain exit. The pretest static leakage was satisfactory on both tests.

The start of the last test at 2586 kPa (275 psia) LOX pressure was satisfactory with no indication of a problem prior to the explosion. The speed spiked up to 18,000 rpm, dropped to zero, increased to 10,000 rpm for 2 seconds, increased to 19,000 rpm and leveled off for 1.5 seconds prior to the explosion. The high frequency data trace is shown in Fig. 128. The start transient was similar to the previous tests. The accelerometer vibration level was low (2 g peak to peak) and did not indicate rubbing contact. The LOX seal upstream and downstream temperatures were normal prior to the explosion.

The tester seal area was severely damaged by the explosion and fire. Five holes were burned through the tester housing in the seal drain area. The tester seal drain cavity was burned out. The LOX seal drain manifold was burned off. The turbine mounting adapter was broken off due to the force of the explosion. There was extensive facility damage to the plumbing, tubing, wiring, instrumentation, and drive turbine.

Build 7 Disassembly

The tester was disassembled due to fire damage. Extensive burning occurred in the LOX and helium seal areas. All the bolts holding the LOX seal flange were broken in tension from the explosion force on the high pressure side.

There were five holes burned through the tester housing. One hole was burned through the helium seal drain and the outboard slave seal housing. Two holes were burned though the helium seal drain. One hole was burned through the LOX seal drain and one large hole was burned through both the LOX and helium seal drains.

The outboard slave seal carbon ring was missing and the housing severely burned. The outboard slave seal mating surface was clean at the carbon contact area but burned elsewhere, indicating burning after rotation had stopped. The complete helium seal assembly was burned out except for three sections of the outer housing. The helium seal mating ring was completely burned away.

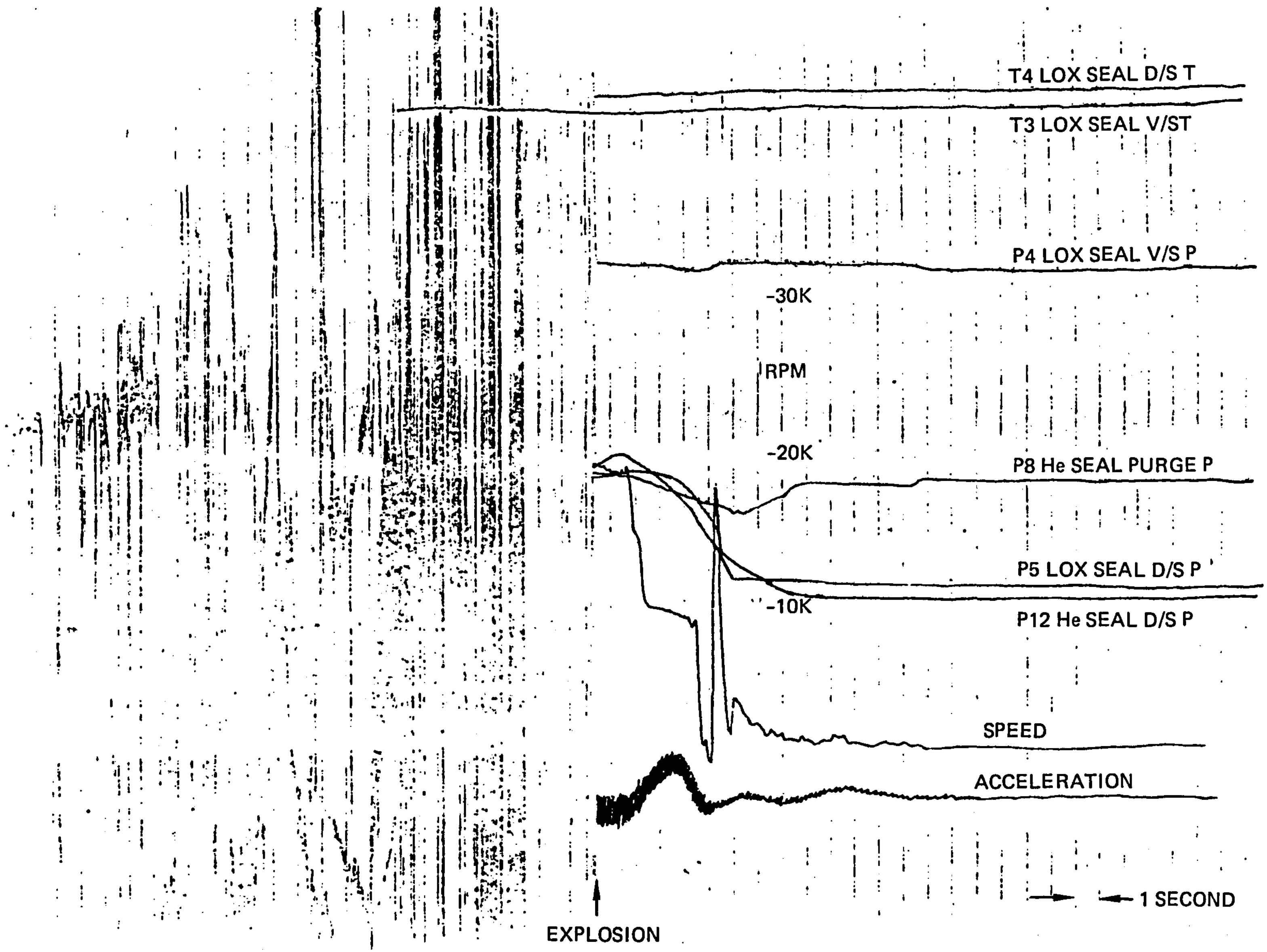


Figure 128. High-Frequency Data Trace, Test 176

The LOX seal housing was severely burned on the downstream side. The upstream side was relatively clean. The flange was burned through at the spring holes and in two areas behind the pilot ring. The pilot ring and springs were completely burned away. The carbon seal ring was intact except for four breaks through the section. The back side of the carbon was clean with no erosion. Half of the Invar retainer band was burned away. The face of the carbon was worn and scored from rubbing, There was no burning on the face except for some erosion at the inside corner.

The LOX seal mating ring surface was worn and scored from rubbing contact. The spiral grooves were completely worn off. The surface was relatively clean with no rotational burning in the wear tract. The outer part of the face had a slag deposit and some spot burning which apparently occurred after rotation stopped. The back side of the mating ring was clean.

The inboard slave seal mating ring face was burned and partially grooved on the carbon contact area. The burning continued uniformly across the face toward the outer diameter indicating the burning occurred after rotation had stopped. The face of the carbon ring was burned and had slag on the outer half. The slag pattern indicates that it was deposited after rotation had stopped. The back side of the mating ring and the inner face of the carbon ring show no burning.

Burning into the shaft occurred after rotation in three places equally spaced over 2/3 of the circumference. The shaft burning ran away from the LOX mate ring surface and appeared to have been pressure fed. The bearings were in good condition with no evidence of burning.

The hardware condition is shown in Fig. 129 through 134.

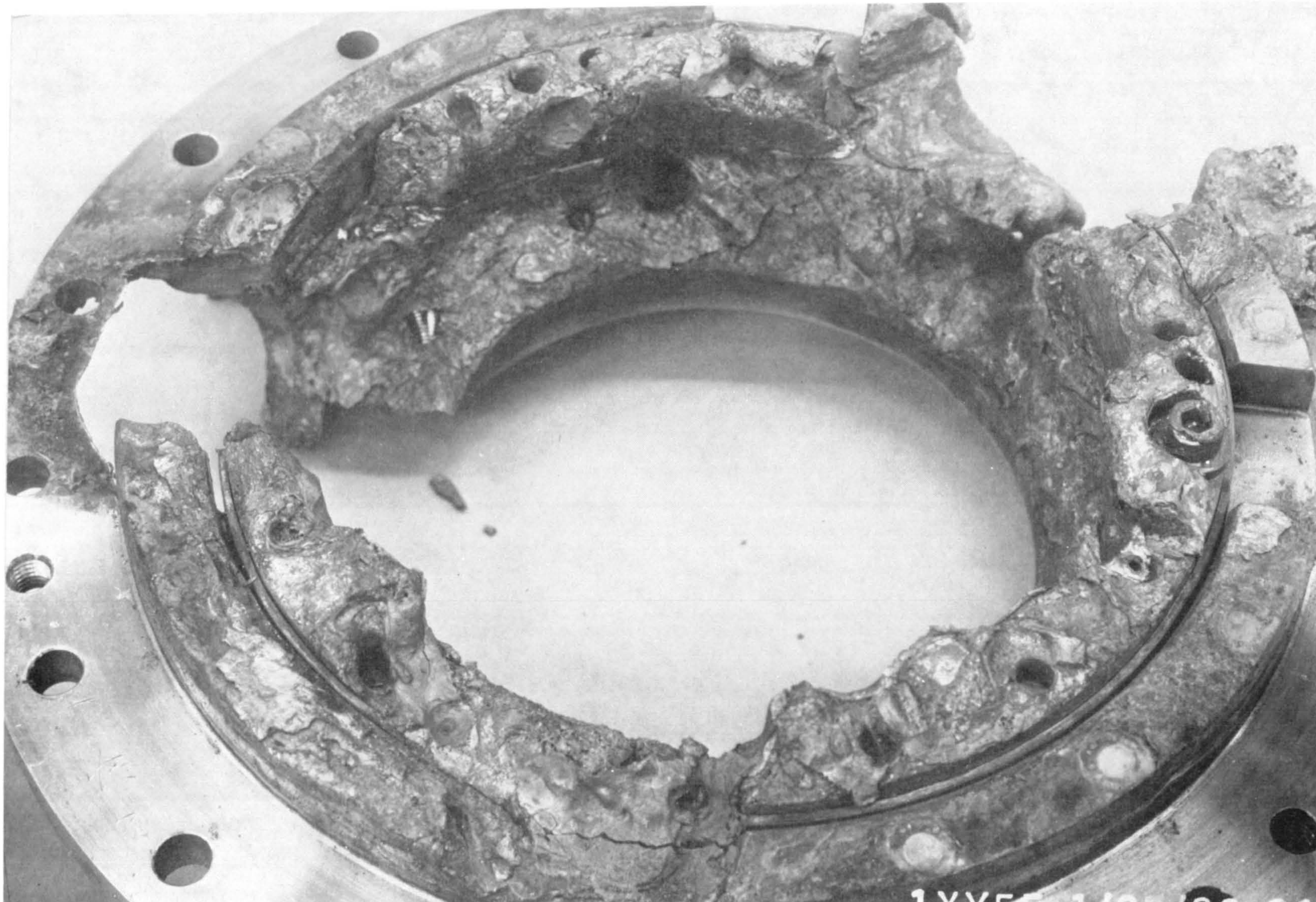
The investigation to determine the cause of the tester explosion and fire indicates that the most probable cause of the fire was the Mod III inward pumping spiral groove LOX seal. The evidence indicates excessive wear and rubbing on the mating ring surface. The spiral grooves were completely worn away.

The mating ring surface was not burned in the wear tract except for spot burning and slag deposits which apparently occurred after rotation stopped; however, it is possible that the heat generation due to rubbing contact started the fire and that the high pressure in the LOX seal upstream cavity forced the major burning into the low pressure drain area. The LOX seal flange was dished toward the drain and the flange bolts were broken in tension, indicating that the explosion occurred on the high pressure side.

It is possible that the fire started due to impact load or fretting at the LOX seal antirotation tangs or at the LOX seal ring pilot; however, the same seal design was successfully tested with the Rayleigh Step hydrodynamic face configuration with no evidence of impact loading or fretting.

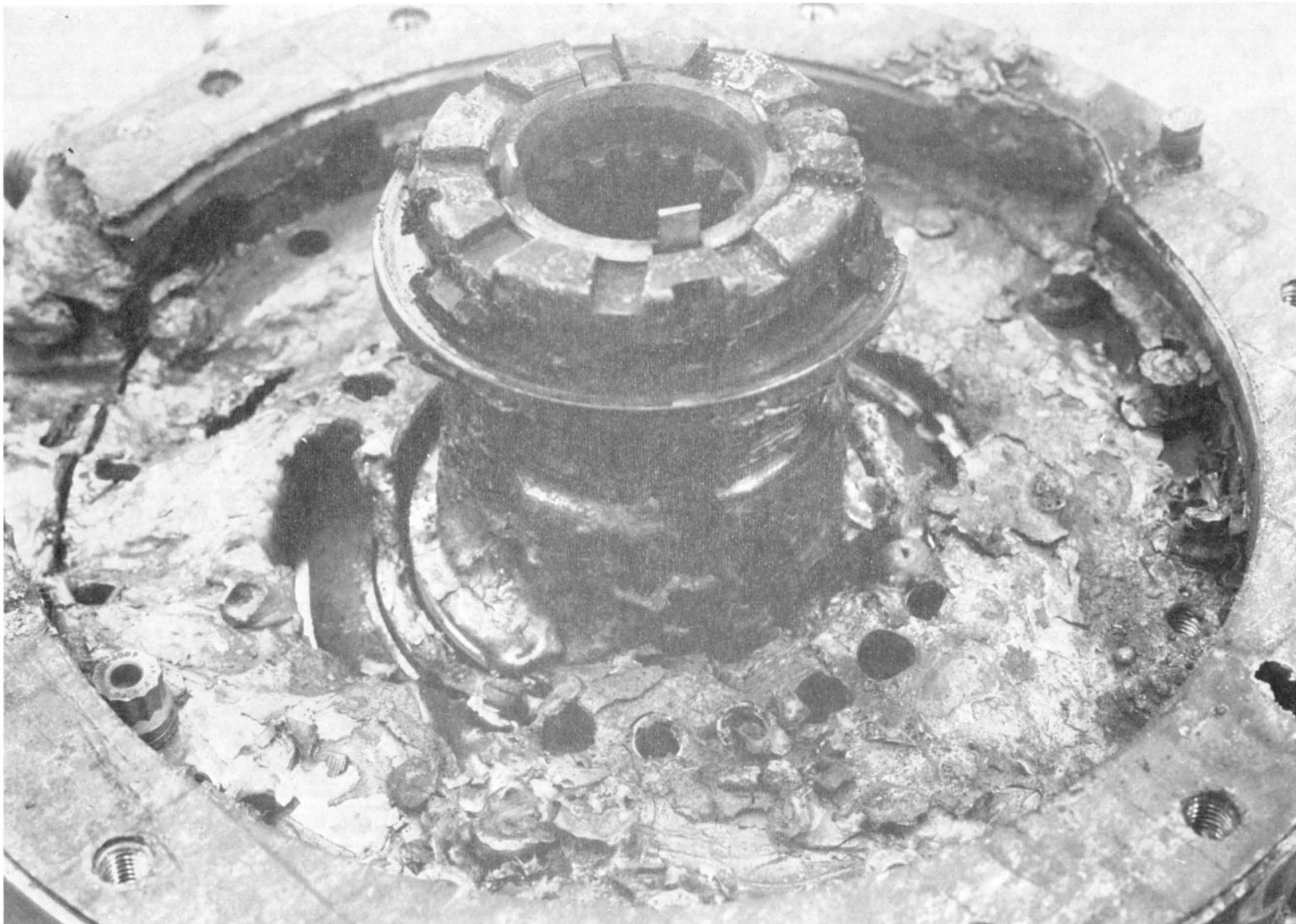
The inboard slave seal mating ring surface was burned toward the outer diameter and partially grooved on the carbon contact area. The burning pattern and slag deposit indicates that the burning occurred after rotation stopped.

Figure 129. Helium Seal Drain and Outboard Seal Area, Posttest 176



1XY55-1/25/80-C1A

Figure 130. Helium Seal and Retainer Housing, Posttest 176



1XY55-1/25/80-C1D

Figure 131. LOX Seal Drain Side, Posttest 176

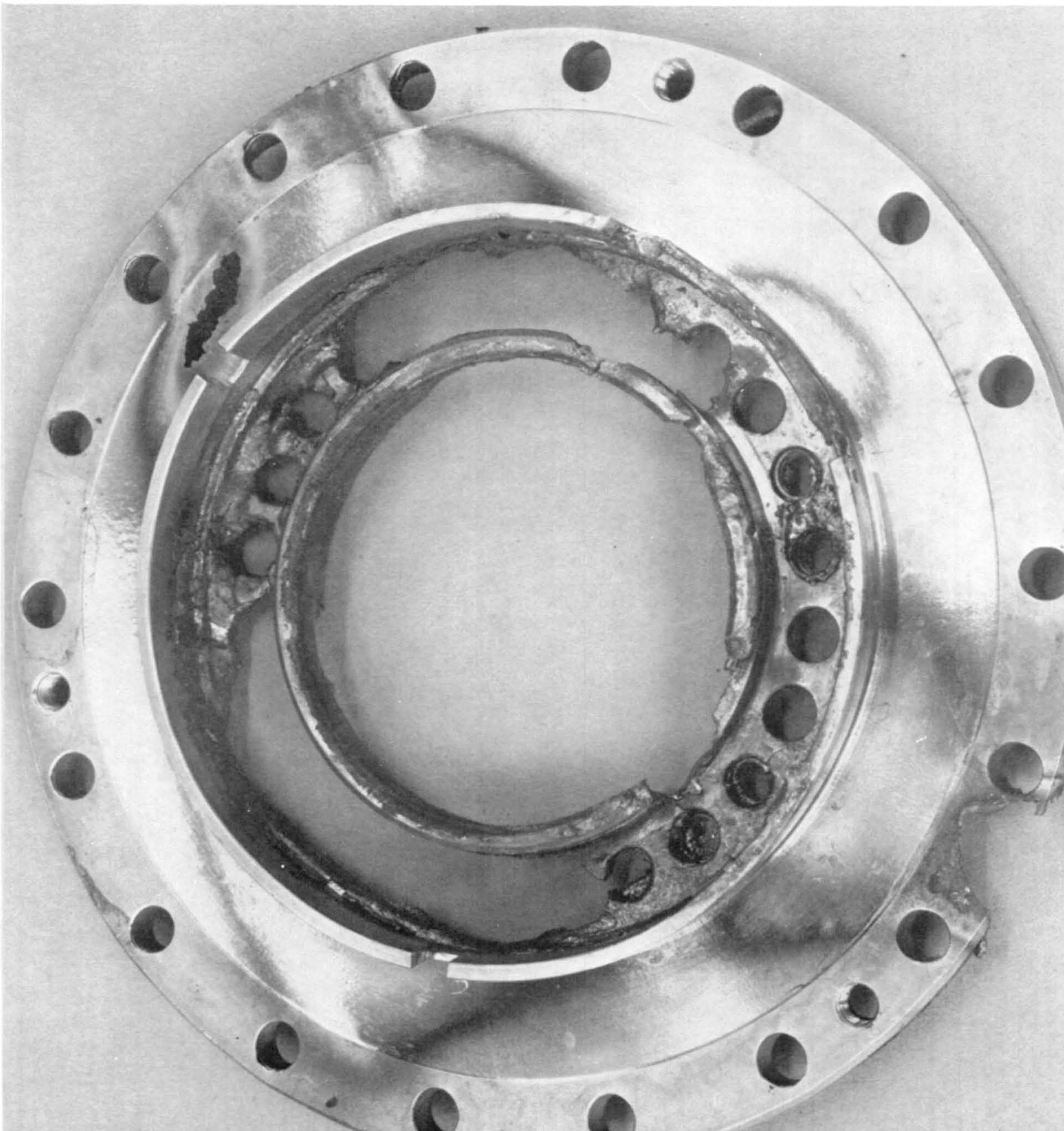


Figure 132. LOX Seal Housing High Pressure Side, Posttest 176

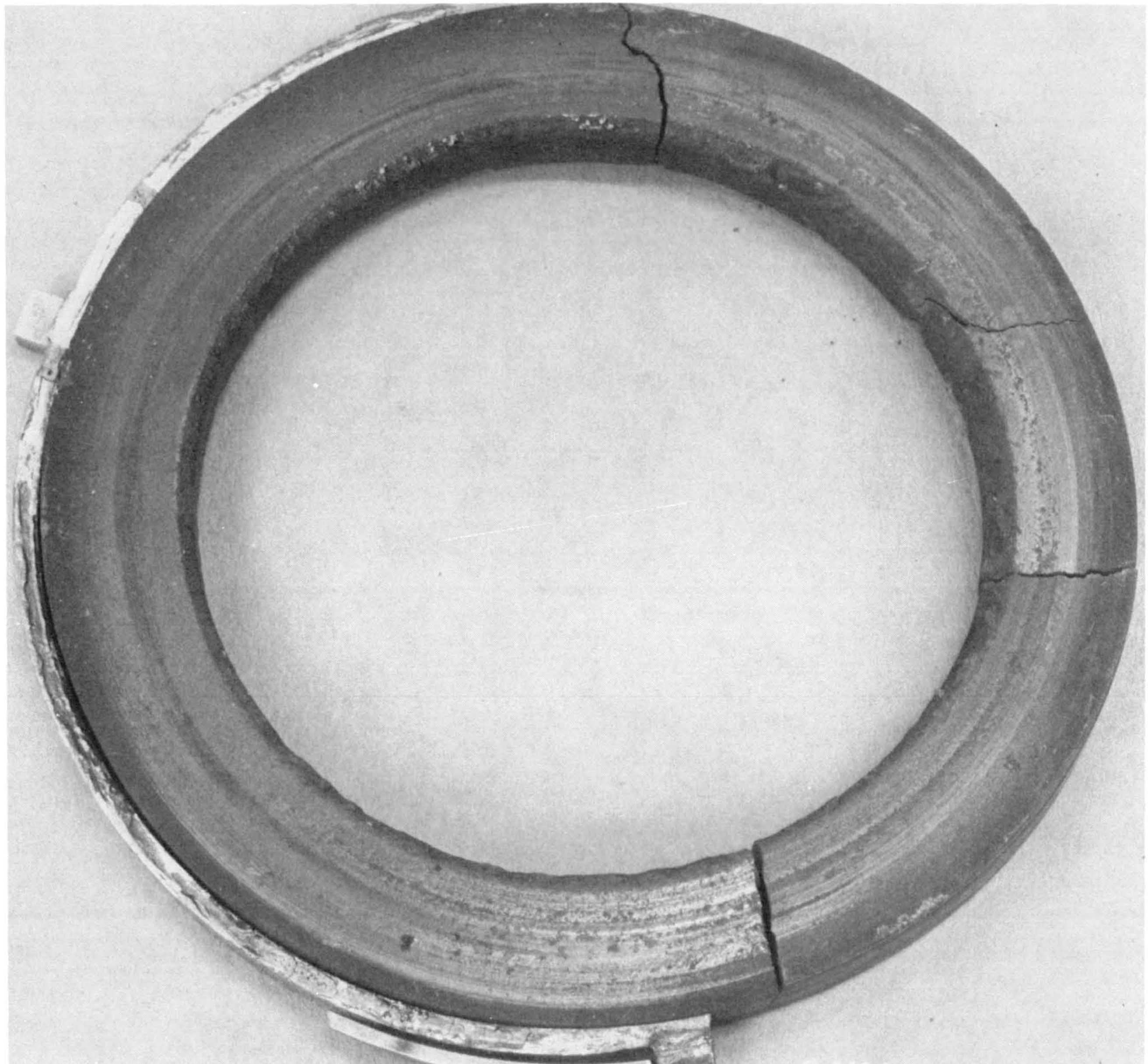


Figure 133. LOX Seal Carbon Seal Ring Face, Posttest 176

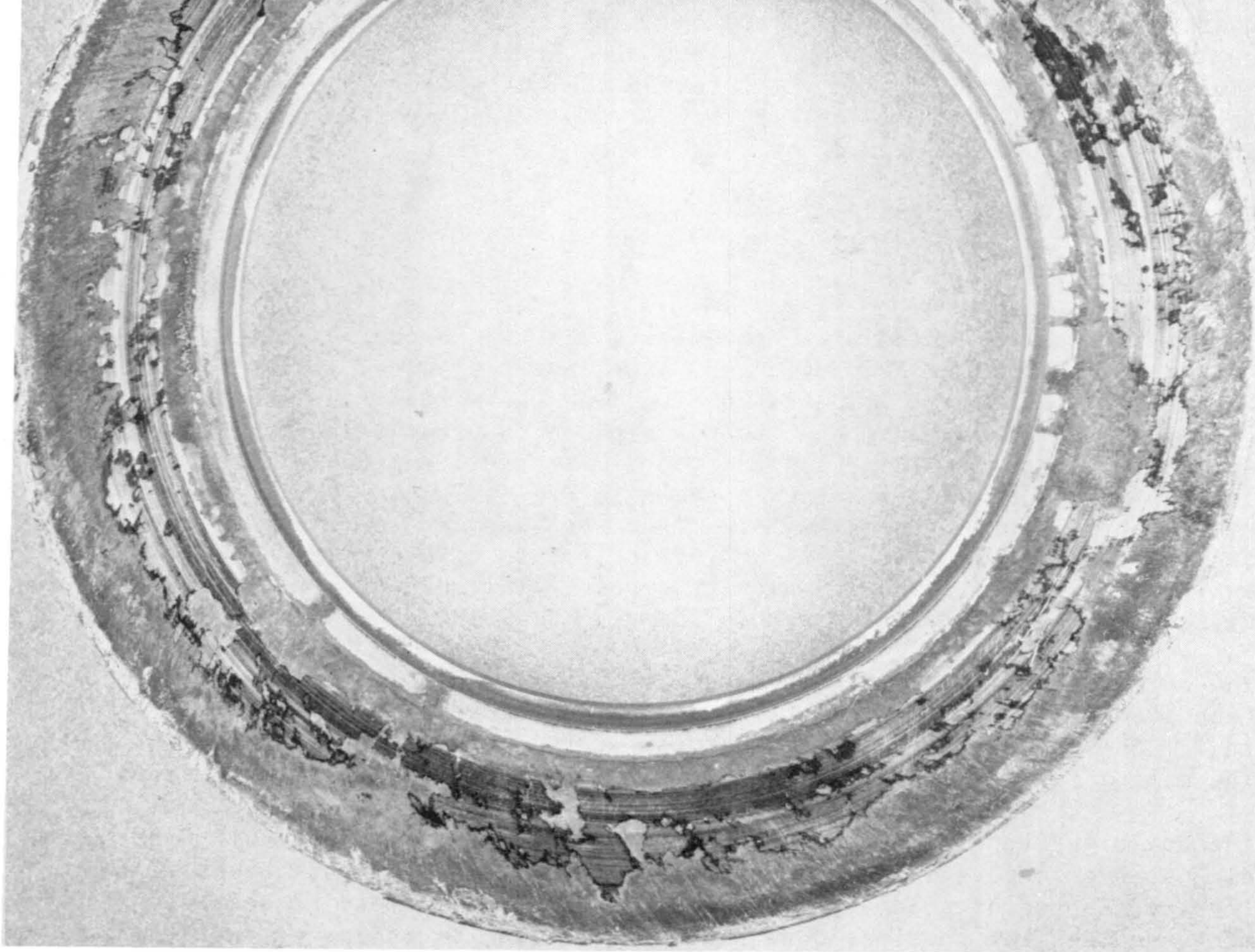


Figure 134. LOX Seal Mating Ring Face, Posttest 176

Also, the LOX cavity between the slave seal and the spiral groove LOX seal was clean and the upstream side of the LOX seal was relatively clean. The evidence indicates that the slave seal burning was a result of the explosion.

The helium seal and mating ring were completely burned away except for three sections of the ouer housing. It is possible that the fire started due to heat generation from rubbing contact between the helium seal carbon segments and the mating ring surface; however, the same helium seal has been used for previous Phase IV testing and the same type of seal has been used successfully for the entire program. The heavy burning in the helium seal area probably occurred after the explosion and resulted from the high pressure LOX feeding the fire in tbe drain cavities.

The test data did not indicate the source of the explosion. The start of test 176 appeared similar to the previous tests prior to the explosion, except that there was a longer (1.5 second) delay at the tester critical speed (19,000 rpm). It is possible that the slight delay at the critical speed resulted in additional shaft deflection which caused the LOX seal to rub the spiral groove mating ring surface; however, if the LOX seal was operating properly, the additional deflection would not cause rubbing contact.

PHASE V LIQUID NITROGEN CHECKOUT

Build 1 Assembly

The tester was assembled with new Phase V LOX and helium seals. The LOX seal uses the same housing and segmented Vespel secondary seal as the Phase IV Rayleigh Step LOX seal. The carbon ring and the mating ring are replaced with the "pressure balanced" (refer to description on page 26) outward pumping special groove parts (Fig. 135 and 136). The surface profile trace of the LOX seal spiral groove mating ring is shown in Fig. 137. The helium seal is the same type segmented carbon Rayleigh Step that was used on Phase IV, except the diameter is reduced from 9.997 cm (3.936 in.) to 6.769 cm (2.665 in.) and the mating ring is replaced with a shaft sleeve. The surface profile trace of the Rayleigh Step helium seal rings is shown in Fig. 138 and 139.

The spiral groove LOX seal was assembled with seven load springs to produce a face load of 62.3 N (14 lb) at the installed compression of 0.180 cm (0.071 in.). The mating ring optical flatness after installation was 3 to 9 HLB. The mating ring surface axial runout was 0.0013 cm (0.0005 in.) total.

The Rayleigh Step segmented carbon helium seal was assembled, using the mating ring sleeve to position the segments. Inspection of the seal revealed that three of the compression springs, which provide axial load to seat the segments against the housing, were bent. Investigation indicated that the springs were bent due to the difference in spring hole spacing from one set of segments to the other when the segments are in the free position. The spring hole spacing is satisfactory when the segments are installed on the mating ring sleeve. The sleeve radial runout measured 0.00076 cm (0.003 in.) total.

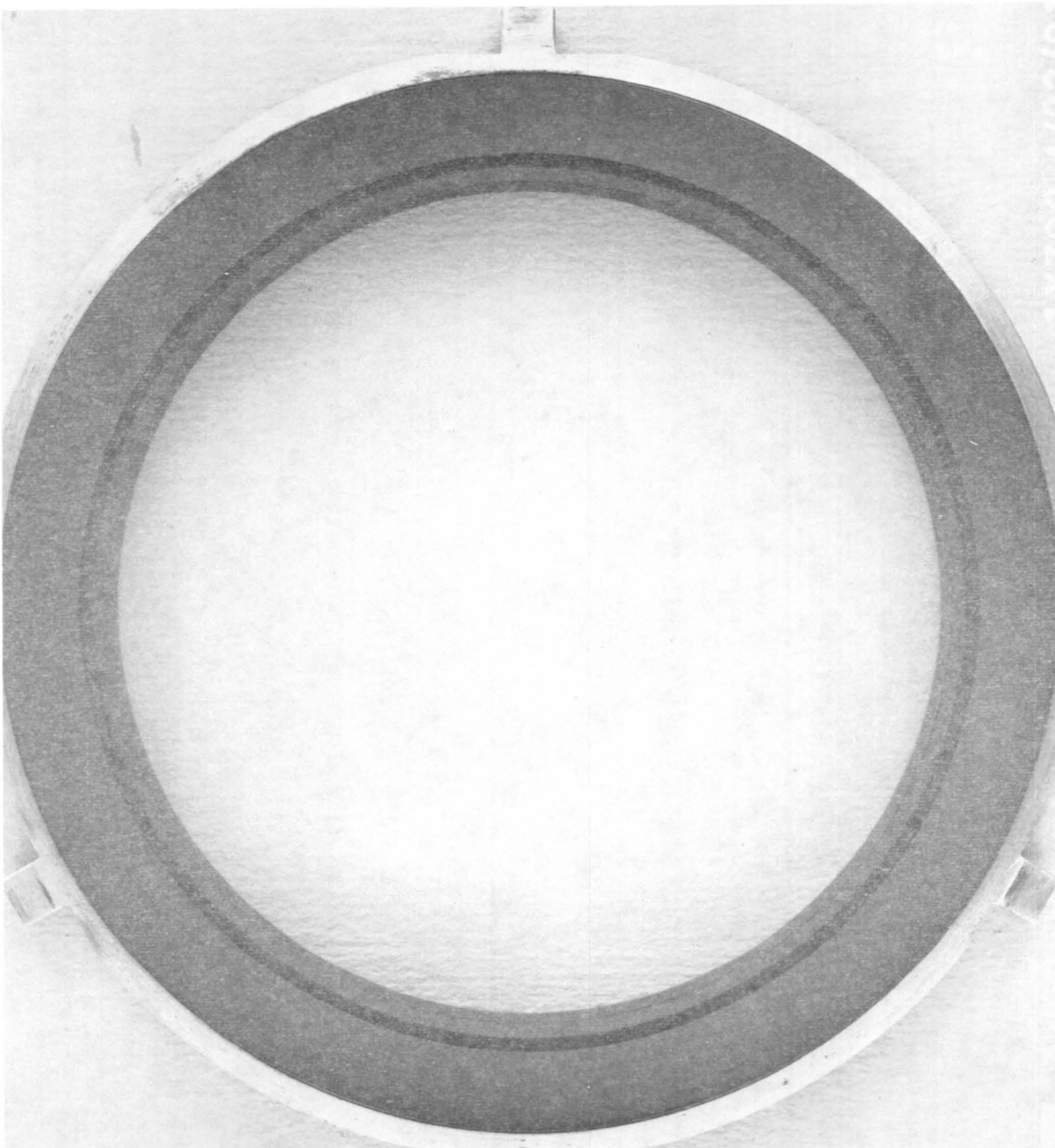


Figure 135. Phase V Pressure Balanced Spiral Groove Carbon Seal Ring
P/N 7R001269-11, S/N 001, New

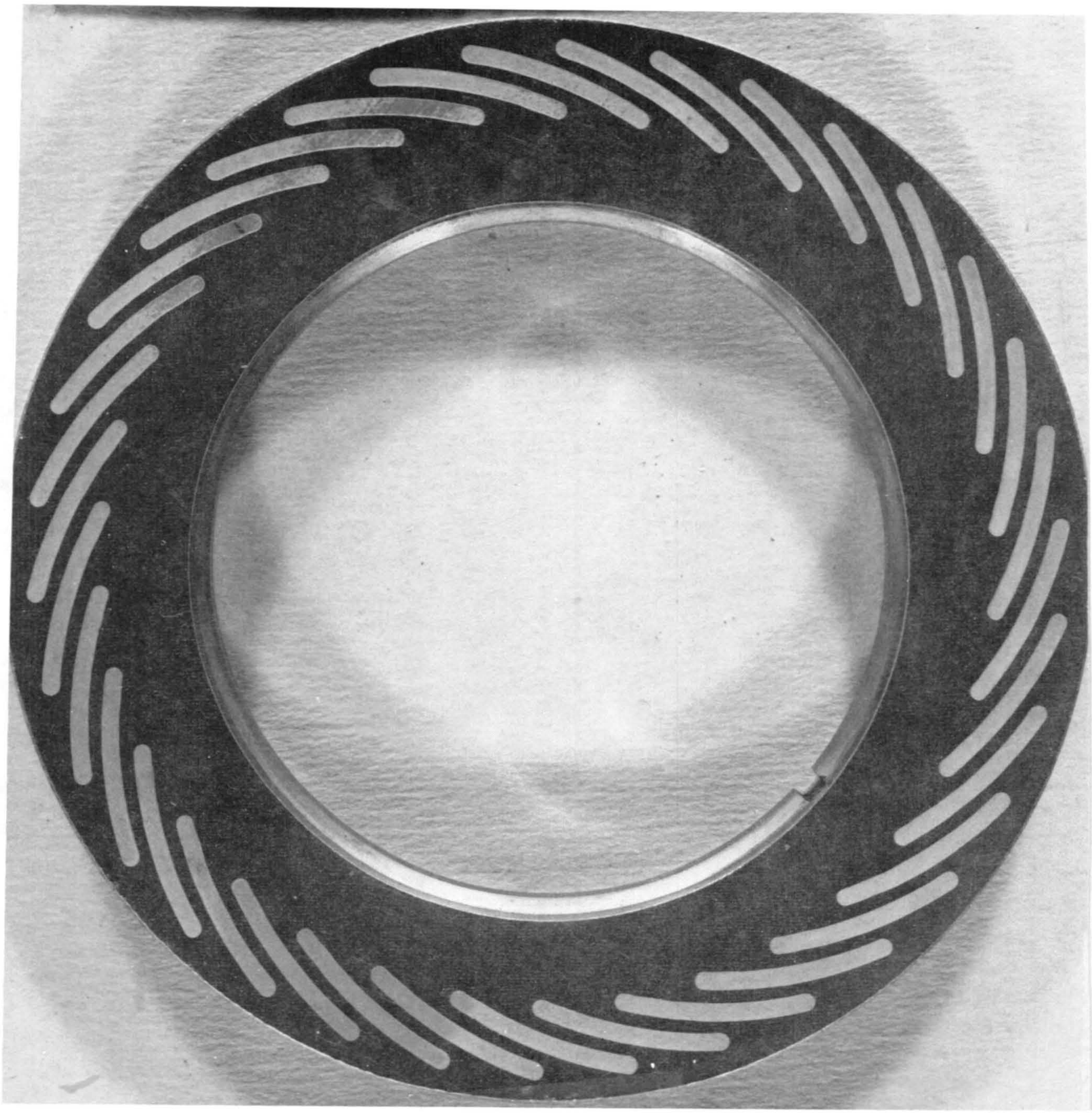


Figure 136. Phase V Pressure Balanced Spiral Groove Mating Ring P/N 7R0012691-7, S/N 001, New

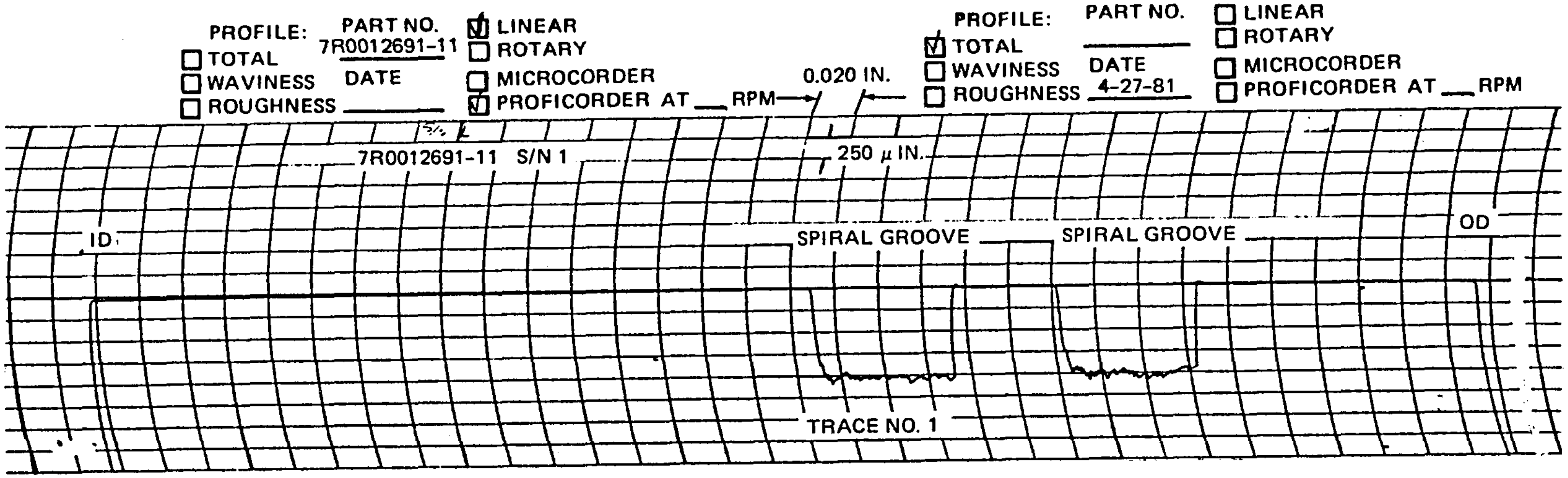


Figure 137. Phase V Spiral Groove Mating Ring Surface Profile
Trace P/N 7R0012691-7, S/N 001, New

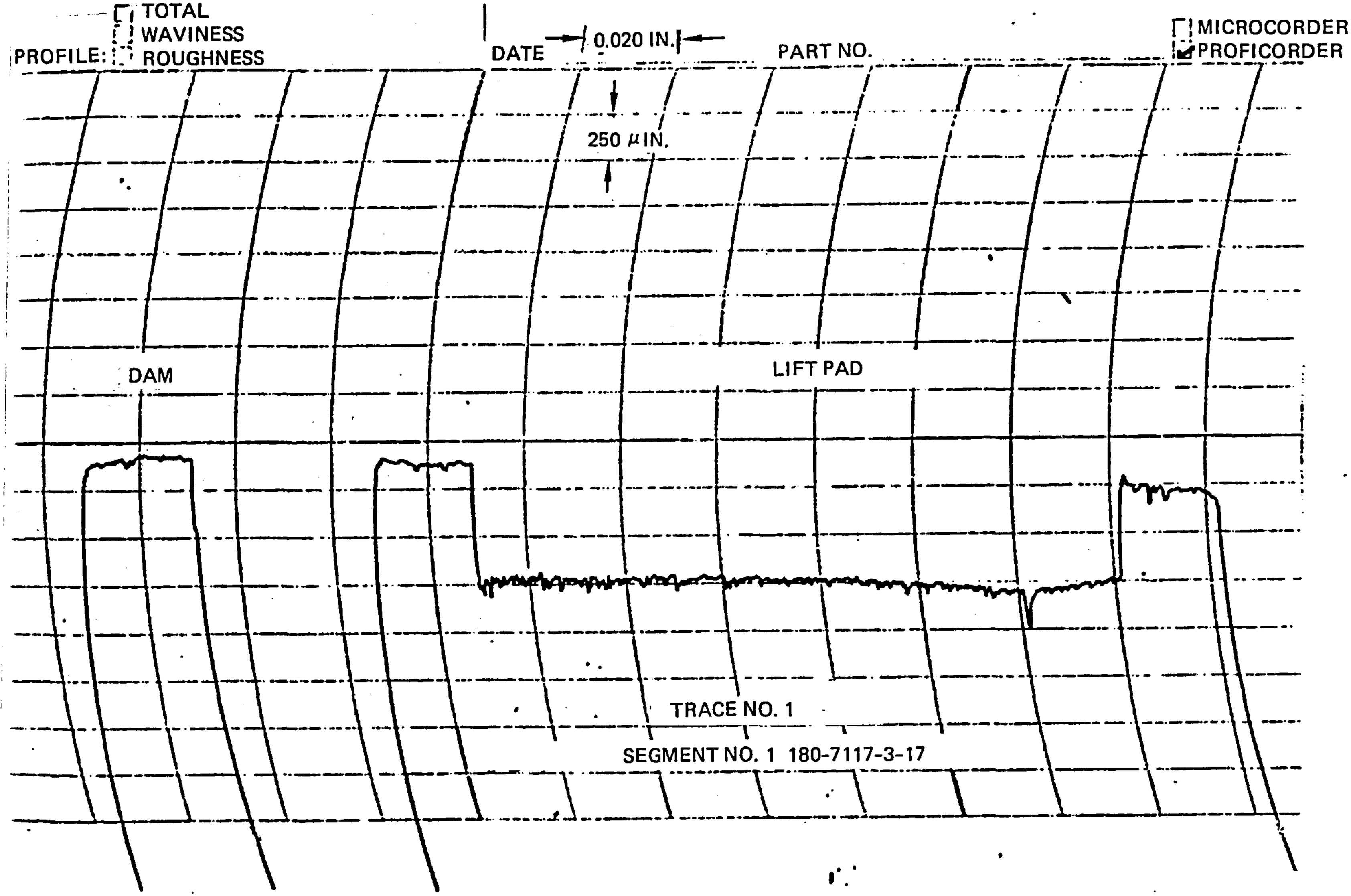


Figure 138. Typical Surface Profile Trace of Rayleigh Step Segmented Carbon Oxidizer Side Seal Ring, P/N 7117-09, New

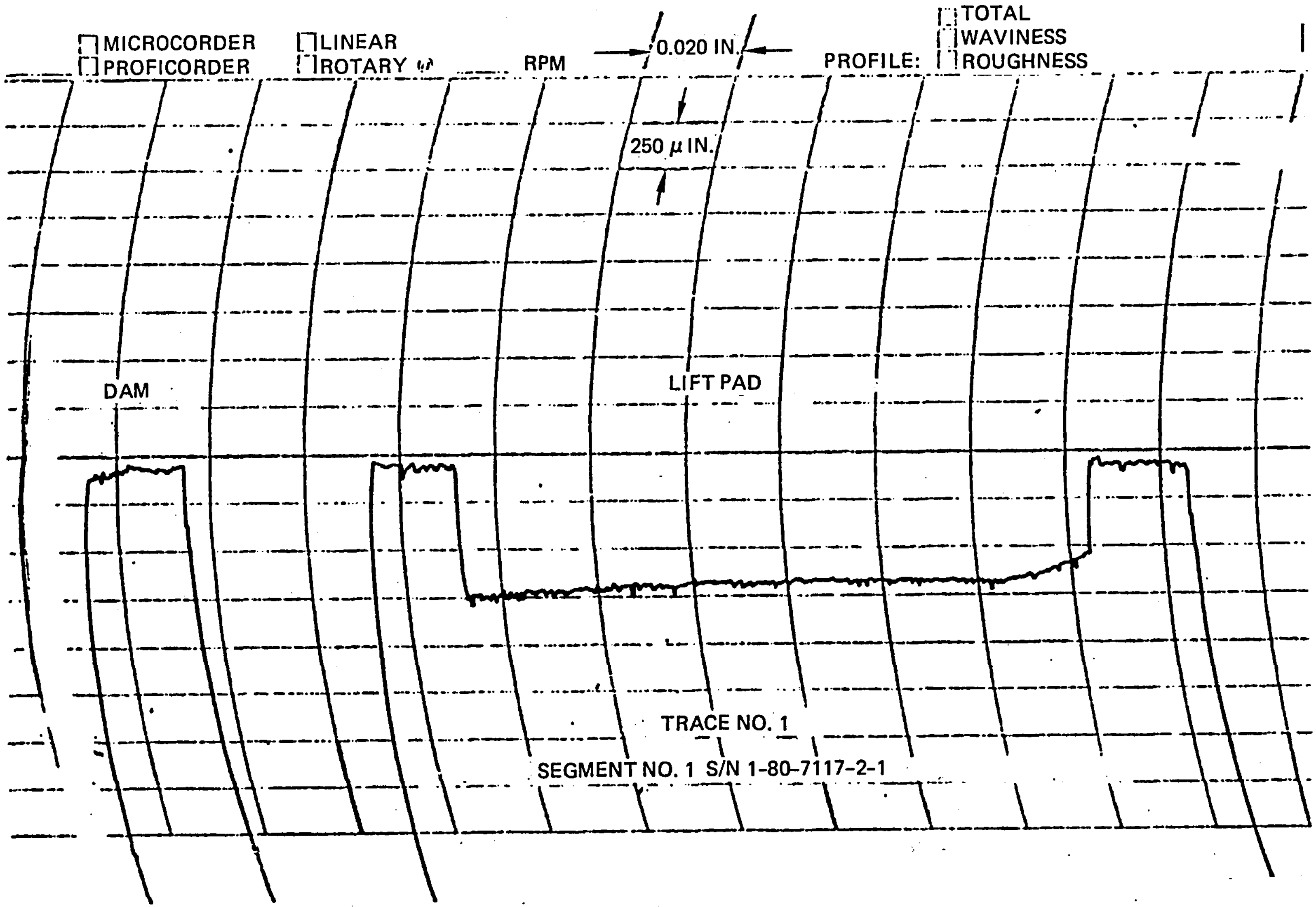


Figure 139. Typical Surface Profile Trace of Rayleigh Step Segmented Carbon Turbine Side Seal Ring P/N 7117-07, New

Tests 1 - 31

The test objective was to perform four checkout tests of 15 minutes duration each with liquid nitrogen at seal cavity pressure increments of 1034, 1724, 2413, 2758, 3103 and 3447 kPa (150, 250, 350, 400,. 450 and 500 psia). A total of 31 starts for 1461 seconds was performed at 1034 kPa (150 psia) the tests were cut off prematurely due to high vibration and speed control problems. The seals were damaged on the last test due to tester overspeed.

The LOX seal performance at 1034 kPa (150 psia) was satisfactory with low leakage. The measured leakage varied from 0.0023 to 0.0079 m^3/s (5 to 17 SCFM) at LN_2 pressures from 896 to 965 kPa (130 to 140 psig). The drain temperature at the leakage orifice also indicated low leakage with ambient temperature gas at the drain exit. The downstream drain cavity pressure was 13.8 to 82.7 kPa (2 to 12 psig). The data indicate satisfactory functioning of the seal.

The Rayleigh Step segmented helium seal also performed satisfactorily with low leakage at 345 kPa (50 psia) inlet pressure. The measured combined leakage (both LOX and turbine side) 0.0009 to 0.00I9 m^3/s (2 to 4 SCFM) at helium pressures of 207 to 324 kPa (30 to 47 psig).

Build 1 Disassembly

Disassembly inspection revealed the spiral groove LOX seal contact surfaces to be rubbed and worn at three locations. The spiral groove mating ring surface was worn 0 to 0.021 cm (0.0030 in.) (Fig. 140). The grooves were completely worn off in two places and partially worn in a third. The carbon seal ring surface was worn 0.00086 to 0.0024 cm (0.000125 to 0.000350 in.) (Fig. 141). The other components of the seal were in good condition.

The helium seal was also severely worn. Rayleigh Step lift pads were completely worn off. The mating ring surface indicated heavy rubbing contact.

A vibration analysis was conducted to determine the cause of the tri-noded wear pattern on the LOX seal mating ring. Natural frequencies and mode shapes were calculated to determine if vibration in any of the modes could have caused the observed wear pattern.

The results of this study showed expected behavior common to most concentric rings of this type namely umbrella modes and diametral modes. No extraneous mode shapes were found which could have caused the wear pattern of three locations spaced approximately 120 degrees apart.

Build 2 Assembly

The tester was reassembled using new Phase V seal hardware of the same configuration. Prior to installing the LOX seal mating ring it was discovered that the ring did not meet the requirement for flatness to within three helium light bands. Subsequent inspection of the one remaining spare ring also revealed that it too was not per print. Both rings were found to be convex with the ID 0.00063 cm (0.00025 in.) higher than the OD. The rings were returned to the supplier for rework prior to completing the tester assembly.

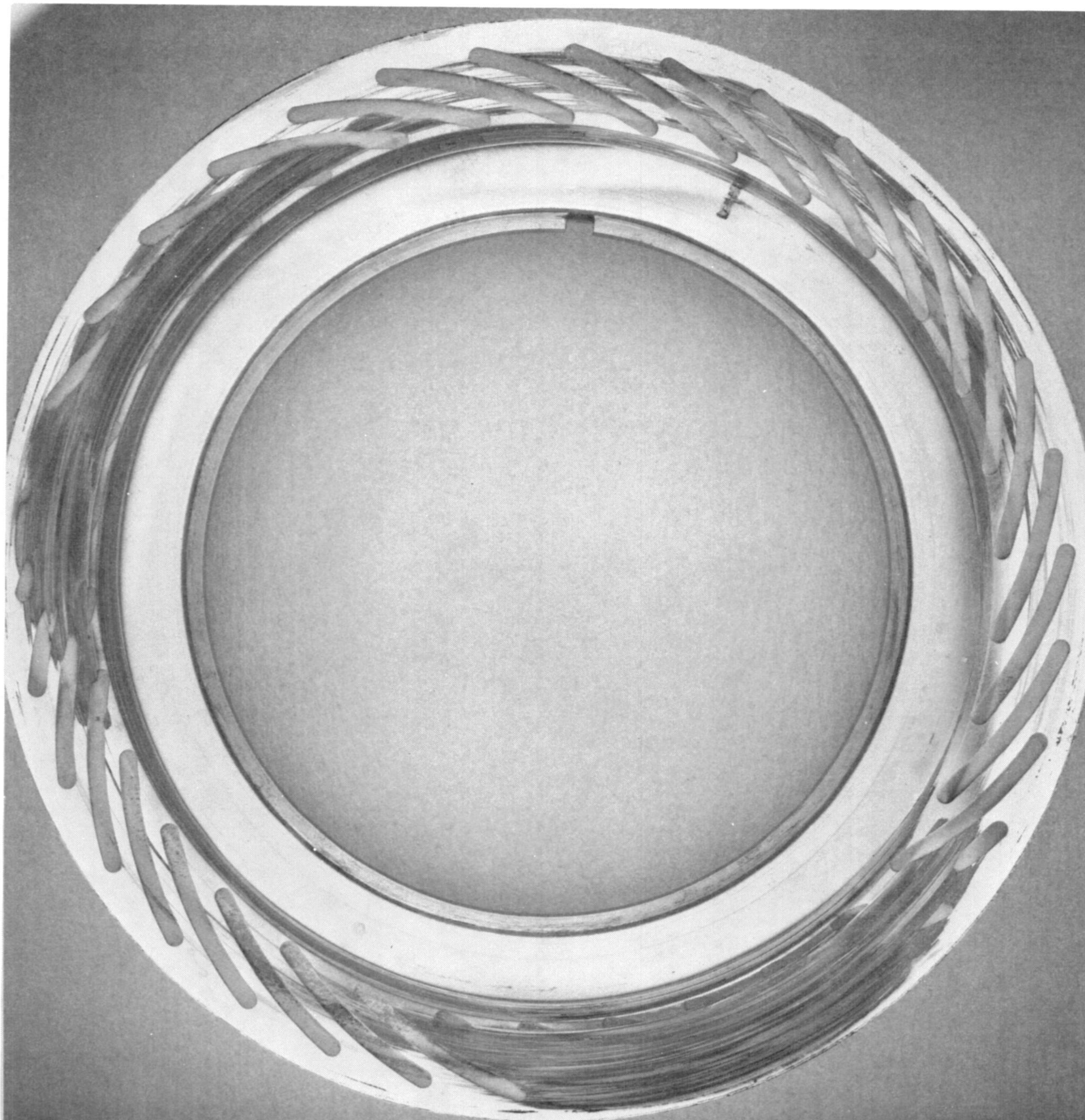


Figure 140. LOX Seal Mating Ring P/N 7R0012691-7, S/N 1, Posttest 031

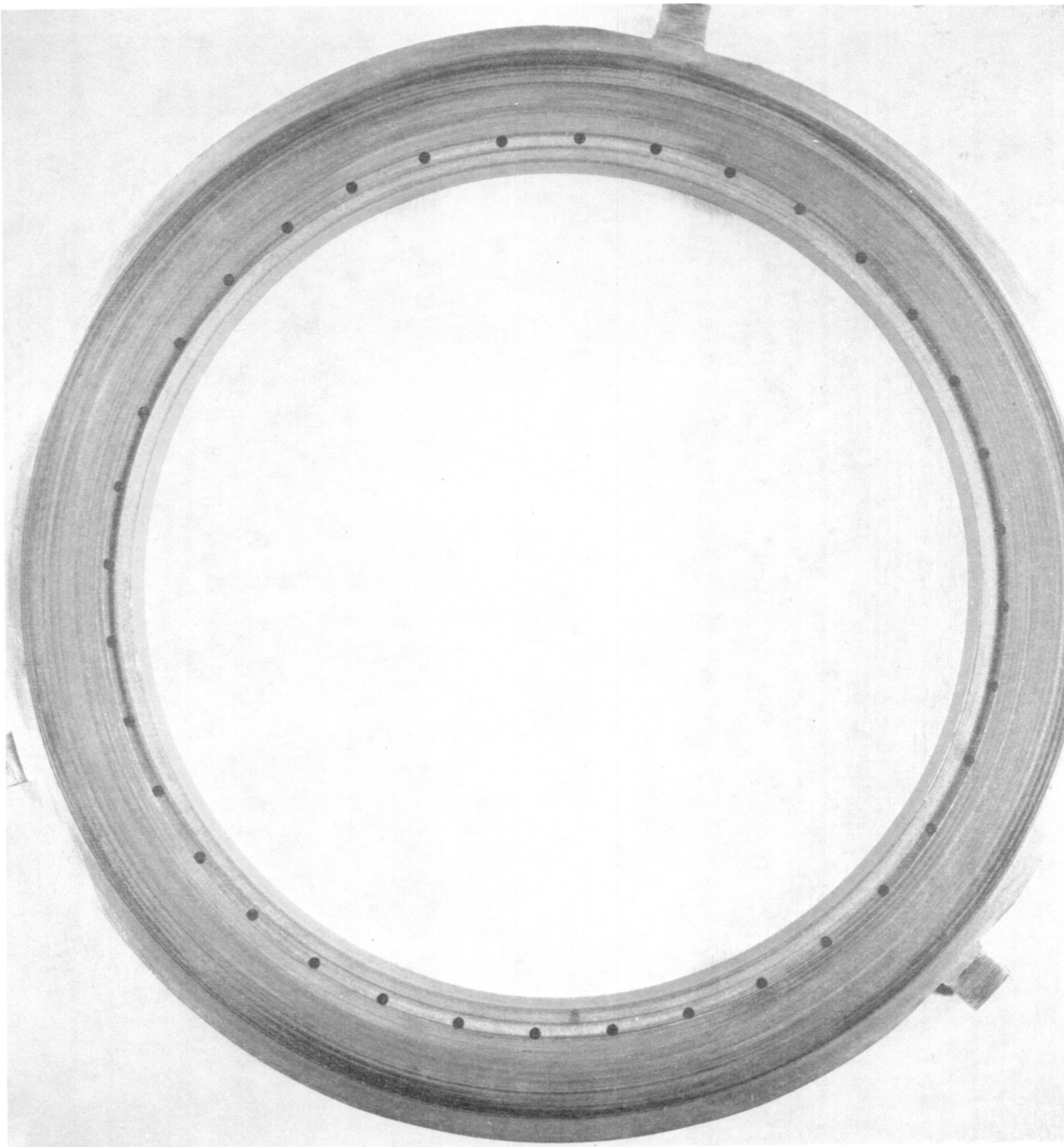


Figure 141. LOX Seal Carbon Ring P/N 7R0012691-11, S/N 01, Posttest 031

It is possible that an out-of-flat condition may have caused the rubbing on the previous build.

The spiral groove LOX seal was assembled with seven load springs to produce a face load of 62.3 N (14 lb) at the installed compression of 0.157 cm (0.066 in.) The mating ring optical flatness after installation was 7 to 9 HLB. The mating ring surface axial runout was 0.0025 to 0.0030 cm (0.0010 to 0.00112 in.) total. The Rayleigh Step segmented helium seal was assembled using the mating ring sleeve to position the segments. This method was adopted to prevent bending of the compression springs due to misalignment of the spring holes. The shaft sleeve radial runout measured 0.0066 to 0.0070 cm (0.00260 to 0.00275 in.) total.

<u>Tests 031 - 048</u>

The test objective was to perform eight tests of 15 minutes duration each with liquid nitrogen at pressure increments of 1034, 1724, 2413, 2758, 3103 and 3447 kPa (150, 250, 350, 400, 450 and 500 psia) at 30,000 rpm. The 1034 kPa (150 psia) and 1724 kPc (250 psia) tests were completed.

Seven tests at 1034 kPa (150 psia) for 986 seconds were performed. The first test was cut off prematurely due to an instrumentation problem. The next five tests were cut off prematurely due to a speed control problem. The seventh 1034 kPa (150 psia) test was of successful programmed duration with steady-state operation. The spiral groove LOX seal performance was satisfactory with low leakage. The measured leakage varied from 0.006 to 0.015 m^3/s (13 to 33 scfm). The downstream drain cavity pressure was 0.69 to 82.7 kPa (0.1 to 0.12 psig). The data indicated satisfactory functioning of the seal.

Nine tests at 1724 kPa (250 psia) for 935 seconds were also performed. The first eight tests were all cut off due to speed control problems. The ninth test at 1724 kPa (250 psia) was successful programmed duration with steady state operation. The LOX seal also performed well at 1724 kPa (250 psia). The measured leakage varied from 0.004 to 0.025 m^3/s (9 to 53 SCFM). The downstream drain cavity pressure was 13.8 to 221 kPa (2 to 32 psig). The data indicate satisfactory functioning of the seal.

One start at 2413 kPa (350 psia) for 136 seconds was then performed. The test was cut off prematurely when the speed suddenly dropped from 30,000 rpm to 10,000 rpm and cycled erraticly at constant turbine inlet pressure, indicating binding of the rotating hardware. The high frequency accelerometer trace indicated a significant vibration level change at each speed cycle. Posttest investigation indicated excessive tester turning torque as the LOX seal pressure was increased.

Data at 2413 kPa (350 psia) also show satisfactory seal performance. The measured leakage was 0.023 m^3/s (50 SCFM). The drain cavity pressure was 110 kPa (16 psig). Helium seal data also indicate satisfactory seal performance with low leakage 0.0005 to 0.0018 m^3/s (1 to 4 SCFM).

Build 2 Disassembly

Disassembly inspection revealed the cause of the erratic tester torque to be excessive wear of the LOX seal cavity inboard slave seal mating ring. A groove 0.103 cm (0.015 in.) deep was worn into the mating ring surface by the carbon nose piece. A subsequent load deflection test revealed the seal load to be above normal as it is compressed. Therefore, it was concluded that high loading on the mating ring caused the carbon nose to wear into the rubbing surface. The seal was apparently binding as the compression increased.

The inspection revealed no significant wear on the spiral groove mating ring (Fig. 142) and minimal wear on the carbon seal ring (Fig. 143). The other components of the seal were in excellent condition. A typical profile trace of the mating ring surface is shown in Fig. 144.

The Raleigh Step segmented helium seal showed heavy wear on the segments. The LOX side lift pads were worn 0.00076 cm (0.003 in.) while the turbine side pads were completely worn off. Two of the turbine side segments were also broken (Fig. 145).

Build 3 Assembly

The tester assembly was completed with a new inboard slave seal and mating ring, new helium seal carbon segments and mating ring, and the same spiral groove LOX seal hardware. The new slave seal was installed with less compression to reduce the face load. The LOX seal spiral groove mating ring axial runout was 0.0084 cm (0.0013 in.) TIR.

Tests 049 to 071

The test objective was to perform 8 tests of 15 minutes duration each, with liquid nitrogen at pressure increments of 2413, 2758, 3103 and 3447 kPa (350, 400, 450, and 500 psia) at 30,000 rpm. The 2413 kPa (350 psia) test point was completed and 611 seconds of the 2758 kPa (400 psia) test point were completed during this test series.

The initial chilldown resulted in excessive leakage through the inboard slave seal, apparently due to the lower installed comrpession to reduce face load. The seal was seated by closing the bearing cavity, pressurizing the LOX seal cavity and then opening the bearing cavity. The LOX seal cavity was pressurized to 2413 kPa (350 psia) and maintained at this approximate value for a total of 16 tests and 15 minutes to complete the test point.

A total of seven tests for 611 seconds were performed at the 2758 kPa (400 psia) test point. The first four tests were maintained at 2758 kPa (400 psia), however, leakage through the inboard slave seal prevented maintaining the required pressure during the last three tests. The pressure dropped to 2344 kPa (340 psig), then to 2068 kPa (300 psig), and finally to 552 kPa (80 psig) on the last test.

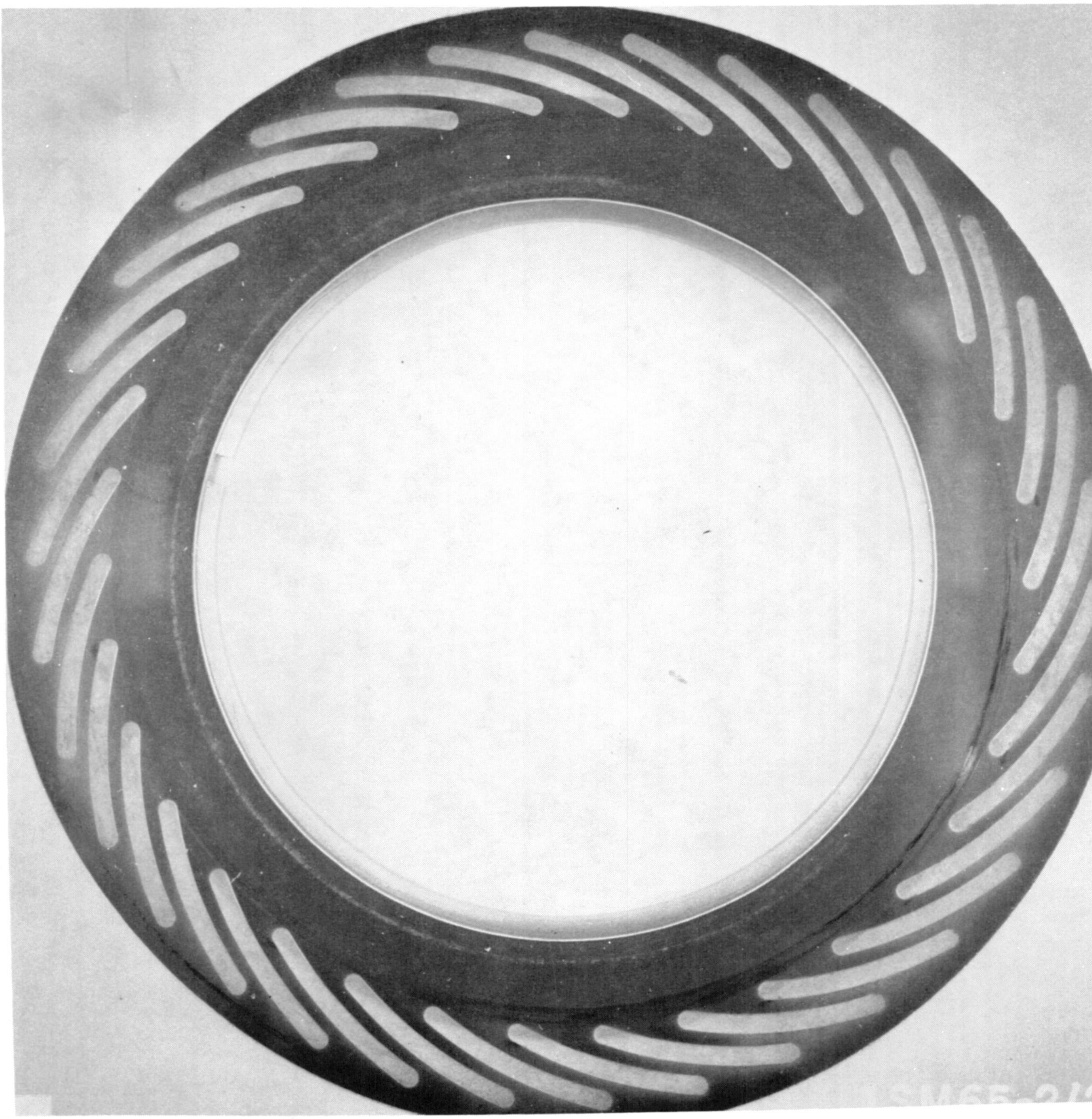


Figure 142. LOX Seal Mating Ring P/N 7R0012691-7, S/N 03, Posttest 048

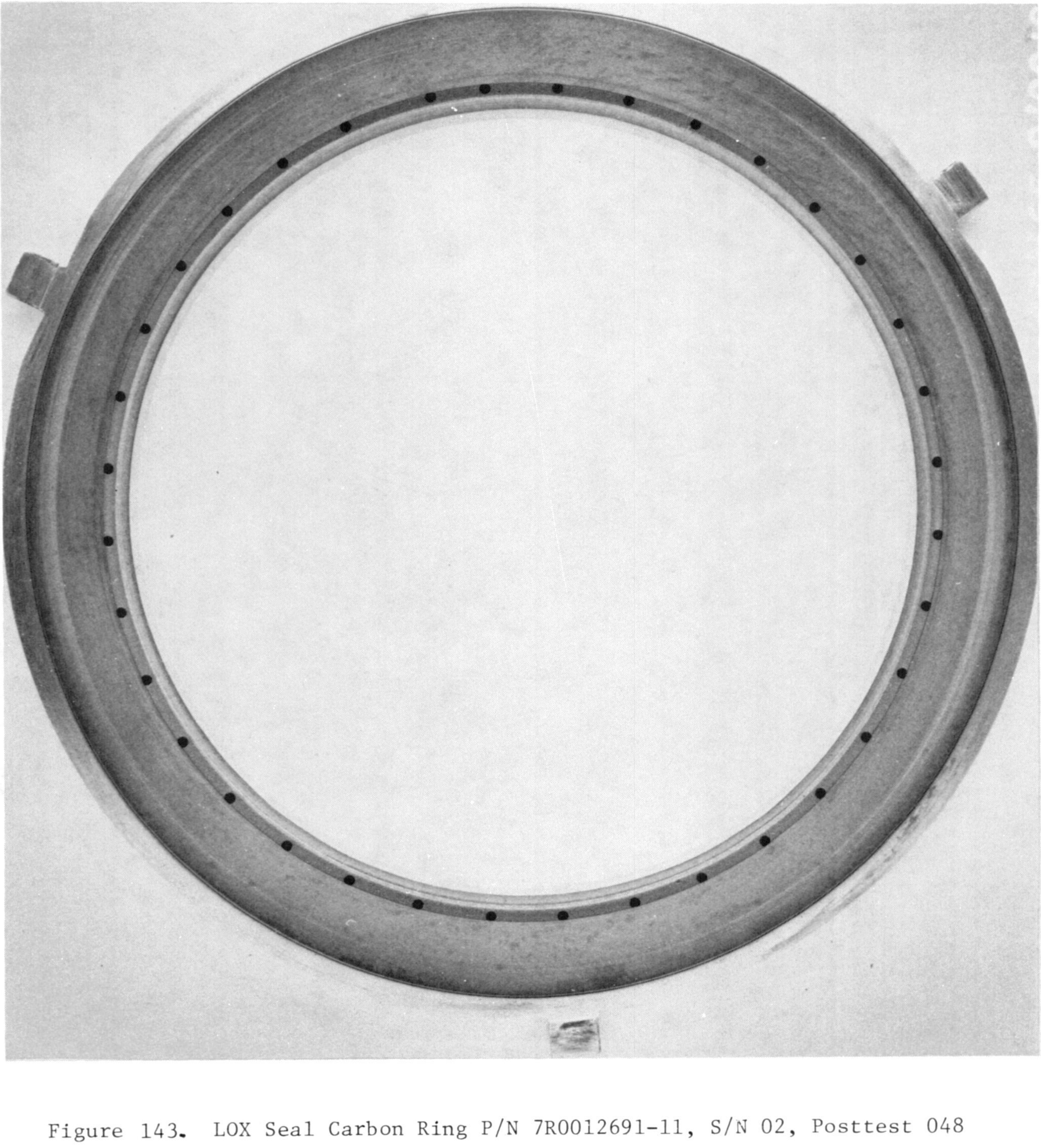


Figure 143. LOX Seal Carbon Ring P/N 7R0012691-11, S/N 02, Posttest 048

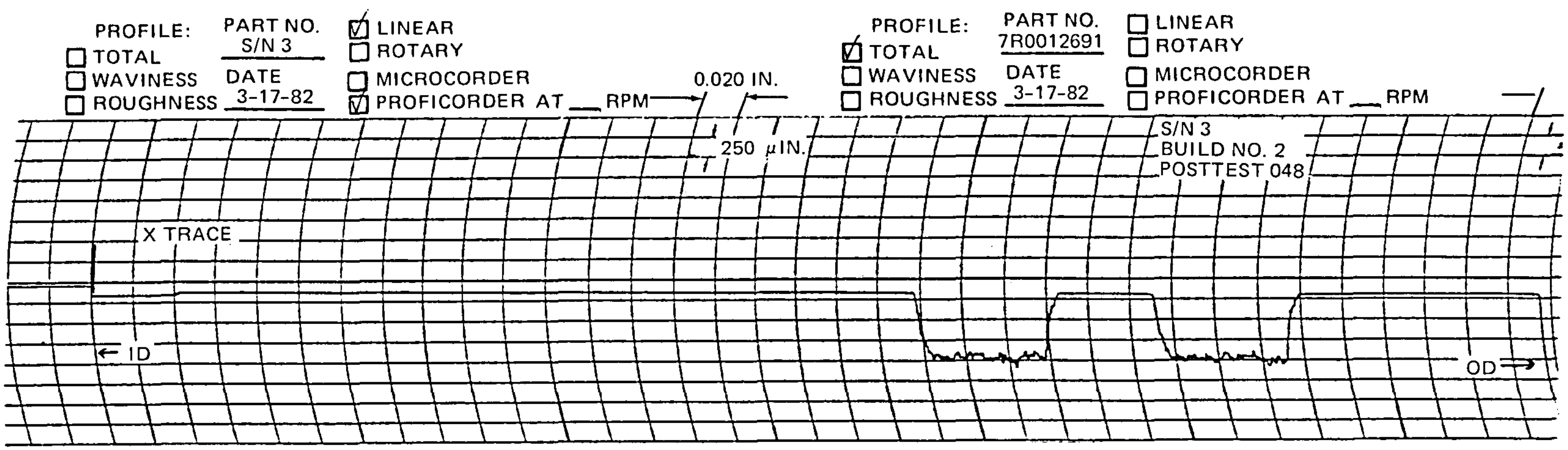
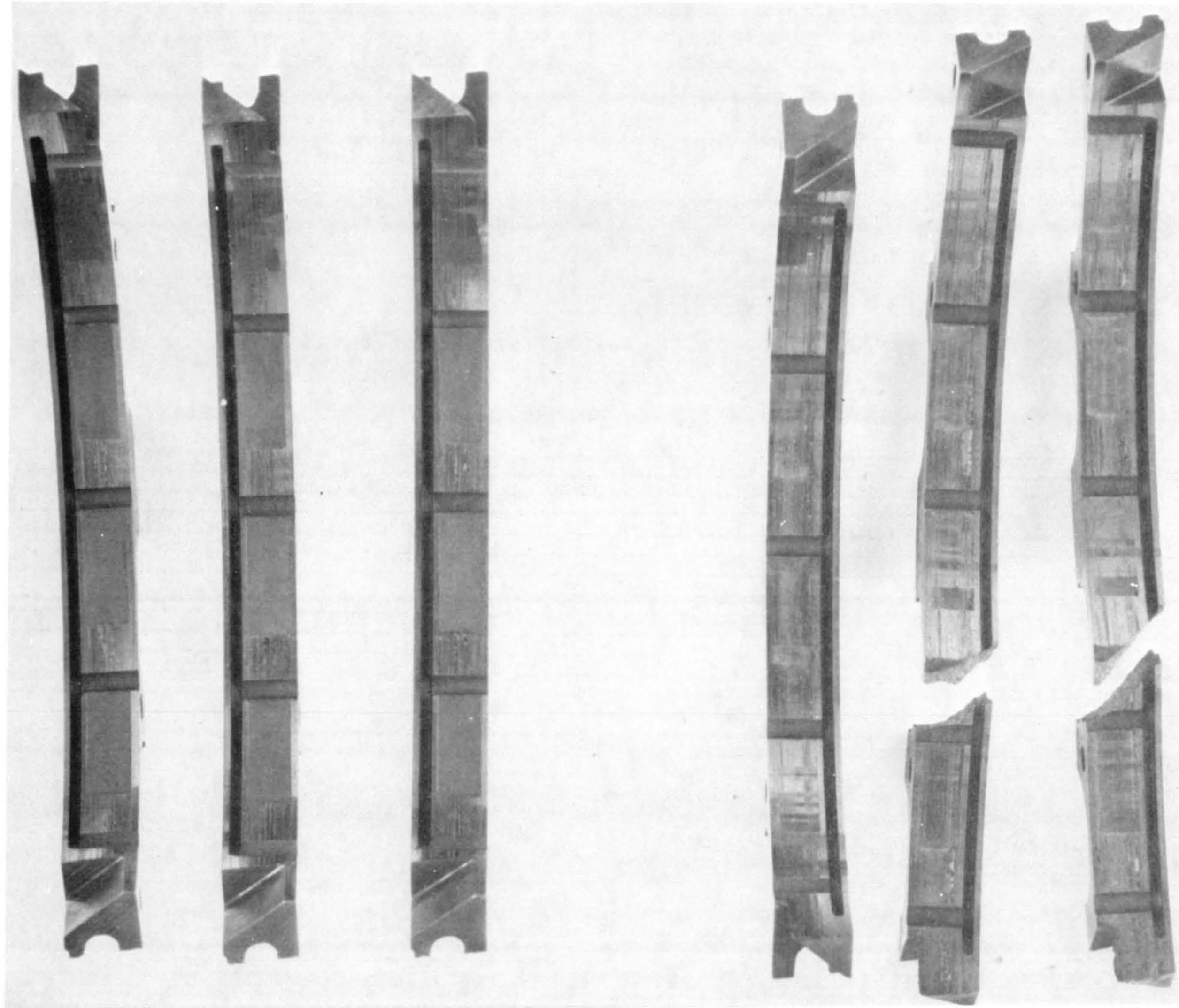


Figure 144. Spiral Groove Mating Ring Typical Surface Profile Trace
P/N 7R0012691-7, S/N 03, Posttest 048



LOX SIDE TURBINE SIDE

Figure 145. Helium Seal Segments P/N SSCY180-7117, S/N 1, Posttest 048, Build 4

The spiral groove LOX seal performance was satisfactory at both 2413 kPa (350 psia) and 2758 kPa (400 psia) liquid nitrogen pressure. The measured leakage varied from 0.020 to 0.088 m^3/s (44 to 190 SCFM). The drain cavity pressures varied from 41 to 400 kPa (6 to 58 psig) and were generally in the range of 69 to 138 kPa (10 to 20 psig).

The helium seal purge pressure varied from (50 to 75 psia) which resulted in a differential pressure of approximately 69 to 386 kPa (10 to 56 psi) on the LOX side and 234 to 414 kPa (34 to 60 psi) on the turbine side. The measured helium purge flow was 0.0007 to 0.0020 m^3/s (1.5 to 4.3 SCFM). The seal performance was satisfactory during all testing.

Build 3 Disassembly

Disassembly inspection revealed severe rubbing and wear on the inboard slave seal mating ring surface. A groove 0.048 cm (0.007 in.) deep was worn into the mating ring surface by the carbon nose piece. The seal installed compression was reduced on this build to minimize the spring load; however, the load increase due to the pressure-induced force from the bellows effective area apparently caused the carbon nose to wear into the rubbing surface. Since a similar failure occurred on the prior build, it is concluded that the bellows-type rubbing contact face seal is not satisfactory at the higher pressures of this test series.

The spiral groove LOX seal was in satisfactory condition with negligible rubbing and wear (Fig. 146 and 147). The spiral groove mating ring surface had indication of very light rubbing contact with no significant wear (Fig. 148). The carbon seal ring surface was scored and worn slightly irregular 0.0006 to 0.0019 cm (0.00025 to 0.00075 in.) at the sealing dam and inner portion of the spiral groove area (Fig. 149). The higher static leakage measured posttest was apparently a result of the sealing dam wear.

The Rayleigh Step segmented helium seal showed heavy wear on the segments. The sealing dam average wear was 0.0025 cm (0.0010 in.) (Fig. 150). The LOX side lift pads were worn 0.0041 cm (0.00062 in.) The turbine side pads were completely worn off. The mating ring surface showed a heavy contact pattern (Fig. 151); however, the surface profile trace (Fig. 152) indicated no wear.

Review of the inboard slave seal problem indicates that the present bellows-type rubbing contact face seal could be replaced with either a Phase IV Rayleigh Step or a Phase V spiral-groove hydrodynamic LOX seal.

An add-on proposal to rework the tester for the inboard slave seal modification and to complete the Phase V test program was submitted to NASA; however, additional funding was not available and the program was terminated.

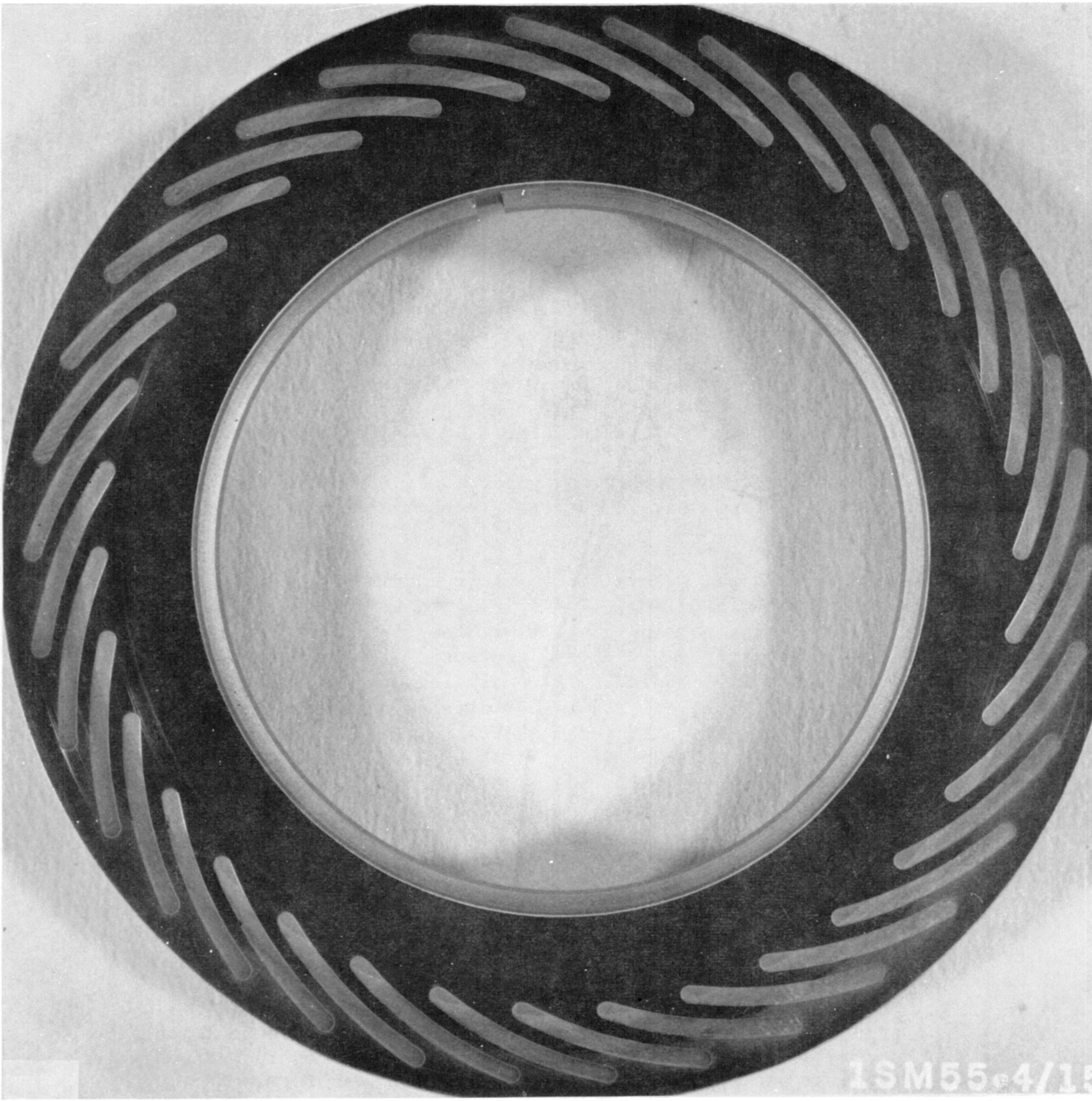


Figure 146. LOX Seal Mating Ring P/N 7R0012691-7, S/N 03, Posttest 071

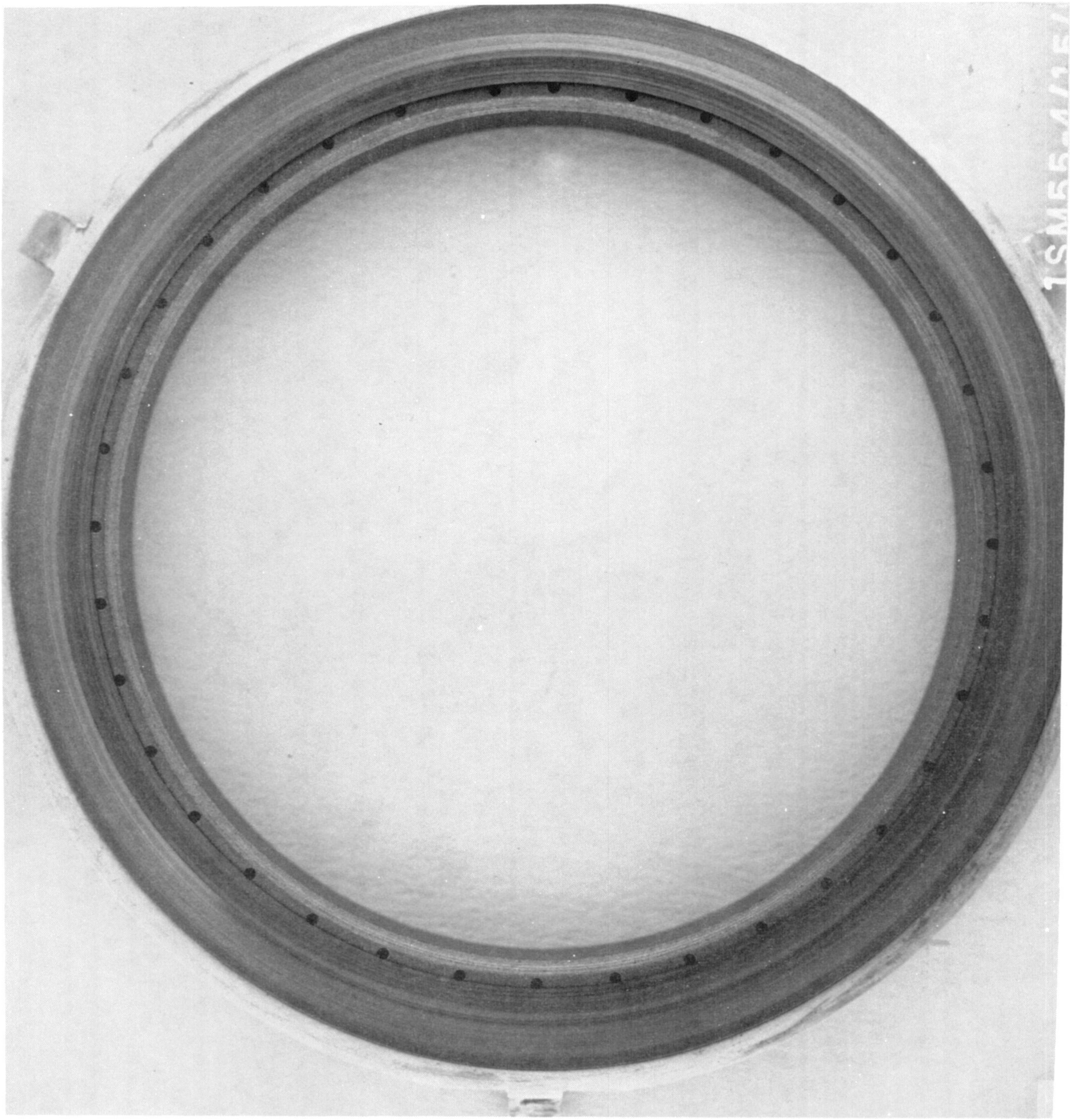


Figure 147. LOX Seal Carbon Ring P/N 7R0012691-11, S/N 02, Posttest 071

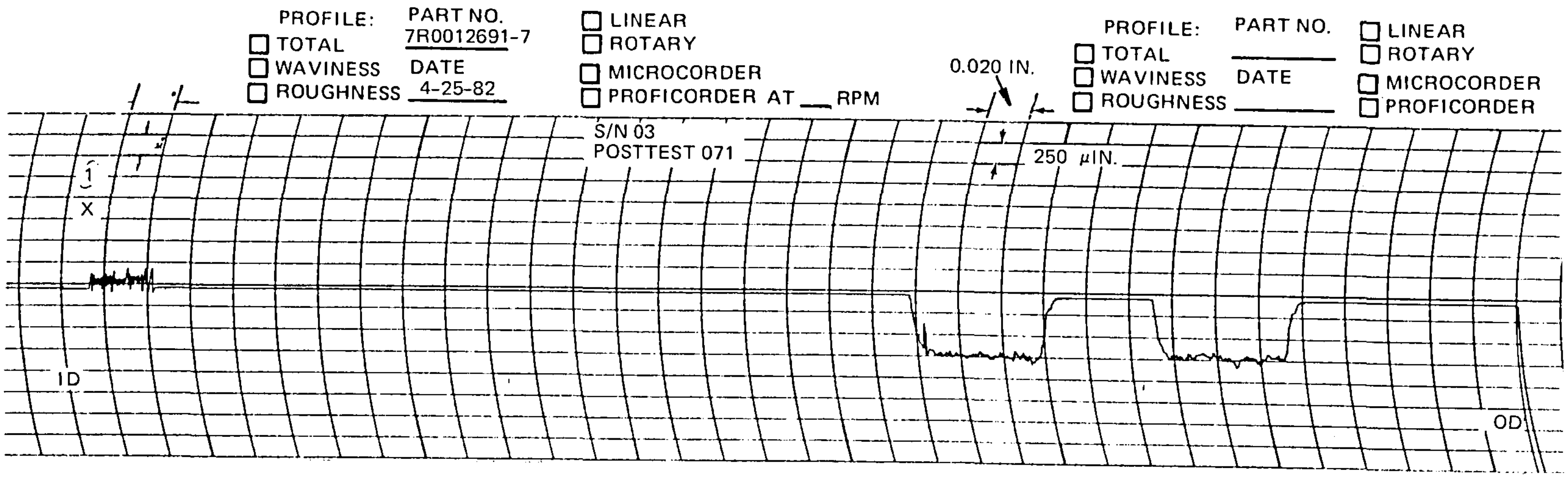


Figure 148. Spiral Groove Mating Ring Typical Surface Profile Trace
P/N 7R0012691-7, S/N 03, Posttest 071

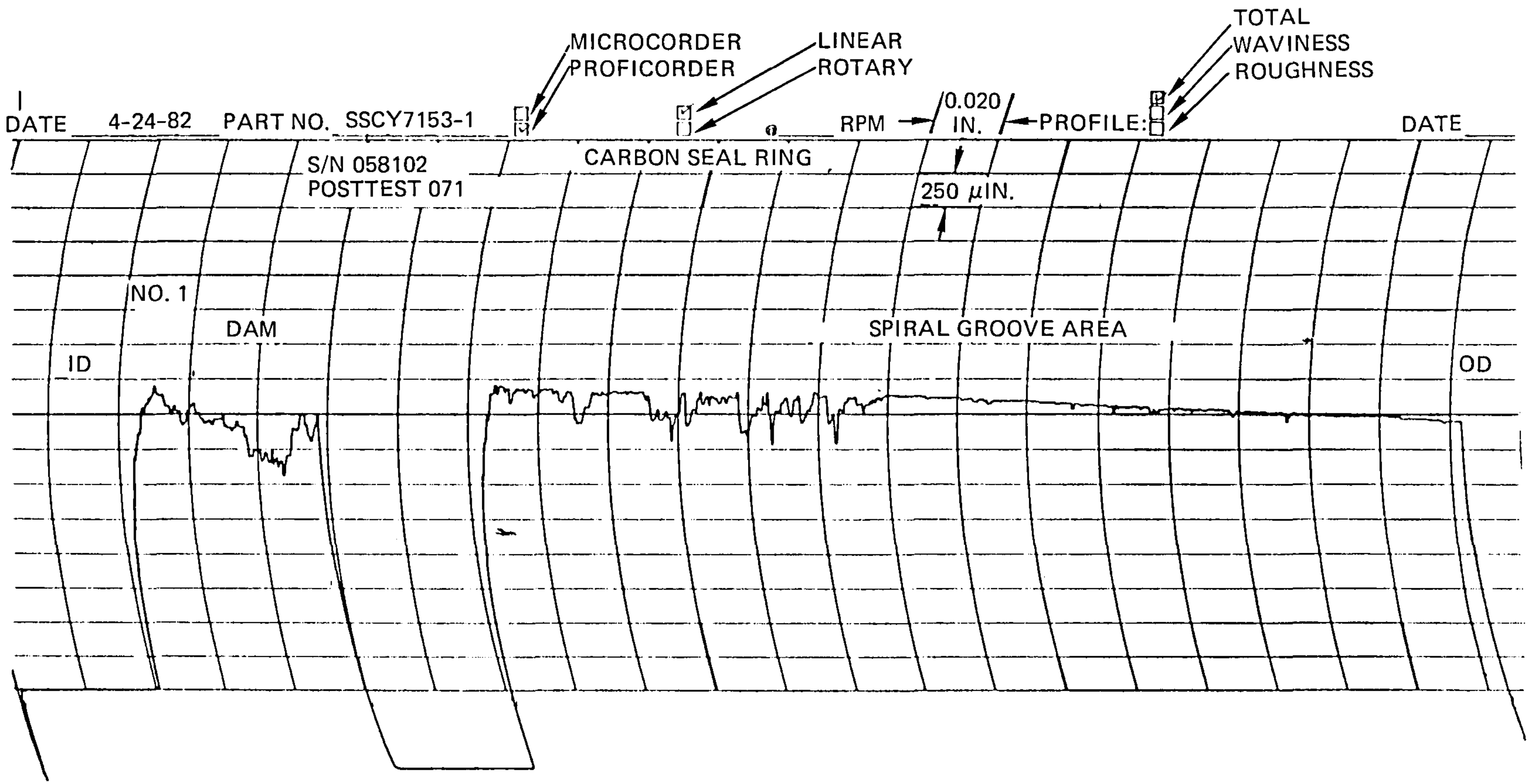
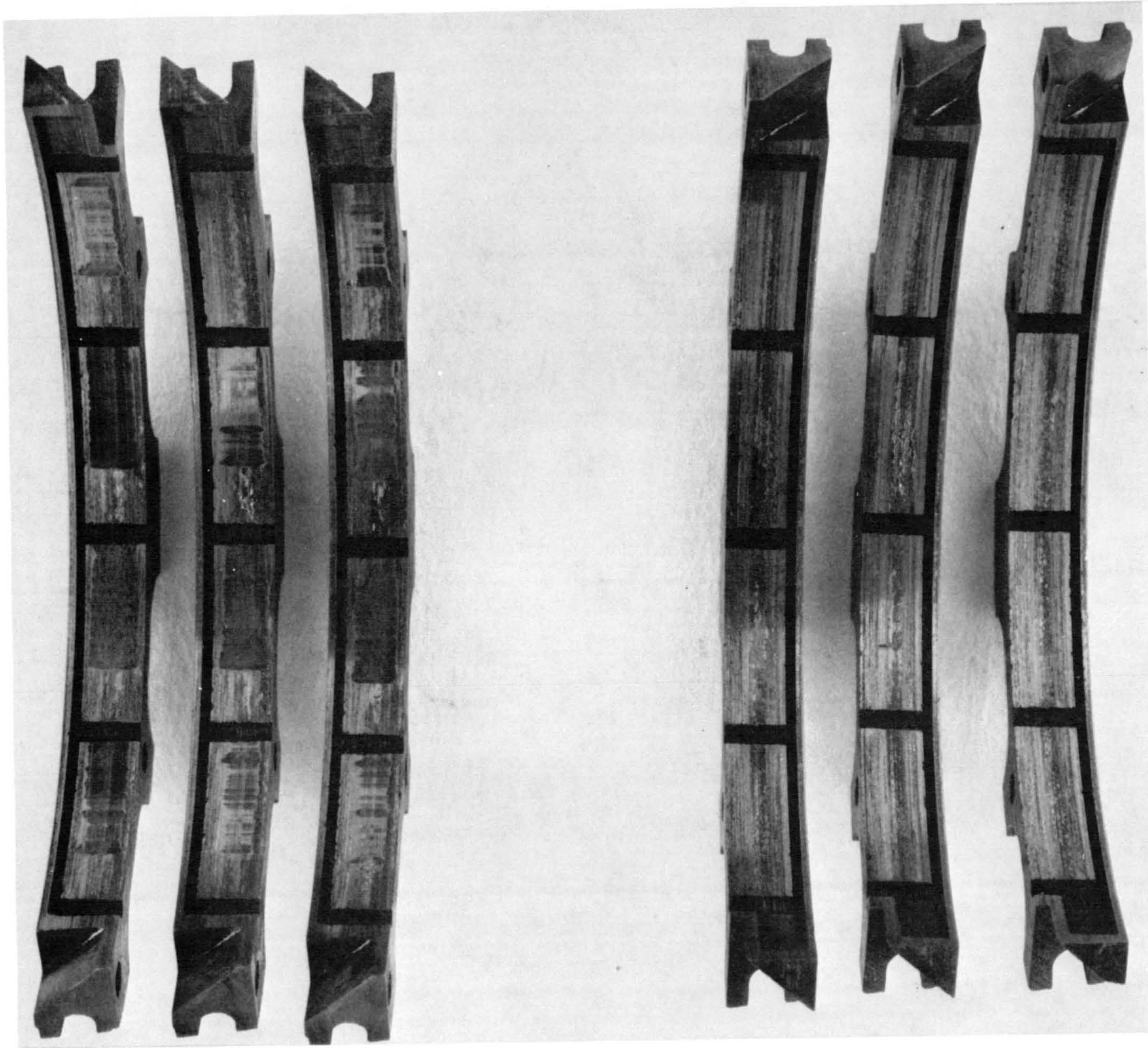


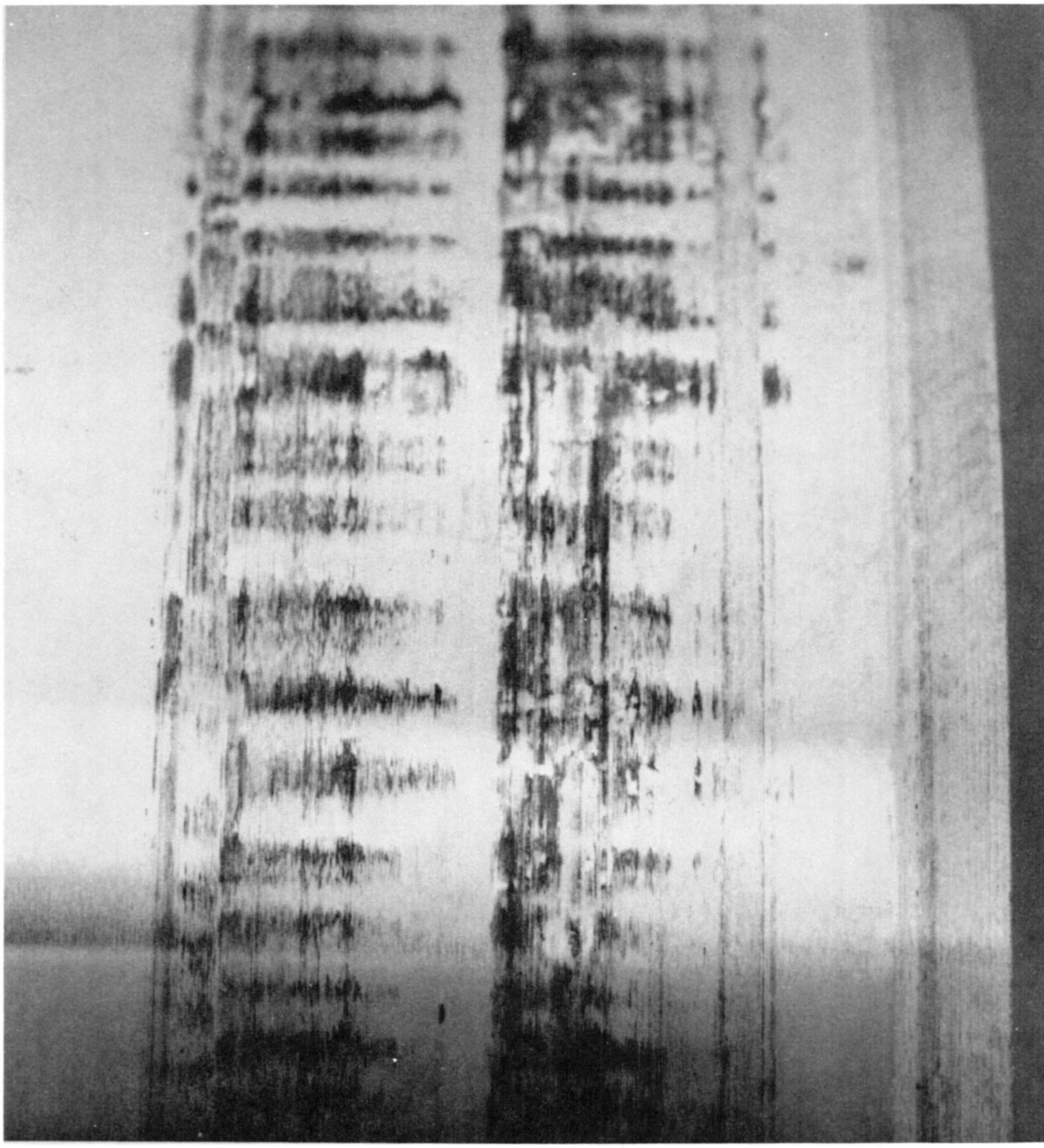
Figure 149. LOX Seal Carbon Ring Typical Surface Profile Trace
P/N 7R0012691-11, S/N 02, Posttest 071



LOX SIDE

TURBINE SIDE

Figure 150. Helium Seal Segments P/N SSCY 7117, Posttest 071



LOX SIDE TURBINE SIDE

Figure 151. Helium Seal Mating Ring P/N 7R0012693, S/N 03, Posttest 071

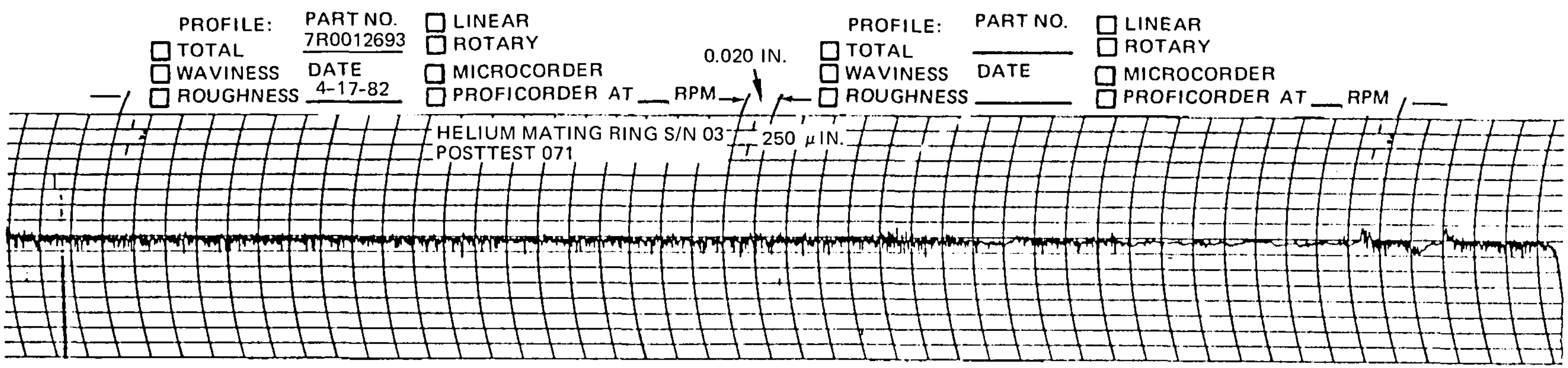


Figure 152. Helium Seal Mating Ring Typical Surface Profile Trace
P/N 7R0012693, S/N 03, Posttest 071

CONCLUSIONS

1. The Rayleigh Step LOX seal demonstrated satisfactory performance for a total of 559 tests and 48.5 hours with negligible wear and acceptable leakage.

2. The outward pumping pressure balanced spiral groove LOX seal demonstrated feasibility during 71 tests and 1.4 hours with negligible wear and satisfactory leakage.

3. The inward pumping spiral groove LOX seal was unsatisfactory due to excessive leakage and wear. The wide sealing dam concept is not satisfactory for cryogenic fluids due to excessive force variation caused by vaporization of the fluid across the sealing interface. The unsatisfactory performance is attributed to the force variation and not the direction of pumping.

4. The Rayleigh Step segmented carbon helium seal demonstrated satisfactory performance for a total of 401 starts and 26.1 hours with negligible wear and low leakage.

5. The Rayleigh Step floating ring helium seal demonstrated satisfactory performance for a total of 168 tests and 25.3 hours with negligible wear and acceptable leakage.

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.

APPENDIX A

LOX SEAL HARDWARE AND INSPECTION SUMMARY

All data are listed in English units. The following conversion factors may be used to convert to SI units:

1 lbf = 4.448 N

1 in. = 2.54 cm

1 SCIM = 0.27 cm^3/s

1 psig = 6.895 kPa

TABLE A-1. NASA LOX SEAL HARDWARE AND INSPECTION SUMMARY, PHASE I

BUILD NO.	TOTAL STARTS	TOTAL TIME MIN.	SEAL RING PN/SN MATERIAL	MATING RING PN/SN MATERIAL	PISTON RING PN/SN MATERIAL	SPRING LOAD @.950 LB	DAM WEAR AVG. IN.	RECESS PAD DEPTH - IN. PRE/POST			STATIC GN_2 LEAKAGE - SCIM PRE/POST, DIFFERENTIAL PRESSURE PSIG						HARDWARE CONDITION	
								1	2	3	50	100	150	200	250	300	PRE TEST	POST TEST
1	1	15	CF851218/01 CARBON P03N	CF851226/01 CHROME/K-MONEL	CF850816/01 CARBON P5NR2	21.5	.010	.0007 .0000	.0005 .0000	.0006 .0000	1550 (1)	3200 (1)	4100 (1)	5250 (1)	7600 (1)	11000 (1)	NEW	CARBON FACE WORN EVEN. MATE SCORED & HEAT DISCOLORED.
2	2	5.9	CF851218/02 CARBON P03N	CF851226/02 CHROME/K-MONEL	CF850816/02 CARBON P5NR2	10.0	.000	.0007 .0007	.0008 .0007	.0007 .0007	1200 9504	2700 15552	4000 22464	7000 29 370	14600 35769	16000 (1)	NEW. INCREASED ANTI-ROTATION TANG CLEARANCE.	CARBON SCORED AT OUTER EDGE OF PADS. MATE SCORED AT OUTER EDGE.
3	1	15	"	"	"	10.0	.001	.0007 .0002	.0007 .0002	.0007 .0002	4490 4750	4320 8640	4320 9504	4320 12610	5702 12096	7603 14688	RELAPPED CARBON FACE. CLEANED MATE SURFACE. REBUILT WITH SAME PARTS.	CARBON FACE WORN EVEN. RECESS PAD DEPTH .0000. TO .0002. MATE HAD HEAVY CONTACT PATTERN BUT NO WEAR.
4	3	1.8	"	"	"	8.0	-	-	-	-	-	-	-	-	-	-	RELAPPED CARBON & MATE. SHAFT DEFLECTION TEST.	TESTER BEARING FAILED. RECESS PADS WORN OFF.
5	1	.03	"	"	"	8.0	-	-	-	-	-	-	-	-	-	-	RELAPPED CARBON & & MATE. SHAFT DEFLECTION TEST.	TESTER BEARING FAILED. SEAL I.D. RUBBED. MATE HEAVILY RUBBED.
6	2	1.6	--	--	--	--	-	-	-	-	-	-	-	-	-	-	NO SEALS INSTALLED	-
7	1	.4	CF851218/03 CARBON P03N	CF851226/03 CHROME/K-MONEL	CF850816/03 CARBON P5NR2	6.8	.000	.0007 .0007	.0007 .0007	.0007 .0007	2100 -	4400 -	7600 -	14200 -	- -	- -	NEW.	SEAL IN GOOD CONDITION. EXCESSIVE TESTER SHAFT DEFLEC.
8	28	18.8	"	CF851226/01 REPLATED CHROME/K-MONEL	"	6.6	.000	.0007 .0007	.0007 .0007	.0007 .0007	703 705	3800 8294	10281 12528	13132 16416	21340 19872	(1) 24192	RELAPPED CARBON MATE 01 REPLATED.	SEAL & MATE IN GOOD CONDITION. SLIGHT CONTACT PATTERN. NO WEAR.
9	29	85.8	"	"	"	6.6	.000	.0006 .0006	.0006 .0006	.0007 .0007	953 1164	4080 2140	7949 2849	10714 7706	16416 13357	21772 17452	REINSTALLED SAME PARTS. NO REWORK.	SEAL & MATE IN GOOD CONDITION. SLIGHT CONTACT PATTERN. NO WEAR.
10	7	10.4	"	"	"	6.6	0/.0001	.0006 .0006	.0006 .0006	.0007 .0007	630 960	- -	7776 13132	8294 17349	8726 18662	12787 26956	REINSTALLED SAME PARTS. NO REWORK.	SEAL & MATE IN GOOD CONDITION. CARBON DAM SCORED WITH CONCENTRIC GROOVES. WEAR 0 TO .0001 IN. MATE HAS SLIGHT CONTACT PATTERN.
11	13	148.15	"	"	"	10.2	.000	.0006 .0006	.0006 .0006	.0007 .0007	1620 1450	3780 3400	5184 6048	12269 12528	15898 19008	22810 26784	REWORKED LOX SEAL FROM 7 TO 9 SPRINGS. RELAPPED CARBON FACE.	SEAL & MATE IN GOOD CONDITION. SLIGHT CONTACT PATTERN. NO WEAR.

(1) EXCESSIVE LEAKAGE

TABLE A-1. NASA LOX SEAL HARDWARE AND INSPECTION SUMMARY, PHASE I AND III

BUILD NO.	TOTAL STARTS	TOTAL TIME MIN.	SEAL RING PN/SN MATERIAL	MATING RING PN/SN MATERIAL	PISTON RING PN/SN MATERIAL	SPRING LOAD @.950 LB	DAM WEAR AVG. IN.	RECESS PAD DEPTH - IN. PRE/POST			STATIC GN_2 LEAKAGE - SCIM PRE/POST — DIFFERENTIAL PRESSURE PSIG						HARDWARE CONDITION	
								1	2	3	50	100	150	200	250	300	PRE TEST	POST TEST
12	7	38.11	CF851218/03 CARBON P03N	CF851226/01 REPLATED CHROME/K-MONEL	CF850816/03 CARBON P5NR2	9.25	.000	.0006 .0006	.0006 .0006	.0007 .0007	1450 1010	3250 2080	6048 3330	8294 8294	15898 11750	21600 19354	REINSTALLED SAME PARTS. NO REWORK.	SEAL & MATE IN GOOD CONDITION. NO WEAR.
13	2	120.05	"	"	"	9.16	.0005	.0006 .0006	.0006 .0006	.0007 .0007	1180 3450	1890 8294	4666 15898	9158 22464	14342 30758	19354 38448	RELAPPED CARBON FACE SLIGHTLY.	CARBON DAM SCORED WITH CONCENTRIC GROOVES UP TO .003 IN. DEEP. MATE IN GOOD CONDITION.
14	15	62.30	CF851218/05 CARBON P03N	CF851226/01 CHROME/K-MONEL	"	11.80	.0022	.0007 .0007	.0008 .0008	.0008 .0008	860 17107	1620 31450	2340 45446	4493 (1)	8986 (1)	14342 (1)	INSTALLED NEW CARBON SEAL RING & NEW MATING RING.	CARBON DAM WORN DOWN CONCENTRICALLY. MATE IN GOOD CONDITION.
15	46	211.26	CF851218/01 CARBON P03N REWORKED	CF851226/04 CHROME/K-MONEL	"	11.80	(1)	.0008 (1)	.0008 (1)	.0006 (1)	1180 (1)	2075 (1)	2940 (1)	6048 (1)	8813 (1)	12528 (1)	INSTALLED REWORKED CARBON SEAL RING AND NEW MATING RING	FIRE AT SEALS. CARBON METAL BAND AND PILOT RING MISSING. 60° CARBON RING SEGMENT. MATE RING GROOVED WITH SLAG DEPOSITS AND PLATING MISSING.
16	10	28.49	CF851218-1/01 CARBON P692 (PHASE III)	CF851226/02 CHROME/K-MONEL	CF850816-005/01 VESPEL SP21 (PHASE III)	15.0	.000	.0007 .0007	.0007 .0007	.0006 .0006	2315 1030	3629 1901	5322 2851	6843 5360	10403 4493	14861 8694	NEW PHASE III ASSEMBLY	SEAL & MATE IN GOOD CONDITION. NO WEAR.
17	7	31.12	"	"	"	14.6	.000	.0007 .0007	.0007 .0007	.0006 .0006	1244 1123	1884 1935	2903 2799	3715 4009	5028 5115	13132 10368	REINSTALLED SAME PARTS, NO REWORK	SEAL & MATE IN GOOD CONDITION. NO WEAR.
18	20	204.78	"	"	"	14.6	.000	.0007 .0007	.0007 .0007	.0006 .0006	2419 1000	4925 2020	9331 2790	12614 9072	16675 10714	20736 12442	REINSTALLED SAME PARTS, NO REWORK.	SEAL & MATE IN GOOD CONDITION. NO WEAR.
19	12	136.2	"	"	"	14.1	.000	.0007 .0007	.0007 .0007	.0006 .0006	900 1075	1770 1625	2530 2340	3550 2960	3800 4800	10200 6840	REINSTALLED SAME PARTS, NO REWORK.	SEAL & MATE IN GOOD CONDITION. NO WEAR. MATE HAS POLISHED CONTACT PATTERN.
20	24	204.76	"	"	"	14.0	.000	.0007 .0007	.0007 .0007	.0006 .0006	- 1300	2000 1800	2750 2700	3400 3800	4900 4800	6300 11600	REINSTALLED SAME PARTS, NO REWORK.	SEAL & MATE IN GOOD CONDITION. NO WEAR. CARBON POLISHED WITH FAINT CIRCUMFERENTAL MARKS. MATE HAS POLISHED CONTACT PATTERN. PISTON RING IN GOOD CONDITION WITH UNIFORM CONTACT PATTERN.

(1) NO READING DUE TO FIRE DAMAGE

TABLE A-1. NASA LOX SEAL HARDWARE AND INSPECTION SUMMARY, PHASE III

BUILD NO.	TOTAL STARTS	TOTAL TIME MIN.	SEAL RING PN/SN MATERIAL	MATING RING PN/SN MATERIAL	PISTON RING PN/SN MATERIAL	SPRING LOAD @.950 LB	DAM WEAR AVG. IN.	RECESS PAD DEPTH - IN. PRE/POST			STATIC GN_2 LEAKAGE - SCIM PRE/POST						HARDWARE CONDITION	
											DIFFERENTIAL PRESSURE PSIG						PRE TEST	POST TEST
								1	2	3	50	100	150	200	250	300		
21	52	236.56	CF851218-1/02 CARBON P692	CF851226/05 CHROME/K-MONEL	CF850816-005/02 VESPEL SP21	13.7	.0000	.0008 .0008	.0008 .0008	.0008 .0008	920 440	1470 800	2140 1000	2500 1680	3800 2100	6100 3000	NEW	SEAL & MATE IN GOOD CONDITION. CARBON POLISHED. MATE HAS LIGHT CONTACT PATTERN WITH CIRCUMFERENTAL MARKS & 3 SYMETRICAL SPOTS.
22	70	313.64	"	"	"	14.2	.0000	.0008 .0008	.0008 .0008	.0008 .0007	750 750	1425 1310	2150 2090	2700 2600	3600 3500	4600 4800	SAME AS BUILD 21 - NO REWORK.	SEAL AND MATE IN GOOD CONDITION. NO SIGNIFICANT CHANGE FROM BUILD 21 - THE 3 SPOTS SMOOTH OUT.
23	73	366.72	"	"	"	13.9	.0001	.0008 .0006	.0008 .0007	.0007 .0006	745 1200	1445 1520	2100 2200	2900 3100	4200 5400	6100 7700	SAME AS BUILD 22 EXCEPT CARBON LAPPED FLAT	SEAL & MATE IN SATISFACTORY CONDITION. 4 HIGH SPOTS ON MATE. WEAR ON CARBON RING AT LIFT PADS.

TABLE A-1. NASA LOX SEAL HARDWARE AND INSPECTION SUMMARY, PHASE IV

BUILD NO.	TOTAL STARTS	TOTAL TIME MIN.	SEAL RING PN/SN MATERIAL	MATING RING PN/SN MATERIAL	PISTON RING PN/SN MATERIAL	SPRING LOAD LB	DAM WEAR AVG. IN.	RECESS PAD DEPTH - IN. PRE/POST			STATIC GN2 LEAKAGE - SCIM PRE/POST DIFFERENTIAL PRESSURE PSIG						HARDWARE CONDITION	
								1	2	3	50	100	150	200	250	300	PRE TEST	POST TEST
1	10	52.3	SSCY 5636-8 04 CARBON P692	SSCY 4685-7 02 CHROME/K-MONEL	SSCY 5636-3 01 3 SEGMENT VESPEL SP211	12.2	.0001	.0009 .0008	.0008 .0007	.0009 .0008	1150 540	1750 870	3330 1600	5600 2740	8122 6134	15725 12890	NEW	EXCELLENT CONDITION. CARBON POLISHED. MATING RING HAS LIGHT POLISHED PATTERN AT DAM & PADS.
2	67	299.6	"	"	"	11.7	.0000	.0008 .0008	.0007 .0007	.0008 .0008	455 310	1050 700	1800 1400	3100 3000	5200 5600	9849 9331	SAME AS BUILD 1 NO REWORK	EXCELLENT CONDITION CARBON POLISHED. NO ADDITIONAL WEAR. MATING RING HAS LIGHT POLISHED PATTERN WITH 10 μ IN. WEAR AT OUTER LAND & 5 μ IN. WEAR AT DAM OD
3	56	302.8	"	"	"	12.6	.0000	.0008 .0008	.0007 .0007	.0008 .0008	580 860	1620 2440	3250 4900	6200 7260	6912 14340	11232 23330	SAME AS BUILD 2 NO REWORK	EXCELLENT CONDITION CARBON POLISHED. NO ADDITIONAL WEAR. MATING RING CONDITION SAME AS POST BUILD 2. NO ADDITIONAL WEAR.
4	9	10.5	SSCY 6563-1 SN 01 CARBON P692	SPIRAL GROOVE RS009696E C28-2500-015 SN 01 CHROME/K-MONEL	CF 850816-005 S/N 03 VESPEL SP 211	13.3	(1) .040- .060	(2) .00015 (3)	.00018 (3)	.00020 (3)	8640 19008	15552 29722	21254 34042	27130 40090	32314 61690	37152 -	NEW	HEAVY RUBBING & WEAR ON SPIRAL GROOVE SURFACE. MATING RING WORN .011 - .025 IN. CARBON WORN .040-.060 IN.
5	3	.3	SSCY 6888-1 SN 01 CARBON P692 (DECREASED ID)	SPIRAL GROOVE RS009696E C28-2500-015 SN 02 CHROME/K-MONEL	CF 850816-005 S/N 04 VESPEL SP 211	13.6	(1) .0004- .0022	(2) .00020 (3)	(2) .00020 (3)	(2) .00020 (3)	12960 7430	19872 12614	29376 15897	33696 18317	42336 19526	- -	NEW	RUBBING & WEAR ON SPIRAL GROOVE SURFACE. MATING RING WORN .0002 IN. CARBON WORN .0004-.0022 IN.
6	24	34.3	SSCY 6888-1 SN 02 CARBON P692	SPIRAL GROOVE NARROW DAM RS009696E-1 SN 03 CHROME/K-MONEL	CF 850816-005 S/N 05 VESPEL SP 211	13.0	(1) .0121 .0192	(2) .00040 (3)	(2) .00040 (3)	(2) .00040 (3)	812 657	1218 890	1529 1132	2765 1391	2125 1564	- -	NEW SPIRAL GROOVE MATING RING, CARBON SEAL, PILOT RING, & PISTON RING. SAME HOUSING AS BUILD 5.	RUBBING & WEAR ON SPIRAL GROOVE SURFACE. MATING RING WORN .0005 IN. CARBON WORN .0121-.0192 IN.

(1) CARBON (2) SPIRAL GROOVE (3) WORN OFF

TABLE A-1. NASA LOX SEAL HARDWARE AND INSPECTION SUMMARY, PHASE IV

BUILD NO.	TOTAL STARTS	TOTAL TIME MIN.	SEAL RING PN/SN MATERIAL	MATING RING PN/SN MATERIAL	PISTON RING PN/SN MATERIAL	SPRING LOAD @.950 LB	DAM WEAR AVG. IN.	RECESS PAD DEPTH - IN. PRE/POST			STATIC GN_2 LEAKAGE - SCIM PRE/POST, DIFFERENTIAL PRESSURE PSIG						HARDWARE CONDITION	
								1	2	3	50	100	150	200	250	300	PRE TEST	POST TEST
7	7	45.29	SSCY6888-1 S/N 027903 CARBON P692	RS009696E MOD III CHROME/K-MONEL	CF850816-005 S/N 05 VESPEL SP211	14.9	(1) (4)	(2) .00070 (3)	(2) .00070 (3)	(2) .00070 (3)	3600 (4)	6400 (4)	9300 (4)	12200 (4)	15000 (4)	- -	NEW CARBON SEAL RING AND MATING RING. SAME PISTON RING PILOT RING AND HOUSING AS BUILD 6.	MATING RING SPIRAL GROOVES WORN OFF. CARBON SURFACE WORN AND SCORED. HOUSING, PILOT RING AND PISTON RING SEVERELY DAMAGED BY FIRE.

(1) CARBON (2) SPIRAL GROOVE (3) WORN OFF (4) NOT AVAILABLE DUE TO FIRE DAMAGE

TABLE A-1. NASA LOX SEAL HARDWARE AND INSPECTION SUMMARY, PHASE V

BUILD NO.	TOTAL STARTS	TOTAL TIME	SEAL RING PN/SN MATERIAL	MATING RING PN/SN MATERIAL	SECONDARY SEAL PN/SN MATERIAL	SPRING LOAD LB	DAM WEAR AVG. IN. (1)	SPIRAL GROOVE DEPTH - IN. PRE/POST			STATIC GN_2 LEAKAGE - SCIM PRE/POST						HARDWARE CONDITION	
											DIFFERENTIAL PRESSURE PSIG							
								1	2	3	50	100	150	200	250	300	PRE TEST	POST TEST
1	31	24.35	SSCY7153-1 058101 CARBON P5N	7R0012691-7 01 SPIRAL GROOVE MONEL K-500	1775636-3 4-1, 2, 3 VESPEL SP211	14	.000125 .000350	.001 .001	.001 (2)	.001 .0008	670 35424	1600 53568	3050 79660	6050 104544	12096 128563	24192 154656	NEW	HEAVY RUBBING + WEAR ON SPIRAL GROOVE SURFACE IN THREE PLACES.MATING RING WORN 0-.001". CARBON RING WORN .000125 - .000350".
2	17	34.28	SSCY7153-1 058102 CARBON P5N	7R0012691-7 03 SPIRAL GROOVE MONEL K-500	1775636-3 5-1,2,3 VESPEL SP211	14	.000184 .000312	.00079 .00079	.00082 .00082	.00065 .00065	1050 1800	2700 3700	5702 5000	9686 6566	13478 6912	22464 8380	New	Minimal rubbing & wear on spiral groove surface. Carbon ring worn .000184-.000312".
3	23	25.18	"	"	"	14	.00025 .00075	.00079 .0007	.00082 .0008	.00065 .00065	500 2800	1150 5000	2200 8640	4500 15552	7776 23328	14256 31104	SAME AS BUILD 2	NEGLIGIBLE RUBBING & WEAR ON SPIRAL GROOVE SURFACE. CARBON RING WORN & SCORED .00025-.00075".

(1) CARBON (2) SPIRAL GROOVE (3) WORN OFF

APPENDIX B

HELIUM SEAL HARDWARE AND INSPECTION SUMMARY

All data are listed in English units. The following conversion factors may be used to convert to SI units.

1 in. = 2.54 cm

1 SCIM = 0.27 cm^3/s

1 psig = 6.895 kPa

TABLE B-1. NASA HELIUM SEAL HARDWARE AND INSPECTION SUMMARY

BUILD NO.	TOTAL STARTS	TOTAL TIME MIN.	SEAL PART NO. TYPE MATERIAL	SEGMENT SER. NO. LOX/TURB	HOUSING SER. NO.	MATING RING PART NO. SER. NO. MATERIAL	DAM WEAR AVG. IN.		RECESS PAD DEPTH - IN. PRE/POST						STATIC H_e LEAKAGE - SCIM PRE/POST						HARDWARE CONDITION	
									LOX SIDE			TURB SIDE			LOX SIDE - PSIG			TURB SIDE - PSIG			PRE TEST	POST TEST
							LOX	TURB.	1	2	3	1	2	3	50	75	100	50	75	100		
1	2	15	CB851250 3 SEGMENT CARBON G84	A-3/A-5	01	RS004406X 01 CHROM/MONEL	.0000	.0001	(2)	(2)	(2)	(2)	(2)	(2)	1000	2350	3100	1320	1840	2900	NEW. TAPERED BORE. RECESS DEPTH .0000-.0015 IRREGULAR.	CARBON POLISHED WITH NEGLIGIBLE WEAR. MATE HAD SLIGHT CONTACT PATTERN.
2	2	5.9	"	A-1/A-7	02	RS004406X 02 CHROM/MONEL	(1)	(1)	(2)	(2)	(2)	(2)	(2)	(2)	1900	-	1600	2400	-	4000	NEW. SAME AS ABOVE.	CARBON SEGMENTS BROKEN. MATE HAD SLIGHT TRACE OF CONTACT.
3	1	15	"	A-4/A-6	01	"	(1)	(1)	.0005 (1)	.0006 (1)	.0005 (1)	.0005 (1)	.0004 (1)	.0006 (1)	13132 12096	18662 19526	23500 25920	9849 6912	13996 9504	17798 12960	REWORKED SEGMENTS FOR STRAIGHT BORE & NEW RECESS PADS. CLEANED HOUSING.	CARBON SEGMENTS BROKEN. SLIGHT CONTACT TRACE ON MATE.
4	3	1.8	--	--	-	--	-	-	-	-	-	-	-	-	-	-	-	-	-	-	BENTLYS INSTALLED IN PLACE OF HELIUM SEAL FOR SHAFT DEFLECTION TEST.	
5	1	.03	--	--	-	--	-	-	-	-	-	-	-	-	-	-	-	-	-	-	"	
6	2	1.6	--	--	-	--	-	-	-	-	-	-	-	-	-	-	-	-	-	-	"	
7	1	.4	CB851250 3 SEGMENT CARBON G84	A-2/A-8	03	RS004406X 03 CHROM/MONEL	(1)	(1)	.0006 (1)	.0005 (1)	- -	- -	.0006 (1)	.0007 (1)	10100 (1)	14400 (1)	- -	7600 (1)	11000 (1)	-	NEW. REWORKED SEGMENTS FOR STRAIGHT BORE & NEW RECESS PADS.	CARBON SEGMENTS BROKEN. MATE RUBBED HOUSING DUE TO EXCESSIVE SHAFT DEFLECTION.
8	28	18.8	CB120673 6 SEGMENT CARBON P5N	B-5/B-10	01 REWORKED	RS004406X 04 CHROM/MONEL	.0000	.0015	.0006 .0001	.0006 .0001	.0006 .0002	.0006 .0002	.0006 .0001	.0006 .0001	1910 970	3320 1500	5120 2500	3047 26544	5400 39862	8450 52612	HOUSING REWORKED FROM 3 SEGMENT DESIGN. NEW SEGMENTS.	CARBON WORN UNEVEN. LOX SIDE INNER LAND WORN OFF. TURB SIDE DAM & OUTER LAND WORN OFF. RECESS PADS NEARLY WORN OFF.
9	29	85.8	"	"	"	"	.0001	.0005	.0001 .0000	.0001 .0000	.0002 .0000	.0002 .0000	.0001 .0000	.0001 .0000	890 481	1500 684	2280 961	27994 24883	40608 35078	-- 45446	REBUILT WITH SAME PARTS AS BUILD 8. NO REWORK	SAME AS ABOVE WITH SLIGHTLY MORE WEAR.

(1) SEGMENTS BROKEN (2) RECESS PAD DEPTH .0000 TO .0015 IRREGULAR

TABLE B-1. NASA HELIUM SEAL HARDWARE AND INSPECTION SUMMARY

BUILD NO.	TOTAL STARTS	TOTAL TIME MIN.	SEAL PART NO. TYPE MATERIAL	SEGMENT SER.NO. LOX/TURB	HOUSING SER.NO.	MATING RING PART NO. SER. NO. MATERIAL	DAM WEAR AVG. IN.		RECESS PAD DEPTH - IN. PRE/POST						STATIC H_e LEAKAGE - SCIM PRE/POST						HARDWARE CONDITION	
									LOX SIDE			TURB SIDE			LOX SIDE - PSIG			TURB SIDE - PSIG			PRE TEST	POST TEST
							LOX	TURB.	1	2	3	1	2	3	50	75	100	50	75	100		
10	7	10.4	CB120673 6 SEGMENT CARBON P5N	B-1/B-7	01 REWORKED	EWR244525 01 CHROM/MONEL	0	.0039	.00054 .00035	.00050 .00036	.00045 .00035	.0004 0	.0004 0	.0004 0	580 580	1025 1400	1580 2380	500 35770	850 50803	1360 58752	SAME HOUSING AS BUILD 9. NEW SEGMENTS. NEW MATE REWORKED TO PHASE III CONFIG.	CARBON WORN UNEVEN. LOX SIDE INNER LAND WORN .00014 IN. NO WEAR ON OUTER LAND OR DAM. TURB SIDE INNER LAND WORN .0003 IN. DAM WORN .0039 IN. MATE FLARED OUT .003 IN. RADIAL ON TURB.SIDE.
11	13	148.1	"	B-1/B-5	02 REWORKED	RS004406X 05 CHROM/MONEL	0	.0033	.00035 0	.00036 0	.00035 0	0	0	0	555 330	950 570	1230 840	1300 31104	2005 44928	2900 53568	HOUSING REWORKED TO 6 SEG. DESIGN. SAME LOX SEGMENTS AS BUILD 10. LOX SEGMENTS FROM BUILDS 8 & 9 USED ON TURB. SIDE. NEW PHASE I MATE.	CARBON WORN UNEVEN. LOX SIDE INNER LAND WORN OFF. NO WEAR ON OUTER LAND OR DAM. TURB. SIDE INNER LAND WORN .0005 IN. DAM WORN .0033 IN.
12	2	38.11	CB120673 6 SEGMENT CARBON P5N	B-3/B-9	02 REWORKED	EWR 244525 002 CHROM/MONEL	0	.0033	.0006 .0006	.0007 .0007	.0006 .0006	.0006 0	.0005 0	.0005 0	850 535	1700 1022	2900 1900	2900 31450	4000 44237	5250 56333	NEW SEGMENTS. REWORKED PHASE III MATE FROM BUILD 10 GROUND ROUND AND REPLATED.	CARBON WORN UNEVEN. LOX SIDE INNER LANDS COMPLETELY WORN OFF. TURB. SIDE RECESS PADS WORN OFF.
13	2	120.05	"	"	"	RS004406X 04 CHROM/MONEL	0	0	.0006 .0006	.0007 .0006	.0006 .0006	0 0	0 0	0 0	1650 1240	3320 2580	5280 4020	46656 44410	68602 83808	88819 103680	REINSTALLED SAME SEGMENTS WITH USED PHASE I MATE.	NO ADDITIONAL WEAR ON SEGMENTS. MATE WORN SLIGHTLY.
14	15	62.30	"	"	"	"	0	0	.0006 .0006	.0006 .0006	.0006 .0006	0 0	0 0	0 0	2500 998	4200 2080	5770 3770	35770 29549	60134 41818	79834 53914	REINSTALLED SAME SEAL AND MATE. NO REWORK.	NO CHANGE IN SEAL OR MATE CONDITION.
15	46	211.26	"	"	"	"	(1)	(1)	.0006 (1)	.0006 (1)	.0006 (1)	0 (1)	0 (1)	0 (1)	1165 (1)	2490 (1)	3770 (1)	28166 (1)	38016 (1)	49075 (1)	REINSTALLED SAME SEAL AND MATE. NO REWORK.	FIRE AT SEALS. 90° SEGMENT OF MATE RING AND CARBON SEGMENTS. RUBBING SURFACE IN GOOD CONDITION.
16	10	28.49	PHASE III 99RS006215 FLOAT RING INCONEL BANDED CARBON G84	02/02	PHASE III 02	RS010476X 002 CHROM/ INCO. 903 "Z" RING	(3)	(3)	.0007 (2)	.0007 (2)	.0006 (2)	.0008 .0005	.0006 .0002	.0008 .0003	33005 56678	48384 81734	71539 99878	26784 25402	38880 35770	50284 48557	NEW PHASE III ASSEMBLY LOX SIDE DIA CLEAR = .0054 IN. TURB. SIDE DIA CLEAR = .0050 IN.	LOST CLEARANCE ON LOX SIDE RING, WORE AWAY PADS. WORE GROOVE INTO PLATING. CARBON DAMAGED. TURB. SIDE RING RUBBED AND SCORED SLIGHTLY. MATE FLARED OUT ON LOX SIDE.

(1) NO READING DUE TO FIRE DAMAGE (2) PADS WORN AWAY (3) CARBON DAMAGED BY RUBBING CONTACT

TABLE B-1. NASA HELIUM SEAL HARDWARE AND INSPECTION SUMMARY

BUILD NO.	TOTAL STARTS	TOTAL TIME MIN.	SEAL PART NO. TYPE MATERIAL	SEGMENT SER.NO. LOX/TURB	HOUSING SER.NO.	MATING RING PART NO. SER. NO. MATERIAL	SEAL RING, DIA. CLEAR. IN. PRE/POST		RECESS PAD DEPTH - IN. PRE/POST						STATIC He LEAKAGE - SCIM PRE/POST						HARDWARE CONDITION	
									LOX SIDE			TURB SIDE			LOX SIDE - PSIG			TURB SIDE - PSIG			PRE TEST	POST TEST
							LOX	TURB.	1	2	3	1	2	3	50	75	100	50	75	100		
17	7	31.12	PHASE III 99RS006215 FLOAT RING INCONEL BANDED CARBON G84	03/03	04	RS010476X 001 CHROME/ INCO 903 "Z" RING	.0076 .0085	.0077 .0086	.0007 .0007	.0006 .0006	.0007 .0007	.0008 .0008	.0007 .0007	.0006 .0006	37152 28857	52704 41472	67738 54605	35770 28684	50285 40608	63936 49594	NEW PHASE III MATE REWORKED TO INCREASE SEAL CLEARANCE	EXCELLENT CONDITION SLIGHT CONTACT MARKS.
18	20	204.78	"	"	"	"	.0085 -	.0086 -	.0007 .0005	.0006 .0005	.0007 .0004	.0008 .0007	.0007 .0005	.0006 .0005	34560 20736	44928 44928	57024 57888	24192 41472	33696 62208	42768 82944	SAME AS BUILD 17. NO REWORK.	GOOD CONDITION. HEAVY RUB PATTERN ON LOX SIDE & SLIGHT RUB PATTERN ON TURB SIDE DUE TO TESTER BEARING FAILURE.
19	12	136.2	"	"	"	RS010476X 001-1 CHR/INC 903	- .0076	- .0072	.0005 .0004	.0005 .0005	.0004 .0004	.0007 .0007	.0005 .0005	.0005 .0005	47520 41472	67392 57888	86745 73094	33350 23512	47693 39744	60480 50112	SAME SEAL AS BUILD 18, NO REWORK. MATING RING REPLATED.	GOOD CONDITION. SLIGHT RUB PATTERN DUE TO BEARING FAILURE.
20	24	204.76	"	"	"	"	.0076 .0078	.0072 .0072	.0004 .0004	.0005 .0005	.0004 .0004	.0007 .0006	.0005 .0005	.0005 .0005	49248 31104	67392 44928	63936 58752	32832 24750	46656 33500	58752 41500	SAME SEAL AS BUILD 19. NO REWORK. MATING RING BURNISHED TO REMOVE RUB PATTERN.	GOOD CONDITION. UNIFORM RUB PATTERN WITH LIGHT CARBON DEPOSIT ON MATE. CARBON POLISHED WITH RUB MARKS.
21	52	236.56	99RS006215 FLOAT RING INCO. BAND CARBON G84	01/01	03	"	.0059 .0074	.0060 .0073	.0006 .0000	.0005 .0000	.0006 .0000	.0006 .0003	.0006 .0000	.0006 .0002	40608 46656	57024 63936	75168 84672	38880 22464	55296 32832	71712 43200	SEAL NEW, MATE SAME AS BUILD 20 EXCEPT CARBON DEPOSIT WAS REMOVED.	LOX SIDE SEAL RING LOST CLEARANCE & WORE GROOVE .003-.004 INCH INTO MATING RING. LOX SIDE CARBON WORN & SCORED. TURB SIDE CARBON WORN .0013 INCH DIA. TURB SIDE MATE HAS HEAVY RUB PATTERN.
22	70	313.64	99RS006215 FLOAT RING INCO BAND CARB G84	04/04	01	RS010476X 003 CR/INC903	.0080 .0080	.0079 .0078	.0006 .0006	.0007 .0006	.0006 .0005	.0006 .0007	.0006 .0005	.0006 .0005	38016 47520	51840 67392	65664 82080	34560 35424	46656 52704	57024 69120	NEW	GOOD CONDITION. SLIGHT RUB PATTERN, HEAVIER ON LOX SIDE. CARBON POLISHED ON HIGH SPOTS WITH VERY SLIGHT WEAR.

TABLE B-1. NASA HELIUM SEAL HARDWARE AND INSPECTION SUMMARY

BUILD NO.	TOTAL STARTS	TOTAL TIME MIN.	SEAL PART NO. TYPE MATERIAL	SEGMENT SER.NO. LOX/TURB	HOUSING SER.NO.	MATING RING PART NO. SER. NO. MATERIAL	SEAL RING DIA. CLEAR IN. PRE/POST		RECESS PAD DEPTH - IN. PRE/POST						STATIC H_e LEAKAGE - SCIM PRE/POST						HARDWARE CONDITION	
									LOX SIDE			TURB SIDE			LOX SIDE - PSIG			TURB SIDE - PSIG			PRE TEST	POST TEST
							LOX	TURB.	1	2	3	1	2	3	50	75	100	50	75	100		
23	73	366.72	PHASE III 99RS006215 FLOAT RING INCO. BAND CARBON G84	04/04	01	RS010476X 003 CR/INC 903	.0080 .0078	.0078 .0077	.0006 .0005	.0006 .0005	.0005 .0004	.0007 .0007	.0005 .0003	.0005 .0005	42336 30586	62208 44928	78624 58061	35000 26266	49248 37498	63936 49248	SAME SEAL AS BUILD 22. CARBON DEPOSIT ON MATE REMOVED.	GOOD CONDITION. SLIGHT RUB PATTERN, HEAVIER ON LOX SIDE. CARBON POLISHED ON HIGH SPOTS WITH VERY SLIGHT WEAR.

TABLE B-1. NASA HELIUM SEAL HARDWARE AND INSPECTION SUMMARY

BUILD NO.	TOTAL STARTS	TOTAL TIME MIN.	SEAL PART NO. TYPE MATERIAL	SEGMENT SER.NO. LOX/TURB	HOUSING SER.NO.	MATING RING PART NO. SER. NO. MATERIAL	DAM WEAR AVG. IN.		RECESS PAD DEPTH - IN. PRE/POST						STATIC He LEAKAGE - SCIM PRE/POST						HARDWARE CONDITION	
									LOX SIDE			TURB SIDE			LOX SIDE - PSIG			TURB SIDE - PSIG			PRE TEST	POST TEST
							LOX	TURB.	1	2	3	1	2	3	50	75	100	50	75	100		
1	10	52.3	201001 6 SEGMENT CARB G84	C-3 C-11	2	RS010476X 5 CHROM/INC 903	.0002	.0003	.0007 .0005	.0007 .0007	.0006 .0005	.0005 .0002	.0007 .0003	.0007 .0005	1720 2000	3100 4400	5400 7100	780 890	1240 1320	1850 1840	NEW	EXCELLENT CONDITION. CARBON POLISHED. LIGHT CONTACT PATTERN ON MATING RING.
2	67	299.6	"	"	"	"	.0000	.0000	.0005 .0005	.0007 .0007	.0005 .0005	.0002 .0002	.0003 .0003	.0005 .0005	1300 2300	2100 3800	3400 7700	400 1040	580 1560	770 2230	SAME AS BUILD 1 NO REWORK	EXCELLENT CONDITION. CARBON POLISHED. NO ADDITIONAL WEAR. LIGHT CONTACT PATTERN ON MATING RING.
3	56	302.8	"	"	"	"	.0000	.0000	.0005 .0005	.0007 .0007	.0005 .0005	.0002 .0002	.0003 .0003	.0005 .0005	2000 4000	3800 8800	6600 15800	960 750	1560 1200	2000 1610	SAME AS BUILD 2 NO REWORK	EXCELLENT CONDITION. CARBON POLISHED. NO ADDITIONAL WEAR. CONDITION SAME AS POST BUILD 2.
4	9	10.5	201001 6 SEGMENT CARB G84	C8/C10	1	RS010476X 6 CHR/INC 903	.0000	.0002	.0004 .0004	.0005 .0005	.0003 .0003	.0004 .0003	.0003 .0001	.0005 .0002	1300 7800	2000 11600	3200 16500	1060 11450	2200 13600	2700 19008	NEW	NO WEAR ON LOX SIDE. ONE LOX SEGMENT BROKEN. TURB SIDE SEG WORN .0001 - .0003 IN. HEAVY RUB ON ONE SIDE OF MATING RING. DAMAGE DUE TO LOX SEAL FAILURE & SHAFT DEFLECTION.
5	3	.3	201001 6 SEGMENT CARB G84	C1/C16	1	RS010476X SN 8 CHR/INC 903	.0000	.0000	.0004 .0004	.0004 .0004	.0008 .0008	.0008 .0008	.0007 .0007	.0006 .0006	7776 7948	11664 11577	15552 15206	9936 10368	14688 12960	20304 16329	NEW	EXCELLENT CONDITION EXCEPT DAM ON LOX SEGMENT BROKEN AT INSTALLATION. CARBON POLISHED. LIGHT CONTACT PATTERN ON MATING RING.
6	24	34.3	"	"	"	"	.0001	.0003	.0004 .0003	.0004 .0003	.0008 .0006	.0008 .0005	.0007 .0004	.0006 .0004	7949 9850	11664 14688	15466 21600	10368 5184	14256 7776	17971 9936	SAME AS BUILD 5. C-1-1 SEGMENT DAM CHIPPED.	GOOD CONDITION. CARBON POLISHED WITH .0001-.0003 WEAR. LIGHT CONTACT PATTERN ON MATING RING.

TABLE B-1. NASA HELIUM SEAL HARDWARE AND INSPECTION SUMMARY

BUILD NO.	TOTAL STARTS	TOTAL TIME MIN.	SEAL PART NO. TYPE MATERIAL	SEGMENT SER. NO. LOX/TURB	HOUSING SER. NO.	MATING RING PART NO. SER. NO. MATERIAL	DAM WEAR AVG. IN.		RECESS PAD DEPTH - IN. PRE/POST						STATIC H_e LEAKAGE - SCIM PRE/POST						HARDWARE CONDITION	
									LOX SIDE			TURB SIDE			LOX SIDE - PSIG			TURB SIDE - PSIG			PRE TEST	POST TEST
							LOX	TURB.	1	2	3	1	2	3	50	75	100	50	75	100		
7	7	45.29	2001001 6 SEGMENT CARB 684	C1/C16	1	RS010476X S/N 8 CHR/INC 903	(1)	(1)	.0003 (1)	.0003 (1)	.0006 (1)	.0005 (1)	.0004 (1)	.0004 (1)	8800 (1)	11650 (1)	15206 (1)	6100 (1)	6800 (1)	10500 (1)	SAME AS BUILD 6 C-1-1 SEGMENT DAM CHIPPED	CARBON SEGMENTS AND MATING RING BURNED AWAY. THREE HOLES BURNED IN HOUSING.

(1) NOT AVAILABLE DUE TO FIRE DAMAGE

TABLE B-1. NASA HELIUM SEAL HARDWARE AND INSPECTION SUMMARY

BUILD NO.	TOTAL STARTS	TOTAL TIME MIN.	SEAL PART NO. TYPE MATERIAL	SEGMENT SER.NO. LOX/TURB	HOUSING SER.NO.	MATING RING PART NO. SER. NO. MATERIAL	DAM WEAR AVG. IN.		RECESS PAD DEPTH - IN. PRE/POST $X10^{-3}$						STATIC He LEAKAGE - SCIM PRE/POST						HARDWARE CONDITION	
									LOX SIDE			TURB SIDE			LOX SIDE - PSIG			TURB SIDE - PSIG			PRE TEST	POST TEST
							LOX	TURB.	1	2	3	1	2	3	50	75	100	50	75	100		
1	31	24.35	Res 1377 6 Segment Carb G84	7117-2 7117-3	108002	7R0012693 01 Inconel 718	.000625 .0082	.000625 .0094	.687 (1)	.625 (1)	.562 (1)	.625 (1)	.625 (1)	.625 (1)	940 510	2600 1556	7800 5200	1500 435	8200 2750	10200 5500	New	Heavy wear on segments - Pads worn off. Mating Ring worn .00005" on contact surface
2	17	34.28	Res 1377 6 segment Carb G84	7117-4 7117-1	108002	7R0012693 02 Inconel 718	.0006 .0114	0 .0025	.484 .437	.500 .437	.546 .245	.703 (1)	.875 (1)	.593 (1)	562 710	1950 1650	4375 3500	900 3150	2400 4750	4700 5850	New Segments & Mating Ring	Heavy wear on segments. Turbine side pads worn off. Mating ring worn .000059" on contact surface. Two of the turbine side carbon segments were broken.
3	23	25.18	RES 1377 6 SEGMENT CARB G84	7117-9 7117-7	108002	7R0012693 03 INCONEL 718	.0010	.0015	.780 .160	.500 .200	.550 (1)	.560 (1)	.400 (1)	.440 (1)	900 700	2400 1850	4700 3000	562 1750	1950 1900	4375 2900	New Segments & Mating Ring	Heavy wear on segments. Turbine side pads worn off. Negligible wear on mating ring.

(1) WORN OFF

APPENDIX C

NASA CRYOGENIC SEAL TEST DATA SUMMARY

All data are listed in English units. The following conversion factors may be used to convert to SI units.

1 psig = 6.895 kPa

K = 0.555 (F + 460)

1 SCFM = 0.000466 m^3/s

1 in. = 2.54 cm

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY

						LOX SEAL					HELIUM SEAL							
															LEAKAGE SCFM			
BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	U/S PR. PSIG	D/S PR PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM	U/S PR PSIG	D/S PR PSIG	U/S TEMP °F	D/S TEMP °F	LOX SIDE	TURB. SIDE	TOTAL	REMARKS
1	001 (1)	GASEOUS NITROGEN CHECKOUT 15 MIN.	08-09-73	15	20300	150	2-10	50	116	8.2-26.4	50	0	92	73	--	--	8.7	DURATION TEST - LOX SEAL LIFT PADS WORN .010. LOX MATING RING SCORED. H_e SEAL RUBBED. ROTATED WRONG DIRECTION.
2	002	"	08-29-73	.9	12250	155	1.5	10	-70	4.6	30	4	88	75	.9	1.8	2.7	CUT DUE TO SPEED CONTROL PROBLEM.
2	003	"	09-17-73	5	20000	150	3.5	10	-60	3.0	20	3.2	72	50	-	1.5	5.0	DURATION TEST - LOX SEAL RUBBED SLIGHTLY. H_e SEAL SEGMENTS BROKEN. NO RUBBING
3	004	"	09-26-73	15	25000	150	5.0	10	-45	3.0	34	4.5	96	73	--	--	12.1	DURATION TEST - LOX SEAL WORN .0005. H_e SEAL SEGMENTS BROKEN, NO RUBBING.
4	005	SHAFT DEFLECTN.	11-13-73	1.6	32550	150	--	-35	--	7.1	--	--	--	--	--	--	--	SPEED RAMPED FROM 0 TO 32550 RPM TO MEASURE SHAFT DEFLEC-TION AT H_e SEAL. CRITICAL SPEED AT 19000 RPM.
4	006	"	11-16-73	.1	32725	165	--	-20	--	8.6	--	--	--	--	--	--	--	START TEST TO MEASURE SHAFT DEFLECTION DURING ACCELERATION THROUGH CRITICAL SPEED. BENTLY NOT RECORDED.
4	007	"	11-16-73	.1	32725	165	--	-20	--	7.5	--	--	--	--	--	--	--	FAST START TEST. TESTER BEARING FAILED.
5	008	"	12-14-73	.03	27000	156	--	-10	--	--	--	--	--	--	--	--	--	FAST START TEST. TESTER BEARING FAILED. LOX SEAL DAMAGED BY SHAFT RUBBING.
6	001	"	05-06-74	1.3	32200	--	--	--	--	--	--	--	--	--	--	--	--	GRADUAL START WITH REWORKED TESTER MOUNT & ALIGNMENT. SHAFT DEFLECTION & VIBRATION SATISFACTORY.
6	002	"	05-06-74	.3	32000	--	--	--	--	--	--	--	--	--	--	--	--	FAST START TEST. SHAFT DEFLEC-TION & VIBRATION SATISFACTORY LOX & H_e SEALS NOT INSTALLED.
7	003	GASEOUS NITROGEN CHECKOUT 15 MIN.	05-23-74	.4	32200	150	5.0	35	-18	8.0-12.2	33.6	3.5	76	61	--	--	11.3	CUT DUE TO SUDDEN VIBRATION INCREASE. HELIUM SEAL SEG-MENTS BROKEN DUE TO SHAFT DEFLECTION. TESTER OVERHAULED.

(1) ROCKETDYNE CTL-4B

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL U/S PR. PSIG	LOX SEAL D/S PR. PSIG	LOX SEAL U/S TEMP °F	LOX SEAL D/S TEMP °F	LOX SEAL LEAKAGE SCFM	HELIUM SEAL U/S PR. PSIG	HELIUM SEAL D/S PR. PSIG	HELIUM SEAL U/S TEMP °F	HELIUM SEAL D/S TEMP °F	HELIUM SEAL LEAKAGE SCFM LOX SIDE	HELIUM SEAL LEAKAGE SCFM TURB. SIDE	HELIUM SEAL LEAKAGE SCFM TOTAL	REMARKS
8	076 (2)	GASEOUS NITROGEN CHECKOUT 15 MIN.	04-07-75	.45	32800	150	10.5	5	15	--	7	--	63	71	--	--	--	TESTER ACCEL OVER 10g REDLINE. BRG. LOX FLOW & PR DECAYED. He SEAL PR. DROPPED AT START DUE TO REGULATOR.
8	077	"	04-14-75	.05	24400	--	--	--	--	--	--	--	--	--	--	--	--	ERRONEOUS G-LEVEL.
8	078	"	04-14-75	.2	28400	--	---	--	--	--	--	--	--	--	--	--	--	TURB. IN AIR HOSE RUPTURED.
8	079	"	04-14-75	.31	28400	--	--	--	--	--	--	--	--	--	--	--	--	TURB. IN AIR HOSE RUPTURED.
8	080	"	04-17-75	.02	28800	157	14.2	-85	-41	6.4	41	.01	61	70	22.4	1.0	23.4	LOW SPEED.
8	081	"	04-17-75	.07	33200	157	11.4	-103	-36	7.8	54	.20	60	69	20.1	4.0	24.1	OVERSPEED.
8	082	"	04-17-75	.63	29600	145	12.5	-70	10	11.6	74	.39	60	73	19.3	5.6	24.9	LOW SPEED.
8	083	"	04-17-75	.06	33200	160	18.4	-110	-53	10.7	57	.17	55	73	18.6	3.7	22.3	OVERSPEED.
8	084	"	04-17-75	.13	33200	153	--	-83	-30	11.4	55	.12	55	78	19.8	3.1	22.9	OVERSPEED.
8	085	"	04-17-75	.26	32800	142	19.4	-72	-1	12.2	52	.37	55	80	18.2	5.4	23.6	ERRONEOUS G-LEVEL.
8	086	"	04-17-75	.78	23200	137	21.4	-120	-5	12.4	53	.32	45	61	18.3	5.2	23.5	SPEED DECAY.
8	087	"	04-17-75	.08	33000	161	22.5	-103	-41	15.3	67	.70	78	57	15.2	7.7	22.9	OVERSPEED.
8	088	"	04-17-75	.13	33000	160	22.2	-79	--	14.9	73	.7	59	82	14.1	7.6	21.7	OVERSPEED.
8	089	"	04-17-75	.42	33000	147	23.8	-67	5	13.0	60	.3	60	81	20.6	4.7	25.3	OVERSPEED.
8	090	"	04-17-75	1.12	32000	145	22.5	-57	15	--	54	.2	61	81	--	--	--	SPEED DECAY 32000 TO 17200.
8	091	"	04-18-75	.13	33000	--	--	--	--	--	--	--	--	--	--	--	--	OVERSPEED.
8	092	"	04-18-75	.17	33000	--	--	--	--	--	--	--	--	--	--	--	--	OVERSPEED.
8	093	"	04-18-75	.25	33000	--	12.6	-50	8	--	54	1.0	--	--	--	--	--	OVERSPEED.
8	094	"	04-18-75	.75	31200	--	14.0	-52	31	--	47	.2	--	--	--	--	--	LOST P4 SIGNAL.
8	095	"	04-18-75	3.0	32000	148	12.4	-33	69	8.7	41	.3	75	90	12.7	5.2	17.9	ERRONEOUS G-LEVEL.
8	096	"	04-18-75	.1	33000	--	--	--	--	--	--	--	--	--	--	--	--	OVERSPEED.
8	097	"	04-18-75	.13	33000	--	--	--	--	--	--	--	--	--	--	--	--	OVERSPEED.
8	098	"	04-18-75	3.0	32000	150	13.5	-20	85	9.1	47	.4	74	95	13.8	5.6	19.4	SPEED DECAY 32000 TO 26000.
8	099	"	04-18-75	2.0	32000	132	12.0	-27	73	8.7	50	.3	76	94	14.0	4.7	18.7	SPEED DECAY 32000 TO 28000.
8	100	"	04-24-75	.15	--	--	--	--	--	--	--	--	--	--	--	--	--	NO SPEED SIGNAL.
8	101	"	04-24-75	2.9	32000	145	1.4	-30	79	--	52	.01	70	87	--	--	--	SPEED DECAY 32000 TO 26000.
8	102	"	04-24-75	.3	--	(3) --	--	--	--	--	--	--	--	--	--	--	--	TESTER G-LEVEL INCREASE.
8	103	"	04-24-75	1.25	32240	(3) 78	1.8	--	19	--	.6	.04	79	87	--	--	--	TURBINE G-LEVEL INCREASE. ALL PARTS IN GOOD CONDITION, EXCEPT He SEAL WORN. TURB AIR CHANGED TO GN_2 TO PREVENT SPEED DECAY CAUSED BY ICING.

(2) WYLE LABS - NORCO

(3) RAN WITH NO GN_2 PRESSURE. SEAL PRESSURIZED BY LOX LEAKAGE THRU SLAVE SEAL.

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL					HELIUM SEAL							REMARKS
						U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM	U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM LOX SIDE	LEAKAGE SCFM TURB. SIDE	LEAKAGE SCFM TOTAL	
9	104	GASEOUS NITROGEN CHECKOUT 15 MIN.	05-19-75	.05	--	--	--	--	--	--	--	--	--	--	--	--	--	BAD SPEED PICKUP.
9	105	"	05-19-75	.05	--	--	--	--	--	--	--	--	--	--	--	--	--	BAD SPEED PICKUP.
9	106	"	05-19-75	.33	15800	116.5	1.8	-157	-50	--	1	.66	68	76	--	--	--	LOW SPEED.
9	107	"	05-19-75	.27	16120	151	2.1	-160	-47	--	2	.86	67	76	--	--	--	LOW SPEED.
9	108	"	05-19-75	.27	20800	151	2.2	-137	-52	--	3.4	1.4	67	76	--	--	--	LOW SPEED.
9	109	"	05-19-75	.47	28360	151	3.2	-110	-57	--	3.6	0	68	76	--	--	--	TURBINE PRESSURE DECAY.
9	110	"	05-19-75	.37	28760	150	3.2	-147	-46	--	3.8	2.4	66	75	--	--	--	TURBINE PRESSURE DECAY.
9	111	"	05-20-75	.58	33000	153	4.2	-310	-7	--	5.2	2.9	66	72	--	--	--	OVERSPEED.
9	112	"	05-20-75	.42	32800	182.5	4.4	-175	-47	--	5.2	3.0	65	73	--	--	--	OVERSPEED.
9	113	"	05-20-75	.43	32920	187.5	4.9	-200	-60	--	6	3.2	60	70	--	--	--	OVERSPEED.
9	114	"	05-20-75	.22	33200	115	1.3	-165	-15	--	0	.2	60	69	--	--	--	OVERSPEED.
9	115	"	05-20-75	3.8	33000	182.5	9.2	-235	-77	--	40	5	60	73	--	--	--	OVERSPEED.
9	116	"	05-20-75	2.8	32920	175	4.2	-215	-50	--	32.8	3.6	65	73	--	--	--	OVERSPEED.
9	117	"	05-20-75	11.2	32800	165	6.6	-197	-35	--	28.6	1.8	65	71	--	--	--	LOW LOX - ACCEPTABLE DURATION. TEST PT. #1.
9	118	"	05-21-75	1.0	28680	199	16.2	-37	-2	16.1	33.4	10	80	93	3.6	5.6	9.2	LOW SPEED.
9	119	"	05-21-75	.70	29960	200	7.45	-50	-25	17.0	0	10	75	90	2.8	5.6	8.4	LOW SPEED.
9	120	"	05-21-75	.52	33280	200	6.7	-50	-26	15.0	33	10	75	90	4.0	5.6	9.6	OVERSPEED.
9	121	"	05-21-75	.17	33120	214	9.0	-87	-39	--	13	6.0	71	86	--	--	--	OVERSPEED.
9	122	"	05-21-75	2.4	33200	197.5	12.8	-25	+19	17.5	36.6	2.5	75	87	3.1	2.5	5.7	OVERSPEED.
9	123	"	05-21-75	.83	31680	203.5	5.5	-52	-22	14.4	34.6	10	76	88	2.4	5.6	8.0	OVERSPEED.
9	124	"	05-21-75	2.7	32000	208.5	8.3	-22	+19	19.0	31.4	2.5	75	85	2.7	2.6	5.3	OVERSPEED.
9	125	"	05-21-75	1.4	30800	208	8.1	-40	-4	20.1	33	3.1	76	85	1.6	2.9	4.5	OVERSPEED.
9	126	"	05-21-75	5.9	29400	209	5.8	-27	+50	14.2	33	2.9	75	80	2.1	2.8	4.9	SPEED DROP. TURB. BRG. FAILED.
9	127	"	05-23-75	15.0	33080	202	5.5	-17	+59	13.9	34	4.4	70	75	1.0	3.5	4.6	DURATION TEST PT. #2.
9	128	"	05-23-75	.38	33080	290	9.5	-45	-7	11.9	20	4.7	92	101	6.6	3.6	10.2	OVERSPEED.
9	129	"	05-23-75	13.2	33080	303.5	6.9	+17	+78	16.5	32	1.6	90	97	3.1	1.9	5.1	O/S, ACCEPTABLE DURATION TEST PT. #3.
9	130	"	05-23-75	.67	31400	313.5	12.5	+2	+12	--	20.4	5.1	85	94	--	--	--	ERRONEOUS P4 REDLINE.
9	131	"	05-23-75	4.5	33120	332.5	24	+20	+64	17.4	31.8	1.5	84	87	3.2	1.9	5.1	OVERSPEED.
9	132	"	05-23-75	15.2	32200	350	15.1	±15	+70	12.0	30.8	4.6	86	94	2.6	3.6	6.2	DURATION TEST PT. #4. COMPLETED GN_2 CHECKOUT TESTING. LOX SEAL IN GOOD CONDITION. NO WEAR. HELIUM SEAL WORN UNEVEN.

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL U/S PR. PSIG	LOX SEAL D/S PR. PSIG	LOX SEAL U/S TEMP F	LOX SEAL D/S TEMP F	LOX SEAL LEAKAGE SCFM	HELIUM SEAL U/S PR. PSIG	HELIUM SEAL D/S PR. PSIG	HELIUM SEAL U/S TEMP F	HELIUM SEAL D/S TEMP F	HELIUM SEAL LEAKAGE SCFM LOX SIDE	HELIUM SEAL LEAKAGE SCFM TURB SIDE	HELIUM SEAL LEAKAGE SCFM TOTAL	REMARKS
10	133	P-I, SCH.II LOX TEST 2.5 HR.	6-10-75	.15	21050	210	50.0	-257	-272	--	41.0	10	92	--	--	--	--	LOX SEAL D/S PR. REDLINE
10	134	"	"	.32	30000	123.5	48.6	-280	-263	--	46.6	10	90	--	--	--	--	LOX SEAL D/S PR. REDLINE. INCREASED LEAK ORIFICE SIZE.
10	135	"	"	.3	33200	66.0	35.5	-273	-272	53.2	37.0	9.5	91	--	--	--	--	OVERSPEED.
10	136	"	"	.65	33200	92.0	39.7	-267	-272	43.5	--	2.1	90	--	--	--	--	OVERSPEED.
10	137	"	"	3.0	33200	152.5	34.0	-253	-237	38.3	31.6	--	90	--	--	--	--	OVERSPEED.
10	138	"	"	.84	22800	160	35.0	-257	-267	41.2	--	12.2	93	--	--	--	--	UNDERSPEED.
10	139	"	"	5.2	32400	157	36.4	-251	-249	40.8	34.0	8.0	94	--	--	--	--	DURATION. TESTER INSPECTION DUE TO EXCESSIVE LOX SEAL D/S PR. LOX SEAL IN GOOD CONDITION. HELIUM SEAL WORN UNEVEN. INCREASED DRAIN SIZE TO REDUCE D/S PR. INCREASED LOX SEAL SPRING LOAD.
11	140	"	7-11-75	PRETEST	0	114	.75	-290	-297	17.1	--	--	--	--	--	--	--	LOX SEAL LEAK ΔP PEGGED. SPEED UNSTABLE.
				.98	28000	245	12.5	-286	-284	--	--	4.0	96	--	--	--	--	
				POSTTEST	0	117	2.25	-275	-293	27.9	--	--	--	--	--	--	--	
11	141	"	"	.22	33280	--	--	--	--	--	--	--	--	--	--	--	--	OVERSPEED.
11	142	"	"	.23	33280	--	--	--	--	--	--	--	--	--	--	--	--	OVERSPEED.
11	143	"	"	.28	33400	--	--	--	--	--	--	--	--	--	--	--	--	OVERSPEED.
11	144	"	"	.28	33000	--	--	--	--	--	--	--	--	--	--	--	--	OVERSPEED.
11	145	"	"	PRETEST	0	112	2.6	-284	-284	22.2	--	--	--	--	--	--	--	OVERSPEED.
				2.6	33040	177	13.3	-242	-284	58.6	19.8	2.5	102	--	3.4	2.2	5.6	
				POSTTEST	0	124	2.5	-265	-287	21.5	--	--	--	--	--	--	--	
11	146	"	"	.18	27000	--	--	--	--	--	--	--	--	--	--	--	--	BLOWN FUSE ON LOX PUMP.
11	147	"	"	PRETEST	0	108	2.0	-286	-294	17.0	--	--	--	--	--	--	--	OVERSPEED.
				6.7	32720	155	13.7	-247	-237	54.8	30.8	3.0	111	--	8.8	1.8	10.6	
				POSTTEST	0	92	2.9	--	--	--	--	--	--	--	--	--	--	
11	148	"	"	PRETEST	0	70	2.2	-286	-292	19.5	--	--	--	--	--	--	--	OVERSPEED.
				15	31680	115	10.8	-257	-287	50.6	35.2	2.5	111	97	8.2	1.9	10.1	
				20.2	33080	108	11.0	-257	-283	49.0	36.6	2.5	111	97	7.6	2.5	10.1	
				POSTTEST	0	67	1.8	-272	-289	17.1	--	--	--	--	--	--	--	
11	149	"	"	.05	1200	--	--	--	--	--	--	--	--	--	--	--	--	BLEW TURBINE INLET HOSE.

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL U/S PR. PSIG	LOX SEAL D/S PR. PSIG	LOX SEAL U/S TEMP °F	LOX SEAL D/S TEMP °F	LOX SEAL LEAKAGE SCFM	HELIUM SEAL U/S PR. PSIG	HELIUM SEAL D/S PR. PSIG	HELIUM SEAL U/S TEMP °F	HELIUM SEAL D/S TEMP °F	HELIUM SEAL LEAKAGE SCFM LOX SIDE	HELIUM SEAL LEAKAGE SCFM TURB SIDE	HELIUM SEAL LEAKAGE SCFM TOTAL	REMARKS
11	150	P-I,SCH.II LOX TEST 2.5 HR.	7-11-75	PRETEST	0	106.5	1.65	-286	-292	14.4	--	--	--	--	--	--	--	TURBINE GN_2 DEPLETION.
				15	31800	136	11.0	-257	-282	52.0	35.6	3.0	108	92	2.0	3.8	5.8	
				30	31000	120	10.6	-257	-289	51.2	35.0	3.0	110	92	1.7	3.9	5.6	
				45	31720	115	10.7	-254	-282	51.1	31.6	3.0	110	92	2.9	2.2	5.1	
				60	31000	111.5	10.35	-257	-289	51.1	37.4	3.0	107	92	1.7	4.5	6.2	
				64.9	29600	110	10.0	-257	-283	51.2	39.2	10.0	107	92	.28	5.5	5.8	
				POSTTEST	0	67.5	2.3	-270	-289	19.7	--	--	--	--	--	--	--	
11	151	"	7-16-75	.53	30960	249	20.6	-242	-297	--	34.8	14.5	76	87	--	--	--	LOX SEAL PRESSURE HIGH.
11	152	"	"	PRETEST	0	92.5	1.5	-293	-298	23.4	--	--	--	--	--	--	--	DURATION. COMPLETED 2.5 HOURS OF TEST POINT 1. SCHEDULED SEAL INSPECTION. LOX SEAL IN GOOD CONDITION, NO WEAR. HELIUM SEAL WORN UNEVEN.
				15	32320	121	10.9	-265	-289	45.7	36	.75	84	77	10.4	1.32	11.7	
				30	32280	117.5	10.05	-265	-289	47.7	36.6	3.0	86	69	4.19	2.86	7.05	
				45	32360	114	10.05	-265	-289	47.1	38	.75	87	69	4.62	1.26	5.88	
				51	32200	113	9.85	-265	-289	46.5	35.4	5.0	90	69	4.08	3.53	7.60	
				POSTTEST	0	70.5	2.05	-285	-292	17.7	--	--	--	--	--	--	--	
12	153	"	8-4-75	PRETEST	0	104	1.2	-282	-290	47.0	--	--	--	--	--	--	--	OVERSPEED.
				2.2	32880	98	17.2	-250	-268	113.01	35.4	11.0	60	-102	4.8	4.6	9.4	
				POSTTEST	0	90	2.1	-275	-287	49.1	--	--	--	--	--	--	--	
12	154	"	"	PRETEST	0	142	3.5	-282	-282	63.5	--	--	--	--	--	--	--	OVERSPEED.
				.51	34120	122	16.9	-245	-272	105.6	35.4	25.0	50	-162	9.5	5.5	15.0	
				POSTTEST	0	130	3.0	-282	-282	58.8	--	--	--	--	--	--	--	
12	155	"	8-5-75	PRETEST	0	124	3.3	-292	-300	15.8	--	--	--	--	--	--	--	LOX DEPLETION.
				12.8	33600	90	32.5	-255	-277	67.8	34.6	18.7	10	-57	--	--	--	
				POSTTEST	0	--	--	--	--	--	--	--	--	--	--	--	--	
12	156	"	"	PRETEST	0	158.5	2.15	-283	-295	26.4	--	--	--	--	--	--	--	SPEED CONTROL.
				2.5	32680	114.5	37.9	-250	-275	117.4	36.8	11.25	-15	-112	0	1.02	1.02	
				POSTTEST	0	134	7.1	-277	-292	37.2	--	--	--	--	--	--	--	

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL U/S PR. PSIG	LOX SEAL D/S PR. PSIG	LOX SEAL U/S TEMP °F	LOX SEAL D/S TEMP °F	LOX SEAL LEAKAGE SCFM	HELIUM SEAL U/S PR. PSIG	HELIUM SEAL D/S PR. PSIG	HELIUM SEAL U/S TEMP °F	HELIUM SEAL D/S TEMP °F	HELIUM SEAL LEAKAGE SCFM LOX SIDE	HELIUM SEAL LEAKAGE SCFM TURB SIDE	HELIUM SEAL LEAKAGE SCFM TOTAL	REMARKS
12	157	P-I, SCH.II LOX TEST 2.5 HRS.	8-5-75	PRETEST	0	200	12	-280	-287	54.2	--	--	--	--	--	--	--	OVERSPEED.
				.45	33640	122.5	41.6	-249	-275	131.0	38.6	10.5	-14	-185	0	1.02	1.02	
				POSTTEST	0	185	8.15	-275	-292	44.5	--	--	--	--	--	--	--	
12	158	"	"	PRETEST	0	190.5	11.75	-277	-287	52.9	--	--	--	--	--	--	--	OVERSPEED.
				8.45	34240	96.5	36.65	-246	-269	111.1	36	9	7	-71	0	4.64	4.64	
				POSTTEST	0	178.5	10.5	-265	-282	48.4	--	--	--	--	--	--	--	
12	159	"	"	PRETEST	0	178	11.5	-290	-290	52.2	--	--	--	--	--	--	--	SUDDEN SPEED DROP. FAILED WATER SEAL IN DRIVE TURBINE. TESTER INSPECTED DUE TO HIGH LOX SEAL LEAKAGE. LOX SEAL IN GOOD CONDITION. HELIUM SEAL WORN UNEVEN. REINSTALLED SAME SEALS.
				11.2	31280	111.5	34.7	-250	-277	129.7	36	21	0	-96	0	4.75	4.75	
				POSTTEST	0	165	9.1	-269	-290	43.7	--	--	--	--	--	--	--	
13	160	"	8-28-75	0.05	--	--	--	--	--	--	--	--	--	--	--	--	--	NO SPEED READING.
	161	"	"	PRETEST	0	151	5.5	-295	-300	51.3	--	--	--	--	--	--	--	DURATION TEST. COMPLTETED 5 HOURS OF TEST POINT 1. SCHEDULED SEAL INSPECTION. LOX SEAL DAM SCORED WITH CONCENTRIC GROOVES. NO ADDITIONAL WEAR ON HELIUM SEAL. INSTALLED NEW LOX SEAL CARBON RING AND MATING RING, SAME HELIUM SEAL. INCREASED LOX SEAL SPRING LOAD.
				15	32520	174.5	20.35	-232	-282	124.7	34	21.5	102	-72	8.526	5.413	13.93	
				30	32120	165	19	-237	-287	115.9	35.2	20	100	-102	9.803	5.234	15.03	
				45	31920	164.5	18.45	-232	-282	113.6	36	21	100	-101	9.555	5.373	14.92	
				60	32000	163	18.55	-237	-287	114.4	40	22	97	-107	9.145	5.674	14.82	
				75	32000	160	17.9	-232	-282	112.0	35	22	102	-110	9.070	5.505	14.57	
				90	31960	158.5	18.4	-240	-287	109.9	32	18	100	-112	11.262	4.895	16.15	
				105	31720	156.5	17.6	-236	-290	107.8	34.8	19	100	-107	11.955	5.078	17.03	
				120	32000	157.5	16.5	-240	-291	104.7	36	19.5	98	-110	11.387	5.182	16.56	
				POSTTEST	0	90	6.1	-275	-297	58.1	--	--	--	--	--	--	--	
14	162	P-I, SCH.II LOX TEST 5 HRS. 250 PSIG	9-15-75	PRETEST	0	260	0.45	-287	-307	4.8	--	--	--	--	--	--	--	
				1.35	31600	306.5	21	-220	-295	77.5	36.6	22.75	90	-132	7.3	8.5	15.8	OVERSPEED CUT.
				POSTTEST	0	200	5.65	-282	-300	37.0	--	--	--	--	--	--	--	
14	163	"	"	PRETEST	0	191.5	5	-282	-232	33.8	--	--	--	--	--	--	--	
				7.05	32880	225	16.35	-227	-285	65.6	36.8	20	94	97	5.7	7.9	13.6	OVERSPEED CUT.
				POSTTEST	0	133	3	-277	-295	23.2	--	--	--	--	--	--	--	
14	164	"	"	PRETEST	0	231	9.3	-277	-282	52.7	--	--	--	--	--	--	--	
				5.95	32480	220	17	-227	-277	66.9	37.6	20	99	97	6.0	7.9	13.9	
				POSTTEST	0	175	5.3	-272	-280	50.0	--	--	--	--	--	--	--	OVERSPEED CUT.

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL					HELIUM SEAL							REMARKS
						U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM	U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM LOX SIDE	LEAKAGE SCFM TURB SIDE	LEAKAGE SCFM TOTAL	
14	165	P-I, SCH. II LOX TEST 5 HRS. 250 PSIG	9-15-75	PRETEST	0	214	4.5	-285	-292	33.1	5.4	5	97	-137	--	--	--	NO ACCEL. READING
				2.28	30960	166.5	17.15	-237	-290	49.6	36.8	21	96	-119	1.8	8.2	10.0	
				POSTTEST	0	235	18	-265	-300	7.8	1.2	6	98	-100	--	--	--	
14	166	"	"	--	--	--	--	--	--	--	--	--	--	--	--	--	--	NO SPEED TRACE.
14	167	"	"	PRETEST	0	--	--	--	--	--	--	--	--	--	--	--	--	DURING ACCELERATION LOX SEAL D/S PRESS OVER RED LINE
				0.01	17600	--	--	--	--	--	--	--	--	--	--	--	--	
				POSTTEST	0	--	--	--	--	--	--	--	--	--	--	--	--	
14	168	"	"	PRETEST	0	--	--	--	--	--	--	--	--	--	--	--	--	DURING ACCELERATION LOX SEAL D/S PRESS OVER REDLINE
				0.01	19400	--	--	--	--	--	--	--	--	--	--	--	--	
				POSTTEST	0	--	--	--	--	--	--	--	--	--	--	--	--	
14	169	"	"	PRETEST	0	298.5	21	-287	-277	249.8	20.4	20	101	-167	--	--	--	CUT TO RESET LOX SEAL CAVITY PRESSURE.
				1	22000	302	36.7	-242	-267	260.0	35.8	18	100	-190	--	2.97	2.97	
				POSTTEST	0	--	--	--	--	--	--	--	--	--	--	--	--	
14	170	"	"	PRETEST	0	240	20.6	-282	-275	246.2	20.4	19.25	100	-165	--	--	--	LOX SEAL CAVITY PRESSURE DECAYED STEADILY DURING TEST. OVERSPEED CUT.
				15	32120	215	22.4	-260	-280	129.1	36	13	100	-117	9.4	6.1	15.5	
				30	32000	170	16	-237	-280	107.5	36	15	102	-124	6.8	6.6	13.4	
				44.65	33600	149	16	-246	-285	105.6	35	11	100	-127	8.6	5.7	14.3	
				POSTTEST	0	70	8.7	-282	-285	97.9	8.6	9	100	-124	--	--	--	
14	171	"	"	PRETEST	0	254	7	-280	-295	78.1	6.6	6	100	-212	--	--	--	CUT WHEN SPEED COULD NOT BE INCREASED.
				.01	18880	222.5	39	-262	-272	>346.3*	39	38	100	-290	--	1.4	1.4	
				POSTTEST	0	215	24.7	-270	-280	273.2	34.6	25	100	-227	--	--	--	
14	172	"	"	PRETEST	0	276	32.6	-275	-281	330.6	30.8	30.25	102	-167	--	--	--	CUT WHEN SPEED COULD NOT BE INCREASED.
				.01	19520	271.5	48	-265	-270	>353.5*	49	43	102	-285	--	1.5	1.5	
				POSTTEST	0	267.5	32	-272	-280	319.1	29.4	30	102	-227	--	--	--	
14	173	"	"	PRETEST	0	268.5	33.7	-277	-281	324.8	32	31.25	101	-172	--	--	--	CUT WHEN SPEED COULD NOT BE INCREASED.
				.01	20300	272.5	48	-260	-270	>352.4*	47	44.25	101	-283	--	1.5	1.5	
				POSTTEST	0	267	29.4	-275	-277	302.0	26.4	30	102	-227	--	--	--	

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL					HELIUM SEAL							REMARKS
						U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM	U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM LOX SIDE	LEAKAGE SCFM TURB SIDE	LEAKAGE SCFM TOTAL	
14	174	P-I, SCH. II LOX TEST 5 HRS. 250 PSIG	9-17-75	PRETEST	0	251	33	-275	-280	320.1	31.2	31	102	-167	--	--	--	CUT WHEN SPEED COULD NOT BE INCREASED
				.01	20,240	256.6	42.7	-257	-281	351.2*	42	41	104	-283	--	1.5	1.5	
				POSTTEST	0	250	28.5	-267	-277	297.1	26	25	104	-250	--	--	--	
14	175	"	"	PRETEST	0	271.5	30	-280	-282	310.3	29	28	102	-120	--	--	--	CUT WHEN SPEED COULD NOT BE INCREASED
				.01	18,840	265	46	-270	-262	348.4*	49.4	44	102	-185	--	1.9	1.9	
				POSTTEST	0	262	33.5	-275	-280	322.9	31.2	27.8	102	-160	--	--	--	
14	176	"	"	PRETEST	0	156.6	28	-277	-280	290.8	27	25	104	-152	--	--	--	LOW SPEED. TESTER INSPECTED DUE TO SPEED PROBLEM. TESTER BRG. FAILED. LOX SEAL DAM WORN. PADS AND MATE IN GOOD CONDITION. NO ADD. WEAR ON He SEAL. INSTALLED NEW LOX CARBON & MATE, SAME He SEAL.
				.01	20,720	175	31.5	-265	-271	351.0*	36	36	102	-190	--	2.0	2.0	
				POSTTEST	0	155	24.5	-272	-277	275.5	22.4	20.8	102	-170	--	--	--	
15	177	"	10-20-75	PRETEST	0	246.6	1	-280	--	7.2	0	0.5	87	-152	--	--	--	LOW SPEED.
				.01	19,480	256.6	15.9	-270	--	119.6	12	13	89	-192	--	--	--	
				POSTTEST	0	245	3	-280	--	33.2	0.2	2	87	-180	--	--	--	
15	178	"	"	PRETEST	0	241.5	3.7	-280	--	42.0	0.8	2.5	87	-162	--	--	--	LOW SPEED.
				.01	19,600	258.5	25	-265	--	201.8	27	25	87	-195	3.8	9.3	13.1	
				POSTTEST	0	242.5	5	-280	--	51.6	32.6	21.5	87	-174	--	--	--	
15	179	"	"	PRETEST	0	240	3.9	-280	--	44.0	1.2	0.3	87	-157	--	--	--	LOW SPEED.
				.01	19,680	254.5	24.7	-265	--	201.9	30	26.5	87	-162	3.2	9.5	12.7	
				POSTTEST	0	244.5	4.7	-280	--	33.2	1.4	3	86	-147	--	--	--	
15	180	"	"	PRETEST	0	238.5	3	-281	--	27.7	0	1.5	90	-90	--	--	--	LOW SPEED.
				.01	19,080	230	15	-268	--	152.3	18.4	19	90	-127	--	4.8	4.8	
				POSTTEST	0	230	6.2	-280	--	64.0	2	4	90	-127	--	--	--	
15	181	"	"	PRETEST	0	231.5	5.9	-285	--	65.1	2	4	87	-150	--	--	--	LOW SPEED.
				.01	22,560	249	17	-284	--	122.3	32	15.5	86	-202	10.3	7.0	17.3	
				POSTTEST	0	230.5	7.7	-284	--	83.6	1	20.5	86	-185	--	--	--	
15	182	"	"	PRETEST	--	150	0.8	-284	--	39.1	0.4	2	84	-118	--	--	--	LOW SPEED.
				1.05	24,520	207.5	8.7	-284	--	81.2	30.8	13	84	-127	9.4	6.3	15.7	
				POSTTEST	--	162.5	6.5	-284	--	60.0	5	24	84	-118	--	--	--	

*ORIFICE ΔP PEGGED; LEAKAGE IS GREATER THAN NUMBER SHOWN

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL U/S PR. PSIG	LOX SEAL D/S PR. PSIG	LOX SEAL U/S TEMP °F	LOX SEAL D/S TEMP °F	LOX SEAL LEAKAGE SCFM	HELIUM SEAL U/S PR. PSIG	HELIUM SEAL D/S PR. PSIG	HELIUM SEAL U/S TEMP °F	HELIUM SEAL D/S TEMP °F	HELIUM SEAL LEAKAGE SCFM LOX SIDE	HELIUM SEAL LEAKAGE SCFM TURB SIDE	HELIUM SEAL LEAKAGE SCFM TOTAL	REMARKS
15	183	P-I, SCH. II	10-20-75	PRETEST	--	242.5	2	-282	--	63.9	2.6	4	85	-152	--	--	--	LOW SPEED.
				.01	19,640	235	21.9	-282	--	191.8	2.6	24.8	85	-199	2.6	8.5	11.1	
				POSTTEST	--	242.5	5	-282	--	70.4	2.8	4.5	85	-185	--	--	--	
15	184	"	"	PRETEST	--	296.5	5.7	-282	--	87.8	4.8	6.5	85	-157	--	--	--	LOW SPEED.
				.55	17,880	295	19	-282	--	169.4	34	16	85	-182	7.6	7.1	14.7	
				POSTTEST	--	300	8	-277	--	108.1	36	22	85	-167	--	--	--	
15	185	"	10-22-75	PRETEST	--	240	1.4	-279	-297	12.3	0	0	69	-227	--	--	--	LOW SPEED.
				.73	21,720	240	20	-260	-282	144.7	32	17	69	-202	10.5	7.4	17.9	
				POSTTEST	--	225	10	-275	-292	90.8	4.6	21.5	69	-180	--	--	--	
15	186	"	"	PRETEST	--	227	8.5	-275	-300	86.2	4	6	69	-147	--	--	--	LOW SPEED.
				9.5'	24,920	261.5	20.2	-252	-285	116.0	36	4	72	-86	13.1	3.0	16.1	
				POSTTEST	--	220	15	-265	-285	119.0	112.4	23	72	-91	--	--	--	
15	187	"	"	PRETEST	--	238.5	5.5	-280	-300	33.8	0	0.1	69	-162	--	--	--	RAN OUT OF LOX.
				15	26,400	248.5	13.4	-255	-290	89.9	33.6	8.5	72	-127	7.9	5.2	13.1	
				30	27,000	251.5	12.8	-257	-290	86.6	34	8	70	-127	7.8	5.0	12.8	
				32.65	27,200	249	12.4	-257	-292	86.1	34.6	8	70	-127	7.8	4.9	12.7	
				POSTTEST	--	190	2	-282	-296	19.6	0	8	70	-127	--	--	--	
15	188	"	"	PRETEST	--	245	1.8	-282	-285	17.5	0	0	72	-135	--	--	--	RAN OUT OF LOX.
				15	25,320	260	16.3	-282	-297	108.7	36	7	78	-122	8.2	4.7	12.9	
				20.15	25,040	257.5	16.3	-260	-292	109.3	36	6.8	75	-118	8.5	4.4	12.9	
				POSTTEST	--	201.5	9	-270	-297	81.2	0	18.5	75	-118	--	--	--	
15	189	"	"	PRETEST	--	238.5	0.6	-280	-291	15.7	0	0	75	-285	--	--	--	RAN OUT OF LOX.
				15	23,600	245	16.4	-255	-291	120.2	33.6	4	75	-147	7.7	3.5	11.2	
				26.8	22,480	162.5	7	-255	-291	74.2	14.4	3.25	75	-142	3.7	3.2	6.9	
				POSTTEST	--	40	0.7	-267	-295	15.5	2.4	2	75	-132	--	--	--	
15	190	"	"	PRETEST	--	244.9	0.2	-280	-297	13.1	0	0	72	-187	--	--	--	OVERSPEED.
				4.7	33,280	250	10.5	-250	-287	80.3	32.2	25	75	-132	11.8	2.7	14.5	
				POSTTEST	--	173.5	14	-265	-287	128.4	30	16	75	-137	--	--	--	

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL					HELIUM SEAL							REMARKS
						U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM	U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM LOX SIDE	LEAKAGE SCFM TURB SIDE	LEAKAGE SCFM TOTAL	
15	191	P-I,SCRII	10-22-75	PRETEST	--	173.5	12.7	-267	-284	113.3	30	17	75	-137	--	--	--	LOW SPEED
				0.01	21,400	180	23	-269	-284	166.4	31	16	75	-137	7.1	7.4	14.5	
				POSTTEST	--	170	9.7	-267	-281	99.8	8	10	75	-127	--	--	--	
15	192	"	"	PRETEST	--	248.5	7	-272	-286	90.5	5.2	11	75	-137	--	--	--	OVERSPEED.
				3.2	33,840	236	10	-255	-296	69.9	33	6.5	72	-142	11.8	2.7	14.5	
				POSTTEST	--	163.5	8	-269	-297	76.0	42.4	6	72	-137	--	--	--	
15	193	"	"	PRETEST	--	233.5	10.2	-277	-292	125.6	8	20.5	70	-137	--	--	--	OVERSPEED.
				13.4	32,400	150	9.6	-252	-291	72.8	34.6	11	73	-137	7.0	6.5	13.5	
				POSTTEST	--	180	2	-267	-300	48.8	27.4	19.5	73	-137	--	--	--	
15	194	"	"	PRETEST	--	230	0.1	-270	-292	13.2	0	0	72	-227	--	--	--	ACCELOMETER LEVEL.
				15.175	31,600	236.5	14.5	-255	-291	94.0	34	6	71	-147	9.0	4.2	13.2	WATER SEAL IN DRIVE TURBINE FAILED. ICE IN SEAL CAVITY.
				POSTTEST	--	50	13.5	-266	-287	79.6	12	5	0	-137	--	--	--	DRIED TESTER. SWITCHED FROM WATER TO AIR IN TURBINE PUMP.
15	195	"	11-5-75	PRETEST	0	249	5.9	-290	-301	77.4	3.4	3	77	-137	--	--	--	LOW TURBINE PRESSURE
				0.05	7,600	228.5	15	-290	-301	110.7	30	30	80	-147	--	6.7	6.7	
				POSTTEST	0	234	16.5	-290	-301	160.1	24	15	80	-171	--	--	--	
15	196	"	"	PRETEST	0	235	13	-285	-292	159.0	10.4	11.5	81	-159	--	--	--	LOW TURBINE PRESSURE
				0.10	12,520	233	24.7	-285	-292	280.4	30.6	30.7	84	-166	--	9.7	9.7	
				POSTTEST	0	227	14.7	-285	-292	172.6	24.6	16.25	81	-186	--	--	--	
15	197	"	"	PRETEST	0	226.5	13.4	-282	-292	162.9	10.4	11.65	83	-157	--	--	--	LOW TURBINE PRESSURE
				0.14	17,560	227.5	27	-277	-292	283.6	29.4	30	85	-157	--	7.5	7.5	
				POSTTEST	0	227	13.9	-281	-292	166.2	10.4	12	84	-177	--	--	--	
15	198	"	"	PRETEST	0	228	15.1	-281	-292	194.5	12	13.5	84	-162	--	--	--	LOW TURBINE PRESSURE
				0.14	18,280	226.6	29.2	-275	-292	306.6	32.4	33.65	85	-177	--	7.5	7.5	
				POSTTEST	0	216	14	-281	-292	160.3	10.4	11.65	83	-190	--	--	--	
15	199	"	"	PRETEST	0	218.5	15.9	-281	-290	198.0	12.6	14	84	-162	--	--	--	LOW TURBINE PRESSURE
				0.14	18,360	227	29.8	-274	-290	299.9	30	31.35	85	-162	--	7.0	7.0	
				POSTTEST	0	215	14.7	-281	-290	170.2	9.4	13.5	83	-187	--	--	--	
15	200	"	"	PRETEST	0	217	16.6	-281	-290	199.4	13.0	14.5	84	-160	--	--	--	LOW TURBINE PRESSURE
				0.2	21,640	225	32.2	-267	-290	314.8	29.4	29.35	85	-195	--	8.4	8.4	
				POSTTEST	0	223.5	14.1	-280	-290	161.2	20	14.85	84	-187	--	--	--	
15	201	"	"	PRETEST	0	224.5	16.8	-280	-287	198.0	13.6	14.75	84	-165	--	--	--	LOW SPEED
				0.41	22,440	216	32.3	-260	-292	282.6	29.4	31.65	84	-202	--	9.9	9.9	
				POSTTEST	0	216	13	-277	-292	205.4	10	11.75	82	-197	--	--	--	

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL					HELIUM SEAL							REMARKS
						U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM	U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM LOX SIDE	LEAKAGE SCFM TURB SIDE	LEAKAGE SCFM TOTAL	
15	202	P-1,8CH-II	11-5-75	PRETEST	0	53.5	6.8	-282	-301	85.3	4	5	79	-157	--	--	--	OVERSPEED
				0.19	36,400	80	22.2	-245	-301	206.2	30.8	29	79	-192	1.5	10.2	11.7	
				POSTTEST	0	53.5	4.8	-282	-310	97.5	26	13	77	-202	--	--	--	
15	203	"	"	PRETEST	0	130	12.2	-285	-298	158.9	9.0	9.75	77	-162	--	--	--	OVERSPEED
				0.29	35,600	175	27.5	-247	-295	248.1	30	30	79	-192	--	8.8	8.8	
				POSTTEST	0	48.5	3.7	-285	-301	40.2	2	13.5	77	-205	--	--	--	
15	204	"	"	PRETEST	0	148.5	14.7	-285	-297	178.8	11.4	12.35	78	-162	--	--	--	LOW SPEED
				1.65	24,520	205	18.7	-257	-297	142.0	29.8	5	77	-107	6.5	4.9	11.4	
				POSTTEST	0	148.5	14.1	-282	-297	131.5	10	.35	77	-105	--	--	--	
15	205	"	11-10-75	PRETEST	0	230	50	-280	-295	18.6	0	.1	91	-182	--	--	--	LOW SPEED
				0.4	22,160	220.5	65	-264	-275	222.5	30.4	27.5	90	-192	--	6.4	6.4	
				POSTTEST	0	206.5	68.7	-278	-278	185.3	13.0	13.5	90	-180	--	--	--	
15	206	"	"	PRETEST	0	253.5	61	-285	-287	151.0	8.6	9.7	83	-183	--	--	--	OVERSPEED
				1.25	33,880	182	67.8	-262	-295	83.1	33.6	3.2	81	-142	6.7	3.8	10.5	
				POSTTEST	0	96.5	59	-282	-285	159.9	11.6	9.5	81	-113	--	--	--	
15	207	"	"	PRETEST	0	143.5	66.7	-282	-283	217.3	14.6	15.7	81	--	--	--	--	
				1.33	33,840	195	60.4	-262	-285	113.0	26	3	81	--	5.0	2.9	7.9	OVERSPEED
				POSTTEST	0	110	65.3	-282	-282	181.8	13	14.6	81	--	--	--	--	
15	208	"	"	PRETEST	0	139.5	62.1	-280	-283	183.9	10	11	79	--	--	--	--	
				12.55	32,080	236	67.5	-242	-290	121.4	34.6	3.5	72	--	7.5	3.5	11.0	LOX DEPLETION
				POSTTEST	0	20	49.6	-280	-295	16.2	0	.3	72	--	--	--	--	
15	209	"	"	PRETEST	0	132.5	56.3	-285	-283	86.6	5	5.9	74	--	--	--	--	
				1.98	31,960	204	62	-280	-284	105.3	35.6	4.9	75	--	5.5	4.3	9.8	INSTRUMENTATION PROBLEM
				POSTTEST	0	121	67	-282	-280	197.1	14.4	17.4	75	--	--	--	--	
15	210	"	"	PRETEST	0	121	65.3	-282	-280	192.4	13.8	15	75	--	--	--	--	
				15.68	32,160	252	67.7	-240	-282	123.7	28.6	7.9	69	--	2.0	5.0	7.0	DURATION - COMPLETED 5 HRS. AT 250 PSIG
				POSTTEST	0	20.5	50	-283	-282	16.9	0	.2	69	--	--	--	--	
15	211	"	"	PRETEST	0	133.5	53.6	-282	-292	62.9	2	3	70	--	--	--	--	
				3.18	32,360	227.5	71	-267	-280	130.5	34	10	72	--	4.5	6.3	10.7	HIGH TURBINE PRESSURE
				POSTTEST	0	149	70	-287	-287	219.6	31.8	24.3	72	--	--	--	--	
15	212	"	"	PRETEST	0	146.5	67.3	-287	-287	220.7	15.8	16.7	73	--	--	--	--	
				16.7	27,320	315	82	-250	-287	240.7	34	5.7	65	--	2.5	4.5	6.9	LOX, GN_2 DEPLETION
				POSTTEST	0	18.5	50	-282	-287	17.7	0	.3	64	--	--	--	--	
15	213	"	11-12-75	PRETEST	0	133.5	.6	-282	-295	95.1	15	13.3	90	-132	--	--	--	1 INCH DIA. LOX DRAIN ORIFICE.
				0.05	NO TRACE	148	14.5	-272	-295	191.3	15	13.3	90	-147	2.4	4.3	6.6	NO SPEED TRACE.
				POSTTEST	0	112	12.7	-282	-282	170.0	12.2	13.5	90	-140	--	--	--	

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL					HELIUM SEAL							REMARKS
						U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM	U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM LOX SIDE	TURB SIDE	TOTAL	
15	214	P-I, SCH-II	11-12-75	PRETEST	0	113.5	12.9	-282	-282	216.3	32.8	7.5	90	-141	--	--	--	
				0.24	27,080	190	24.7	-250	-282	329.8	37.0	8.5	90	-155	2.9	5.2	8.1	ERRONEOUS ACCEL.
				POSTTEST	0	106.5	11.5	-282	-286	225.7	32	9.2	90	-137				
15	215	"	"	PRETEST	0	107.5	15.2	-282	-282	229.6	18	10.2	90	-132				
				0.33	27,800	190	25.3	-250	-282	322.5	30	7.7	90	-145	4.8	4.8	9.6	ERRONEOUS ACCEL.
				POSTTEST	0	106	15.8	-282	-282	203.7	16	5.0	87	-137				
15	216	"	"	PRETEST	0	125	16	-282	-282	225.9	16	6.9	87	-145	--	--	--	
				0.53	30,760	210	14.7	-240	-282	141.4	35.6	6.8	87	-145	7.7	4.8	12.5	ERRONEOUS ACCEL.
				POSTTEST	0	120	14.9	-280	-282	226.6	16	11.2	86	-95				
15	217	"	"	PRETEST	0	121	14.2	-292	-282	218.6	12.8	2.35	87	-122	--	--	--	
				1.6	28,000	256	23.4	-260	-287	200.8	32.8	9	85	-97	5.7	5.2	10.9	LOW TURBINE PRESSURE
				POSTTEST	0	198.5	21	-255	-282	245.1	17.4	18	85	-75	--	--	--	
15	218	"	"	PRETEST	0	210	20.6	-282	-282	259.9	17.4	18.85	85	-60	--	--	--	
				1.15	29,400	275	24	-247	-282	211.8	34	9.5	85	-107	6.7	5.3	12.0	LOW TURBINE PRESSURE
				POSTTEST	0	206	21.7	-282	-282	268.1	18	18.65	85	-76	--	--	--	
15	219	"	"	PRETEST	0	205	20.4	-282	-285	249.2	17.2	18.65	84	-35	--	--	--	
				0.45	39,760	330	25.4	-237	-282	232.8	30	13.6	84	-102	2.1	6.9	9.0	LOW TURBINE PRESSURE, CUT
				POSTTEST	0	268.5	21	-282	-282	252.7	16	13.75	90	-80	--	--	--	LOX PUMP BEFORE TURBINE.
15	220	"	"	PRETEST	0	198.5	14	-282	-282	218.2	16.8	.15	90	NO TRACE	--	--	--	
				3.2	32,400	350	29.7	-242	-275	245.5	35.4	13.3	89	NO TRACE	--	4.3	4.3	
				4.1	32,600	375	32.3	-237	-280	251.5	36.6	13.3	86	NO TRACE	4.2	6.5	10.7	
				7.5	33,720	404	32.3	-237	-282	259.0	35.4	13.15	81	NO TRACE	4.2	6.5	10.7	
				9.5	33,280	398.5	32.3	-237	-282	260.5	35.4	12.15	80	NO TRACE	4.3	6.3	10.6	LOX DEPLETION
				POSTTEST	0	118	21	-282	-282	92.4	18	3.5	80	NO TRACE	--	--	--	
15	221	"	"	PRETEST	0	211.5	8.2	-282	-285	134.1	16	2.5	90	-140	--	--	--	
				2.1	33,240	358	30.1	-235	-277	237.7	34	13.15	87	-85	4.4	6.4	10.9	LOX DEPLETION
				POSTTEST	0	230	27	-277	-277	330.5	28	9.5	87	-75	--	--	--	
15	222	"	"	PRETEST	0	263.5	15.3	-287	-282	222.7	11.4	13.35	85	-90	--	--	--	
				11.0	32,120	340	24.4	-235	-282	194.7	31	9.5	80	-30	5.0	5.5	10.5	FIRE AT SEALS.
				POSTTEST	0	1.5	.4	-235	-282	22.9	0	1	79	0	--	--	--	HOLE THRU HOUSING AT LOX SEAL DRAIN. THREE HOLES THRU HOUSING AT TURBINE SIDE DRAIN.

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL					HELIUM SEAL							REMARKS
						U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM	U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM LOX SIDE	LEAKAGE SCFM TURB SIDE	LEAKAGE SCFM TOTAL	
16	223	P-I, SCH. II	5-14-76	0.100	15160	207.5	28.8	-276	-287	139.6	55.4	24.4	105	-60	11.9	20.9	32.9	SPEED CHECKOUT
"	224	LOX TEST	"	0.175	27400	187.5	26,8	-246	-287	132.4	57.6	19.2	103	-54	27.1	18.0	45.1	BEARING PRES. REDLINE
"	225	0.5 HR.	"	0.175	33800	144.0	21.0	-240	-289	140.2	55.4	14.7	104	-30	28.9	16.2	45.1	BEARING PRES. REDLINE
"	226	250 PSIG	"	0.158	34080	145.0	24.6	-244	-290	136.0	54.0	14.8	104	-36	29.2	15.9	45.1	OVERSPEED
"	227	"	"	0.183	33720	170.0	23.9	-239	-287	131.4	53.6	15.8	105	-21	28.9	16.2	45.1	OVERSPEED
"	228	"	"	0.408	31520	259.5	13.8	-228	-286	74.4	52.0	10.6	105	-33	32.4	12.6	45.1	BEARING PRES. REDLINE
"	229	"	"	0.716	32440	278.0	14.2	-224	-285	75.2	51.8	10.7	104	-42	32.8	12.3	45.1	BEARING PRES. REDLINE
"	230	"	"	2.30	31960	245.5	12.5	-230	-293	66.9	51.6	10.2	100	-45	33.3	12.0	45.3	SPEED SWITCH CUTOFF
"	231	"	"	6.44	35480	246.0	12.8	-227	-290	63.4	51.8	10.3	103	-33	33.4	12.0	45.4	OPERATOR CUTOFF
"	232	"	"	17.83	31720	240.0	12.5	-227	-290	60.3	51.8	10.9	98	-	33.0	12.8	45.8	OPERATOR CUTOFF TESTER INSPECTED DUE TO JERKY TURNING TORQUE. HELIUM SEAL LOX SIDE RING RUBBED THRU CHROME. CARBON WORN EXCESSIVELY. LOX SEAL IN EXCELLENT CONDITION. INSTALLED NEW HELIM SEAL & MATE WITH INCREASED CLEARANCE (.007 INCH) REINSTALLED SAME LOX SEAL.
17	233	PI SCH II LOX TEST	6-30-76	0.150	6320	190.5	11.0	-281	-293	85.3	48.6	13.7	103	-6	30.1	14.3	44.4	NO SPEED TRACE
"	234	.25 HOUR 300 PSIG	"	0.325	34160	299.5	26.9	-220	-284	94.6	53.2	27.4	102	-13	21.2	23.0	44.2	OVERSPEED CUTOFF
"	235		"	2.10	31120	307.5	13.0	-220	-287	78.1	50.0	16.9	102	-28	27.9	16.5	44.3	G-LEVEL CUT, SINGLE SPIKE
"	236	"	"	1.00	36800	330.0	13.3	-220	-290	83.3	49.6	20.8	101	-20	27.0	16.4	43.4	OVERSPEED CUTOFF
"	237	"	"	9.50	29240	305.0	13.0	-224	-293	77.2	49.2	16.3	98	-45	27.0	16.7	43.7	ERRONEOUS UNDERSPEED CUTOFF
"	238	"	"	3.40	31960	309.0	13.0	-221	-293	75.6	50.0	17.3	99	-56	26.5	17.1	43.6	DURATION, COMPLETED TEST POINT #4
"	239	.25 HOUR 350 PSIG	"	15.02	31120	354.5	13.5	-217	-292	83.4	50.0	18.4	96	-83	24.4	19.1	43.5	DURATION, TEST POINT #5 SCHEDULED SEAL INSPECTION. LOX & HELIUM SEALS IN EXCELLENT CONDITION. REINSTALLED SAME SEALS.

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL U/S PR. PSIG	LOX SEAL D/S PR. PSIG	LOX SEAL U/S TEMP °F	LOX SEAL D/S TEMP °F	LOX SEAL LEAKAGE SCFM	HELIUM SEAL U/S PR. PSIG	HELIUM SEAL D/S PR. PSIG	HELIUM SEAL U/S TEMP °F	HELIUM SEAL D/S TEMP °F	HELIUM SEAL LEAKAGE SCFM LOX SIDE	HELIUM SEAL LEAKAGE SCFM TURB SIDE	HELIUM SEAL LEAKAGE SCFM TOTAL	REMARKS
18	240	PI SCH II LOX TEST	7-21-76	.25	20600	-	-	-	-	-	-	-	-	-	-	-	-	LOW SPEED
"	241	4 HOURS 400 PSIG	"	.40	27000	-	-	-	-	-	-	-	-	-	-	-	-	LOW SPEED
"	242	"	"	5.0	32680	405.0	15.0	-217	-292	99.9	50.4	22.4	94	- 95	24.8	21.3	46.1	OPERATOR CUTOFF
"	243	"	"	15.0	31960	382.0	12.0	-221	-296	92.8	49.6	21.1	98	-114	25.3	20.5	45.8	RECORDER PROBLEMS
"	244	"	"	15.0	32680	385.0	15.2	-224	-296	95.0	50.2	21.6	98	-113	25.2	20.6	45.8	
"	"	"	"	30.0	32080	386.5	15.2	-224	-293	96.8	50.4	21.2	100	-117	25.6	20.1	45.7	
"	"	"	"	45.0	31320	392.0	15.1	-227	-296	97.0	51.2	20.6	97	-131	26.3	19.7	46.0	
"	"	"	"	50.0	31120	364.5	16.6	-227	-294	98.2	50.0	20.6	97	-127	26.3	19.7	46.0	LOW GN_2 PRES. VISICORDER STOPPED.
"	245	"	"	15.0	31920	390.0	15.0	-227	-293	98.3	51.4	20.9	96	-120	26.0	20.3	46.3	
"	"	"	"	30.0	32200	391.0	15.2	-228	-296	97.3	51.4	21.4	93	-129	25.7	20.7	46.6	
"	"	"	"	35.3	30480	377.5	19.0	-237	0294	104.6	51.4	19.7	93	-109	27.1	19.5	46.6	LOW GN_2 PRES. NO VISICORDER
"	246	"	7-28-76	.1	17280	-	-	-	-	-	-	-	-	-	-	-	-	ERRONEOUS ACCEL REDLINE
"	247	"	"	.1	11240	-	-	-	-	-	-	-	-	-	-	-	-	ERRONEOUS ACCEL REDLINE
"	248	"	"	16.0	32800	385.0	15.5	-224	-289	88.7	50.2	21.0	99	-106	27.6	17.4	45.0	OPERATOR CUTOFF
"	249	"	"	.65	34440	434.0	14.1	-219	-293	91.6	47.4	13.4	98	- 90	29.7	13.9	43.7	OVERSPEED
"	250	"	"	.83	34360	417.5	13.9	-220	-293	86.3	47.0	12.7	98	- 95	30.2	13.4	43.7	OVERSPEED
"	251	"	"	3.05	31520	414.0	14.6	-220	-292	86.9	50.4	13.9	98	- 96	33.1	14.7	47.7	LOW SPEED
"	252	"	"	5.8	32280	384.0	14.8	-227	-285	97.4	47.4	19.5	100	- 96	25.0	18.4	43.3	INSTRUMENTATION PROBLEM
"	253	"	7-28-76	15.0	31720	376.0	17.0	-230	-285	97.8	53.4	20.1	98	- 91	28.6	19.4	48.0	
"	"	"	"	30.0	32440	362.0	19.4	-240	-293	105.9	50.0	19.8	92	- 83	23.4	19.4	42.8	OPER CUT PAPER LOW
"	254	"	8-2-76	15.0	32080	378.0	21.5	-250	-287	122.5	51.6	22.0	94	- 67	24.4	19.8	44.3	
"	"	"	"	20.0	30400	367.5	22.5	-252	-286	115.6	51.0	20.8	96	- 65	29.8	18.9	48.7	LOW GN_2 PRES.
"	255	"	"	4.9	31680	411.0	17.5	-220	-289	83.6	50.0	12.5	95	- 90	32.6	12.2	44.8	LOW SPEED
"	256	"	"	3.7	32080	398.5	13.9	-220	-293	80.9	50.0	12.4	91	- 87	32.7	12.1	44.7	LOW SPEED
"	257	"	"	7.0	32280	409.5	13.8	-215	-287	82.1	49.8	12.0	93	-101	32.0	12.4	44.4	LOW SPEED

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL U/S PR. PSIG	LOX SEAL D/S PR. PSIG	LOX SEAL U/S TEMP °F	LOX SEAL D/S TEMP °F	LOX SEAL LEAKAGE SCFM	HELIUM SEAL U/S PR. PSIG	HELIUM SEAL D/S PR. PSIG	HELIUM SEAL U/S TEMP °F	HELIUM SEAL D/S TEMP °F	HELIUM SEAL LEAKAGE SCFM LOX SIDE	HELIUM SEAL LEAKAGE SCFM TURB SIDE	HELIUM SEAL LEAKAGE SCFM TOTAL	REMARKS
18	258	PI SCH II LOX TEST 4 HOURS 400 PSIG	8-2-76	6.6	32120	412.0	14.8	-214	-287	82.6	49.6	11.8	90	- 98	30.9	12.6	43.5	LOW SPEED
"	259	"	"	.1	21600	400.5	12.3	-281	-286	99.9	45.8	8.5	91	-137	33.0	10.5	43.5	ACCEL REDLINE. LEVEL INCREASED WITH SPEED TO 10.5 GPP. REMOVED TESTER FOR INSPECTION. TESTER THRUST BEARING FAILED. SEALS IN GOOD CONDITION.
19	260	"	9-2-76	2.67	32800	385.5	21.8	-235	-285	115.4	51.6	16.5	102	- 58	26.8	19.0	45.9	ERRONEOUS CUT
"	261	"	"	1.90	33800	412.5	16.6	-280	-281	105.6	51.6	16.5	104	- 49	27.1	18.9	46.0	OVERSPEED
"	262	"	"	15.0	31360	382.5	17.8	-229	-287	99.5	50.0	17.2	100	- 51	27.6	17.2	44.8	
"	"	"	"	30.0	31960	385.0	18.9	-225	-280	102.2	50.2	17.5	102	- 56	27.0	17.7	44.7	
"	"	"	"	45.35	33600	393.5	17.7	-223	-284	97.2	49.6	16.8	97	- 61	27.8	17.2	45.0	OVERSPEED
"	263	"	"	15.0	33200	391.5	18.2	-221	-284	98.4	48.4	16.7	97	- 60	27.3	17.3	44.6	
"	"	"	"	30.0	32680	384.5	18.0	-227	-287	96.2	49.6	16.6	95	- 60	27.4	17.4	44.8	
"	"	"	"	45.0	33080	381.5	16.6	-223	-285	94.9	48.8	16.6	96	- 59	27.6	17.4	45.0	
"	"	"	"	60.0	31880	370.0	13.7	-230	-287	92.5	48.8	16.2	94	- 74	28.0	17.1	45.1	
"	"	"	"	67.02	29400	339.5	17.5	-230	-289	92.2	48.8	16.0	92	- 82	26.5	18.6	45.1	LOW GN_2 PRESSURE
"	264	"	9-3-76	3.35	31920	385.5	19.3	-230	-282	111.7	52.0	17.9	97	- 78	30.1	16.9	47.0	OVERSPEED
"	265	"	"	1.00	32240	372.5	17.7	-229	-283	96.1	51.4	13.1	97	- 95	33.6	13.5	47.0	OVERSPEED
"	266	"	"	0.5	31960	373.0	15.0	-229	-282	88.2	52.4	11.4	98	- 96	34.2	12.8	47.0	OVERSPEED
"	267	"	"	0.65	32000	394.0	15.0	-234	-287	98.6	52.2	11.2	97	- 96	35.4	11.7	47.2	OVERSPEED
"	268	"	"	4.05	31800	382.0	20.0	-230	-287	99.9	51.6	13.4	101	- 82	33.7	13.6	47.3	OVERSPEED
"	269	"	"	1.55	31960	401.0	20.0	-228	-284	105.5	50.8	11.0	105	- 85	36.0	11.5	47.4	OVERSPEED
"	270	"	"	1.20	31240	370.0	18.8	-229	-281	95.8	50.0	11.5	106	- 67	36.0	11.6	47.6	OVERSPEED
"	271	"	"	7.50	32080	384.0	19.8	-232	-285	108.2	50.2	12.4	102	- 90	31.7	13.1	44.9	ACCEL REDLINE. G-LEVEL INCREASED TO 11.5 GPP. TESTER REMOVED FOR INSPECTION. TESTER THRUST BEARING FAILED. SEALS IN GOOD CONDITION.

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL					HELIUM SEAL							REMARKS
						U/S PR. PSIG	D/S PR. PSIG	U/S TEMP F	D/S TEMP F	LEAKAGE SCFM	U/S PR. PSIG	D/S PR. PSIG	U/S TEMP F	D/S TEMP F	LEAKAGE SCFM LOX SIDE	LEAKAGE SCFM TURB SIDE	LEAKAGE SCFM TOTAL	
20	272	PI SCH II	10-6-76	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	NO SPEED TRACE
"	273	LOX TEST 400 PSI	"	0.4	33520	404.5	20.0	-228	-240	117.4	49.6	18.2	102	-53	20.2	22.0	42.3	OVERSPEED
"	274	"	"	0.6	30400	398.5	19.3	-224	-286	117.9	48.2	17.6	106	-42	17.2	24.4	41.6	OVERSPEED
"	275	"	"	0.63	30400	405.0	20.5	-228	-290	117.1	49.0	18.8	102	-67	16.7	25.1	41.8	OVERSPEED
"	276	"	"	0.7	30560	395.0	20.0	-227	-290	113.7	52.0	18.3	103	-60	19.4	25.1	44.5	OVERSPEED
"	277	"	"	1.78	30480	361.0	20.1	-227	-261	118.0	52.8	18.8	106	-44	18.9	25.9	44.8	OVERSPEED
"	278	"	"	4.15	30000	364.5	20.0	-234	-261	114.8	49.6	18.6	101	-56	15.5	26.5	42.0	OVERSPEED
"	279	"	"	3.55	29320	377.0	20.0	-225	-250	115.1	52.4	18.9	102	-44	18.4	26.5	44.9	OVERSPEED
"	280	"	"	1.68	29360	376.5	21.1	-226	-250	117.7	53.4	19.2	103	-52	17.3	27.6	45.0	OVERSPEED
"	281	"	"	6.05	28480	382.0	21.3	-224	-250	121.9	51.8	20.1	103	-41	15.8	27.9	43.7	OVERSPEED
"	282	"	"	5.35	28960	381.5	21.5	-229	-250	116.3	51.6	19.6	98	-90	15.7	28.1	43.8	OVERSPEED
"	283	"	"	0.2	28800	-	-	-	-	-	-	-	-	-	-	-	-	ACCELEROMETER
"	284	"	"	4.53	29640	373.5	20.2	-225	-196	108.7	51.4	18.4	100	-80	17.2	27.1	44.2	OVERSPEED
"	285	"	"	17.5	28720	378.0	20.9	-227	-281	119.0	50.2	19.5	99	-90	14.6	28.0	42.6	OVERSPEED
"	286	"	"	2.68	29200	377.0	21.0	-226	-280	117.6	50.0	18.9	99	-90	14.7	27.8	42.6	OVERSPEED
"	287	"	"	0.3	29080	-	-	-	-	-	-	-	-	-	-	-	-	ACCELEROMETER REDLINE
"	288	"	"	12.38	29200	359.0	20.0	-228	-285	11.2	50.0	18.5	96	-95	15.6	27.1	42.7	OVERSPEED
"	289	"	"	15.0	28480	382.0	21.0	-230	-281	117.5	50.6	19.4	91	-96	14.5	28.3	42.8	
"	"	"	"	30.0	28200	383.0	21.0	-228	-281	117.4	49.8	19.6	91	-96	14.1	28.3	42.4	
"	"	"	"	35.0	28200	385.0	20.6	-227	-281	116.5	49.8	19.5	91	-96	14.1	28.5	42.5	OPERATOR SHUTDOWN
"	290	"	10-7-76	5.97	28800	375.5	21.3	-226	-285	122.2	50.0	20.5	101	-73	21.1	20.8	41.9	OVERSPEED
"	291	"	"	15.5	28360	389.0	22.3	-228	-286	125.0	50.2	21.5	102	-87	20.2	21.7	41.9	OPERATOR SHUTDOWN
"	292	"	"	2.78	28400	385.0	20.0	-227	-287	125.4	51.0	17.4	105	-73	19.3	23.5	42.8	ACCELEROMETER REDLINE
"	293	"	"	15.0	28160	387.5	20.0	-228	-293	126.1	50.0	18.7	106	-78	16.9	25.8	42.7	
"	"	"	"	30.0	27840	387.5	20.9	-224	-285	128.8	50.4	19.4	107	-78	16.0	26.7	42.7	
"	"	"	"	40.7	28240	387.0	20.8	-224	-285	127.1	50.4	19.1	107	-78	16.4	26.3	42.7	ERRONEOUS ACCELEROMETER

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL U/S PR. PSIG	LOX SEAL D/S PR. PSIG	LOX SEAL U/S TEMP °F	LOX SEAL D/S TEMP °F	LOX SEAL LEAKAGE SCFM	HELIUM SEAL U/S PR. PSIG	HELIUM SEAL D/S PR. PSIG	HELIUM SEAL U/S TEMP °F	HELIUM SEAL D/S TEMP °F	HELIUM SEAL LEAKAGE SCFM LOX SIDE	HELIUM SEAL LEAKAGE SCFM TURB SIDE	HELIUM SEAL LEAKAGE SCFM TOTAL	REMARKS
20	294	PI SCH II	10-7-76	15.0	28360	385.0	19.9	-226	-287	124.2	50.2	18.7	105	-82	16.9	25.9	42.9	
"	"	LOX TEST 400 PSI	"	30.0	28320	385.0	19.8	-223	-283	123.8	50.4	18.6	107	-79	16.9	25.9	42.8	
"	"	"	"	33.3	27520	399.0	20.0	-228	-290	128.4	50.4	19.2	104	-82	16.8	26.2	43.0	LOW GN_2 SHUTDOWN
"	295	"	"	9.0	28280	380.0	20.7	-227	-289	123.6	54.4	18.9	104	-80	19.7	26.7	46.4	DURATION. COMPLETED REQUIRED 10 HOUR FOR PHASE I SCH II TESTING. SEALS IN GOOD CONDITION.
21	296	PHASE III	11-5-76	6.15	31760	384.0	16.6	-237	-290	115.2	48.4	28.2	107	-52	15.6	26.1	41.7	DURATION
"	297	LOX TEST 400 PSI	"	1.10	31880	390.0	20.6	-234	-	126.3	52.4	21.5	113	-31	17.6	26.3	43.9	ACCELEROMETER REDLINE
"	298	ACCELER-ATION	"	1.65	31920	387.5	19.8	-236	-	110.4	52.2	21.1	110	-46	17.5	26.7	44.2	ACCELEROMETER REDLINE
"	299	TESTS "	"	6.15	31000	390.0	20.4	-234	-	121.0	48.0	19.8	107	-53	14.1	26.9	41.0	DURATION
"	300	"	"	6.15	30800	385.0	20.8	-234	-	121.5	47.6	20.0	107	-78	13.7	27.4	41.1	ACCELEROMETER REDLINE
"	301	"	"	1.85	30920	387.0	20.5	-240	-	126.9	49.8	19.4	107	-73	16.0	26.5	42.5	ACCELEROMETER REDLINE
"	302	"	"	0.10	37400	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED
"	303	"	"	7.00	31960	386.5	18.7	-226	-285	112.3	47.8	17.1	103	-82	17.8	25.7	43.5	DURATION
"	304	"	"	6.15	32040	389.0	18.3	-224	-284	111.3	46.6	17.3	102	-85	17.4	26.0	43.4	DURATION
"	305	"	"	6.25	31640	389.0	20.0	-224	-289	113.0	50.4	18.4	97	-86	20.7	27.2	47.9	DURATION
"	306	"	"	4.00	32120	389.5	18.5	-227	-287	106.9	50.8	17.4	96	-83	22.3	26.3	48.6	ACCELEROMETER REDLINE
"	307	"	"	6.05	31600	395.0	18.8	-225	-285	112.3	48.0	18.0	95	-90	18.7	27.1	45.8	DURATION
"	308	"	"	6.05	31480	395.5	20.2	-224	-284	115.0	48.0	18.3	95	-91	18.4	27.4	45.8	DURATION
"	309	"	"	3.05	32000	395.0	18.8	-228	-293	109.2	47.8	17.3	90	-95	19.5	26.6	46.1	ACCELEROMETER REDLINE
"	310	"	11-8-76	0.60	31200	388.5	20.5	-242	-290	115.8	48.8	17.8	96	-30	22.3	23.5	45.8	ACCELEROMETER REDLINE
"	311	"	"	6.15	30600	395.0	21.0	-235	-290	113.7	49.8	18.5	93	-94	22.9	25.3	48.1	DURATION
"	312	"	"	5.80	30400	404.0	20.0	-232	-287	115.8	47.2	18.3	95	-100	19.0	26.1	45.2	ACCELEROMETER REDLINE
"	313	"	"	0.15	30720	-	-	-	-	-	-	-	-	-	-	-	-	ACCELEROMETER REDLINE
"	314	"	"	6.10	30320	385.0	20.7	-234	-285	114.2	48.0	18.2	104	-93	19.7	25.0	44.7	DURATION
"	315	"	"	6.10	30040	390.0	20.0	-239	-293	116.4	52.0	18.7	98	-97	23.5	26.3	49.8	DURATION

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL					HELIUM SEAL							REMARKS
						U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM	U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM			
															LOX SIDE	TURB SIDE	TOTAL	
21	316	PHASE III 400 PSI	11-8-76	6.10	30120	395.0	20.4	-236	-292	116.5	48.0	18.0	99	-98	19.5	26.2	45.6	DURATION
"	317	LOX ACCELER-	"	6.10	30200	397.5	21.0	-232	-283	116.2	47.0	17.8	99	-86	19.8	24.4	44.3	DURATION
"	318	ACTION TESTS	"	1.15	30400	395.0	20.5	-241	-286	117.5	47.6	17.5	97	-58	19.9	24.0	43.9	ACCELEROMETER REDLINE
"	319	"	"	0.70	30320	391.0	20.5	-239	-285	115.4	49.0	17.6	97	-52	20.1	24.1	44.2	ACCELEROMETER REDLINE
"	320	"	"	6.20	29200	394.5	21.0	-240	-290	121.5	51.4	18.4	91	-91	22.2	24.1	46.3	DURATION
"	321	"	"	6.15	29440	395.0	21.0	-237	-287	121.9	48.4	18.7	91	-101	17.7	26.6	44.3	DURATION
"	322	"	"	0.50	29800	394.0	23.0	-240	-286	118.0	49.8	18.7	91	-61	17.9	26.4	44.3	ACCELEROMETER REDLINE
"	323	"	"	0.15	26720	-	-	-	-	-	-	-	-	-	-	-	-	ACCELEROMETER REDLINE
"	324	"	"	6.25	29520	394.0	21.0	-236	-285	121.1	48.6	18.3	89	-96	19.0	25.8	44.9	DURATION
"	325	"	"	1.00	28800	392.5	21.0	-244	-290	124.3	49.6	18.3	86	-80	18.5	26.5	45.0	ACCELEROMETER REDLINE
"	326	"	"	5.25	31240	393.5	19.5	-236	-290	113.0	46.0	17.2	86	-100	18.5	25.2	43.7	ACCELEROMETER REDLINE
"	327	"	"	0.20	30640	-	-	-	-	-	-	-	-	-	-	-	-	ACCELEROMETER REDLINE
"	328	"	"	1.65	29400	392.0	22.0	-240	-286	124.0	51.8	18.2	86	-87	20.9	26.8	47.6	ACCELEROMETER REDLINE
"	329	"	"	0.28	27600	-	-	-	-	-	-	-	-	-	-	-	-	ACCELEROMETER REDLINE
"	330	"	"	0.28	26920	-	-	-	-	-	-	-	-	-	-	-	-	LOW SPEED REDLINE
"	331	"	"	0.45	27200	-	-	-	-	-	-	-	-	-	-	-	-	ACCELEROMETER REDLINE
"	332	"	"	0.35	27600	-	-	-	-	-	-	-	-	-	-	-	-	ACCELEROMETER REDLINE
"	333	"	"	0.75	26800	390.0	20.5	-256	-293	118.8	50.0	15.5	82	-89	22.4	23.6	46.0	ACCELEROMETER REDLINE
"	334	"	11-10-76	2.10	31040	403.0	21.0	-246	-	119.7	49.8	17.6	82	-74	23.4	23.1	46.5	INSTRUMENTATION SHUTDOWN
"	335	"	"	4.15	32000	405.0	20.0	-235	-283	109.9	49.0	17.0	87	-88	23.9	22.8	46.7	OVERSPEED
"	336	"	"	2.25	30720	393.5	20.7	-248	-287	114.4	49.6	17.3	86	-85	23.3	23.1	46.3	LOW SPEED REDLINE
"	337	"	"	0.15	36280	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED
"	338	"	"	1.55	31920	390.0	19.8	-244	-287	107.1	50.6	17.0	87	-67	25.2	22.7	47.9	FACILITY SHUTDOWN
"	339	"	"	10.2	30080	397.5	19.9	-241	-286	112.7	48.4	18.4	83	-100	21.3	24.6	46.0	DURATION
"	340	"	"	0.1	8600	-	-	-	-	-	-	-	-	-	-	-	-	LOW SPEED SHUTDOWN
"	341	"	"	10.1	31320	397.0	16.4	-237	-290	99.9	48.4	16.5	79	-101	23.6	23.7	47.3	DURATION

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL U/S PR. PSIG	LOX SEAL D/S PR. PSIG	LOX SEAL U/S TEMP °F	LOX SEAL D/S TEMP °F	LOX SEAL LEAKAGE SCFM	HELIUM SEAL U/S PR. PSIG	HELIUM SEAL D/S PR. PSIG	HELIUM SEAL U/S TEMP °F	HELIUM SEAL D/S TEMP °F	HELIUM SEAL LEAKAGE SCFM LOX SIDE	HELIUM SEAL LEAKAGE SCFM TURB SIDE	HELIUM SEAL LEAKAGE SCFM TOTAL	REMARKS
21	342	PHASE III	11-10-76	15.2	31600	396.5	18.3	-237	-290	100.3	48.8	16.1	77	-107	22.5	25.5	48.0	DURATION
"	343	400 PSI LOX	"	10.2	31440	395.5	18.3	-236	-286	104.1	49.6	17.0	78	-107	22.5	25.4	47.9	DURATION
"	344	ACCELER-ATION TESTS	"	15.15	31920	395.0	16.5	-231	-285	96.0	49.0	15.4	75	-106	22.5	25.7	48.2	DURATION
"	345	"	"	13.5	31720	394.0	16.5	-237	-290	97.3	48.2	15.6	71	-109	22.5	25.7	48.2	OVERSPEED
"	346	"	"	13.3	31560	391.0	17.0	-239	-293	101.6	51.8	16.2	66	-107	20.8	26.5	47.3	OVERSPEED
"	347	"	"	8.5	30800	390.5	18.2	-237	-285	107.7	48.4	17.4	68	-104	20.6	27.1	47.6	LOW SPEED REDLINE. TESTER REMOVED FOR INSPECTION DUE TO HIGH VIBRATION AND NOISE. LOX SIDE HELIUM SEAL RING WORE GROOVE IN MATING RING. LOX SEAL IN GOOD CONDITION.
22	348	PHASE III	12-20-76	0.95	30680	369.5	14.4	-237	-284	102.7	50.0	16.7	86	-38	24.5	23.8	48.2	OVERSPEED
"	349	400 PSI LOX	"	0.15	34760	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED
"	350	ACCELER-ATION	"	0.15	17480	-	-	-	-	-	-	-	-	-	-	-	-	BEARING PRESSURE REDLINE
"	351	"	"	6.33	31360	396.5	18.0	-234	-286	104.9	47.6	17.0	82	-70	19.9	25.4	45.3	DURATION
"	352	"	"	6.20	31480	396.0	18.8	-232	-283	107.3	48.4	17.2	83	-78	20.3	25.5	45.8	DURATION
"	353	"	"	6.18	31000	396.0	17.7	-229	-281	105.5	48.0	16.4	84	-87	19.8	25.8	45.6	DURATION
"	354	"	"	6.20	31600	395.0	17.0	-233	-286	102.9	47.6	15.8	82	-87	19.2	26.2	45.4	DURATION
"	355	"	"	0.30	31320	-	-	-	-	-	-	-	-	-	-	-	-	ACCELEROMETER REDLINE
"	356	"	"	0.15	27960	-	-	-	-	-	-	-	-	-	-	-	-	ACCELEROMETER REDLINE
"	357	"	"	0.55	29120	398.5	19.7	-252	-280	114.2	52.2	15.6	82	-46	28.2	21.6	49.8	ACCELEROMETER REDLINE
"	358	"	"	0.08	5440	-	-	-	-	-	-	-	-	-	-	-	-	FACILITY CUTOFF
"	359	"	"	6.35	31760	391.0	18.2	-230	-283	105.1	48.6	16.4	78	-92	19.8	26.4	46.2	DURATION
"	360	"	"	0.08	7600	-	-	-	-	-	-	-	-	-	-	-	-	FACILITY CUTOFF
"	361	"	"	6.25	32400	390.0	16.1	-228	-283	97.1	48.0	15.4	76	-92	18.2	27.0	45.1	DURATION
"	362	"	"	6.28	31920	395.0	18.0	-234	-286	100.7	48.6	15.6	72	-96	18.3	27.5	45.8	DURATION
"	363	"	"	6.15	31920	390.5	15.5	-228	-285	95.1	47.4	14.4	72	-100	17.5	26.9	44.4	DURATION
"	364	"	"	0.75	32400	390.0	16.0	-229	-285	93.2	47.8	14.9	72	-87	19.3	27.1	46.4	OVERSPEED
"	365	"	"	6.20	31480	389.5	16.0	-228	-283	97.6	48.6	15.1	72	-98	18.4	27.6	46.1	DURATION
"	366	"	"	5.88	31680	389.5	16.0	-227	-281	94.6	47.2	14.5	71	-100	17.7	27.1	44.8	OVERSPEED
"	367	"	12-21-76	5.05	32120	378.5	15.4	-228	-286	93.1	50.4	16.9	83	-64	24.1	22.8	46.9	OVERSPEED

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL					HELIUM SEAL							REMARKS
						U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM	U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM			
															LOX SIDE	TURB SIDE	TOTAL	
22	368	ACCELERATION TESTS PHASE III 400 PSI LOX	12-21-76	6.25	31680	381.0	14.8	-227	-285	93.1	46.0	15.5	83	-70	20.3	22.7	43.0	DURATION
"	369		"	6.15	31600	386.0	16.1	-231	-293	93.5	49.6	15.4	80	-75	21.8	24.1	45.9	DURATION
"	370		"	6.15	31600	380.5	15.2	-230	-290	91.5	49.0	15.3	81	-78	21.8	24.1	45.9	DURATION
"	371	"	"	0.68	32320	380.0	14.8	-230	-290	92.0	49.6	15.2	81	-65	21.7	24.2	45.9	OVERSPEED
"	372	"	"	6.13	31680	380.0	15.5	-228	-287	91.9	49.6	15.3	82	-77	21.8	24.0	45.8	DURATION
"	373	"	"	1.88	32400	380.5	15.2	-227	-287	90.1	49.8	15.2	83	-74	21.6	24.2	45.8	OVERSPEED
"	374	"	"	6.10	31320	381.5	15.3	-233	-293	95.9	48.4	13.7	81	-80	23.9	22.0	45.9	DURATION
"	375	"	"	4.95	31600	381.5	15.3	-230	-292	91.1	49.4	15.3	82	-78	22.8	23.1	46.0	OVERSPEED
"	376	"	"	6.15	31360	382.5	15.3	-229	-289	91.8	49.4	15.4	82	-77	22.7	23.3	46.0	DURATION
"	377	"	"	6.15	31280	381.5	15.7	-227	-286	93.8	49.6	15.6	83	-78	22.2	23.8	46.0	DURATION
"	378	"	"	3.83	31600	380.5	15.0	-230	-289	91.0	47.6	16.0	85	-72	22.8	21.5	44.2	OVERSPEED
"	379	"	"	1.70	31320	379.5	14.7	-228	-287	90.4	47.6	15.8	86	-74	23.3	21.0	44.3	OVERSPEED
"	380	"	"	3.50	31200	379.5	14.5	-228	-287	92.8	49.4	16.3	86	-74	23.4	22.3	45.7	OVERSPEED
"	381	"	"	6.15	30800	379.5	14.6	-227	-285	90.9	49.8	16.1	86	-74	23.3	22.6	45.9	DURATION
"	382	"	"	6.05	31240	380.0	15.7	-232	-293	90.0	49.8	16.2	82	-80	22.8	23.2	46.0	OVERSPEED
"	383	"	"	4.30	31360	379.0	14.7	-230	-292	90.2	49.8	15.9	82	-82	23.5	22.4	46.0	OVERSPEED
"	384	"	"	10.20	31040	380.5	15.8	-228	-287	91.2	49.6	16.0	83	-82	22.5	23.4	45.8	DURATION
"	385	"	"	10.15	30800	379.0	15.8	-227	-285	91.7	52.2	16.1	84	-78	23.4	24.3	47.7	DURATION
"	386	"	"	9.30	30840	379.0	15.2	-231	-293	92.0	49.0	15.8	81	-84	21.6	23.6	45.2	OVERSPEED
"	387	"	"	4.78	31160	376.0	15.2	-228	-286	91.0	48.4	15.8	78	-76	20.6	24.0	44.6	OVERSPEED
"	388	"	"	7.50	31520	396.5	12.5	-212	-286	76.9	46.6	13.7	77	-84	20.1	23.5	43.6	OVERSPEED
"	389	"	"	4.65	32000	397.5	12.3	-217	-296	75.6	47.8	13.6	73	-88	20.3	24.1	44.4	OVERSPEED
"	390	"	"	1.53	31120	375.5	15.0	-231	-293	91.0	49.6	15.2	73	-83	20.1	25.7	45.8	OVERSPEED
"	391	"	"	4.70	30680	374.0	15.7	-232	-290	93.3	50.2	15.7	73	-85	20.6	25.7	46.3	OVERSPEED
"	392	"	"	0.45	33400	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED
"	393	"	"	0.80	30880	377.5	15.7	-228	-289	93.3	50.2	15.3	73	-80	20.7	25.7	46.5	OVERSPEED
"	394	"	"	4.80	30240	379.0	15.7	-227	-287	91.6	50.2	15.4	73	-83	21.3	25.7	47.1	OVERSPEED
"	395	"	"	3.50	31040	376.5	15.9	-227	-285	92.7	50.0	15.4	74	-82	20.8	25.6	46.4	OVERSPEED
"	396	"	"	0.60	30800	390.0	13.0	-208	-285	87.5	49.8	15.0	74	-76	20.9	25.4	46.3	OVERSPEED
"	397	"	"	0.85	30800	385.0	15.9	-224	-285	92.8	49.8	14.9	74	-75	20.7	25.6	46.3	OVERSPEED
"	398	"	"	5.60	30400	383.5	15.5	-229	-293	94.7	50.0	15.3	69	-87	20.5	26.0	46.5	OVERSPEED
"	399	"	"	3.90	31560	373.5	16.0	-232	-293	93.4	50.6	15.5	69	-87	21.0	26.0	46.9	OVERSPEED

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL					HELIUM SEAL							REMARKS
						U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM	U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM LOX SIDE	LEAKAGE SCFM TURB SIDE	LEAKAGE SCFM TOTAL	
22	399	ACCELERA-TION TESTS	12-21-76	3.90	31560	373.5	16.0	-232	-293	93.4	50.6	15.5	69	-87	21.0	26.0	46.9	OVERSPEED
"	400	PHASE III 400 PSI	"	6.50	31600	375.0	14.8	-229	-290	92.5	50.2	15.1	69	-90	20.1	26.1	46.2	OVERSPEED
"	401	LOX	"	8.25	31080	384.0	15.7	-228	-287	95.7	48.6	15.3	69	-95	19.1	26.1	45.2	OVERSPEED
"	402	"	12-22-76	0.18	33720	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED
"	403	"	"	0.18	33720	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED
"	404	"	"	4.33	31200	395.0	12.7	-212	-287	72.5	48.4	13.9	74	-73	25.6	20.6	46.2	LOW SPEED REDLINE
"	405	"	"	3.45	30840	371.0	14.8	-2 7	-285	91.9	49.6	15.6	74	-75	23.3	22.8	46.1	OVERSPEED
"	406	"	"	2.38	30800	370.0	15.5	-230	-292	90.9	49.4	15.1	73	-81	23.1	23.0	46.1	OVERSPEED
"	407	"	"	7.85	31080	369.5	15.3	-230	-293	9018	49.6	15.0	74	-84	21.7	24.4	46.2	OVERSPEED
"	408	"	"	10.18	30920	368.0	15.3	-228	-287	91.2	49.6	15.0	77	-83	20.8	25.2	46.0	DURATION
"	409	"	"	2.73	30880	366.5	15.3	-227	-286	91.8	49.8	15.0	78	-80	20.8	25.2	46.0	OVERSPEED
"	410	"	"	2.25	31400	366.5	14.5	-227	-286	87.8	50.0	14.7	78	-80	21.4	24.9	463	OVERSPEED
"	411	"	"	3.45	30800	366.0	15.5	-234	-293	92.0	50.0	14.9	76	-85	21.4	25.0	46.4	OVERSPEED
"	412	"	"	4.60	30800	368.0	14.3	-230	-293	88.4	49.6	14.8	77	-85	21.7	24.8	46.5	OVERSPEED
"	413	"	"	7.15	30680	368.0	14.8	-228	-290	91.7	50.0	14.9	79	-83	21.4	25.1	46.5	OVERSPEED
"	414	"	"	7.60	31920	386.0	12.4	-215	-290	72.4	49.4	13.4	81	-82	22.9	23.5	46.5	LOW SPEED REDLINE
"	415	"	"	9.00	30760	364.0	15.5	-224	-285	91.2	50.0	16.2	84	-78	23.8	22.5	46.3	OVERSPEED
"	416	"	"	5.70	31080	364.0	14.1	-228	-293	85.7	50.2	15.6	82	-82	23.6	22.9	46.5	OVERSPEED
"	417	"	"	8.20	31320	382.5	12.6	-215	-293	69.1	50.2	14.3	82	-79	25.2	21.6	46.8	DURATION. TESTER REMOVED FOR SCHEDULED IN-SPECTION AFTER ADDITIONAL 5 HOURS (9 HOURS TOTAL). SEALS IN GOOD CONDITION.
23	418	"	2-15-77	1.52	30600	355.0	25.0	-234	-280	129.1	49.6	17.3	95	-72	15.2	28.6	43.8	ACCELEROMETER CUTOFF
"	419	"	"	0.03	33600	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED
"	420	"	"	2.68	30400	354.0	17.7	-277	-286	93.8	50.2	22.4	90	-47	23.5	23.8	47.3	ACCELEROMETER CUTOFF
"	421	"	2-16-77	0.17	27920	-	-	-	-	-	-	-	-	-	-	-	-	NO ACCELEROMETER INDICATION
"	422	"	"	3.12	31200	394.0	18.7	-236	-285	100.6	49.4	18.1	93	-41	22.1	23.9	46.0	OPERATOR CUTOFF

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL U/S PR. PSIG	LOX SEAL D/S PR. PSIG	LOX SEAL U/S TEMP °F	LOX SEAL D/S TEMP °F	LOX SEAL LEAKAGE SCFM	HELIUM SEAL U/S PR. PSIG	HELIUM SEAL D/S PR. PSIG	HELIUM SEAL U/S TEMP °F	HELIUM SEAL D/S TEMP °F	HELIUM SEAL LEAKAGE SCFM LOX SIDE	HELIUM SEAL LEAKAGE SCFM TURB SIDE	HELIUM SEAL LEAKAGE SCFM TOTAL	REMARKS
23	423	ACCELERA-TION TEST: PHASE III 400 PSI LOX	2-16-77	0.10	34960	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED
"	424		"	1.30	31480	390.0	18.7	-235	-292	101.9	47.2	17.7	94	-33	19.6	23.9	43.5	ACCELEROMETER CUTOFF
"	425		"	4.52	30800	394.0	18.7	-231	-283	103.8	48.4	17.6	94	-30	20.7	24.3	45.0	ACCELEROMETER CUTOFF
"	426	"	"	3.13	30960	390.5	19.5	-234	-280	106.7	48.0	18.0	95	-28	19.7	24.7	44.5	ACCELEROMETER CUTOFF
"	427	"	"	0.05	36720	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED
"	428	"	"	2.12	31200	391.5	19.2	-238	-287	106.6	48.0	17.2	92	-43	20.0	24.8	44.7	ACCELEROMETER CUTOFF
"	429	"	"	6.08	31720	392.5	17.3	-230	-292	95.4	49.6	16.4	94	-50	22.3	24.0	46.3	DURATION
"	430	"	"	6.08	31680	391.0	18.0	-234	-287	105.1	48.6	20.4	95	-53	22.2	21.4	43.6	DURATION
"	431	"	"	6.00	31680	388.5	17.8	-231	-287	103.0	46.6	19.2	95	-61	20.6	21.0	41.6	DURATION
"	432	"	"	6.08	31720	391.0	17.8	-229	-286	101.8	50.0	20.1	95	-65	23.1	21.7	44.8	DURATION
"	433	"	"	0.02	21120	-	-	-	-	-	-	-	-	-	-	-	-	OPERATOR CUTOFF
"	434	"	"	6.07	31720	382.5	17.7	-228	-284	100.7	49.6	19.9	95	-73	22.3	21.8	44.0	DURATION
"	435	"	"	6.02	31640	387.5	18.3	-2[illegible]7	-282	109.0	42.6	19.4	96	-78	20.1	21.3	41.4	DURATION
"	436	"	"	0.82	31200	388.5	21.2	-227	-292	111.6	50.8	21.2	102	-71	28.6	22.5	51.1	ACCELEROMETER CUTOFF
"	437	"	"	6.02	31[illegible]00	376.5	18.1	-234	-287	102.8	48.4	19.5	106	-82	21.0	21.7	42.6	DURATION
"	438	"	"	6.05	31600	388.5	18.7	-230	-286	103.1	51.4	20.6	106	-78	23.2	22.3	45.6	DURATION
"	439	"	"	6.00	31480	390.0	21.2	-234	-286	108.7	50.0	22.2	102	-89	19.9	23.2	43.1	DURATION
"	440	"	"	6.03	31600	388.5	20.7	-234	-287	111.7	50.4	21.2	95	-91	20.2	23.1	43.3	DURATION
"	441	"	"	6.02	31600	385.0	20.3	-233	-286	112.1	50.0	20.7	95	-87	19.4	23.1	42.5	DURATION
"	442	"	"	6.02	31680	380.0	19.9	-232	-285	109.7	48.6	19.9	95	-88	19.1	22.7	41.8	DURATION
"	443	"	"	10.03	31600	390.0	20.7	-228	-283	111.5	50.8	20.6	95	-96	20.6	23.3	44.0	DURATION
"	444	"	"	0.05	34080	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED
"	445	"	"	10.03	31520	390.5	20.8	-232	-286	108.9	51.6	20.5	90	-97	20.9	23.8	44.7	DURATION
"	446	"	"	0.07	34040	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL					HELIUM SEAL							REMARKS
						U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM	U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM LOX SIDE	LEAKAGE SCFM TURB SIDE	LEAKAGE SCFM TOTAL	
23	447	ACCELERA- TION TESTS	2-16-77	10.03	31480	390.0	20.8	-229	-285	109.8	51.6	20.5	90	-92	20.7	24.0	44.7	DURATION
"	448	PHASE III 400 PSI	"	0.05	34480	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED
"	449	LOX	"	6.00	31600	388.5	22.0	-228	-281	114.1	52.0	21.0	90	-91	20.3	24.4	44.7	DURATION
"	450	"	"	10.03	31480	390.0	21.8	-227	-281	112.2	51.4	18.9	78	-104	21.0	24.0	45.0	DURATION
"	451	"	"	10.03	30800	384.5	22.8	-236	-287	117.1	50.2	19.4	74	-109	19.5	24.5	44.0	DURATION
"	452	"	"	10.00	31560	388.5	21.4	-230	-285	111.1	49.6	18.5	74	-109	19.9	24.3	44.2	DURATION
"	453	"	"	4.22	31520	385.0	22.2	-237	-284	114.6	47.8	17.0	72	-108	19.4	22.8	42.2	LOW SPEED CUTOFF
"	454	"	2-17-77	6.03	31520	384.0	19.4	-230	-290	106.2	50.8	20.0	96	-72	24.6	22.0	46.6	DURATION
"	455	"	"	6.02	31400	385.0	19.2	-228	-287	105.1	50.8	19.4	99	-76	24.2	22.1	46.3	DURATION
"	456	"	"	6.03	31080	384.0	20.2	-227	-286	108.0	50.6	19.5	102	-76	23.9	22.2	46.1	DURATION
"	457	"	"	6.03	31000	385.0	19.9	-234	-293	106.8	50.8	18.9	100	-82	23.9	22.2	46.1	DURATION
"	458	"	"	6.03	31240	386.0	19.7	-230	-293	105.2	49.6	18.0	102	-83	23.8	22.1	45.9	DURATION
"	459	"	"	6.03	30840	382.0	20.3	-230	-289	108.7	50.6	18.9	103	-83	22.9	22.8	45.7	DURATION
"	460	"	"	6.03	30520	380.0	20.3	-229	-287	108.8	50.8	18.3	106	-84	23.3	22.2	45.5	DURATION
"	461	"	"	2.05	30560	379.0	20.5	-237	-287	106.2	48.0	15.2	106	-70	26.4	18.0	44.4	OPERATOR CUTOFF
"	462	"	"	2.27	30800	381.5	20.7	-237	-289	111.3	48.4	15.6	105	-63	27.3	17.8	45.1	ACCELEROMETER CUTOFF
"	463	"	"	3.08	31120	376.5	20.1	-232	-285	107.4	50.6	17.1	102	-66	26.8	18.9	45.7	OPERATOR CUTOFF
"	464	"	"	6.03	30200	376.0	20.5	-236	-292	108.2	51.0	17.3	98	-74	26.6	19.6	46.1	DURATION
"	465	"	"	6.02	30080	376.5	21.1	-234	-289	110.9	51.4	17.7	99	-76	25.8	20.4	46.2	DURATION
"	466	"	"	10.03	30120	377.5	21.3	-231	-286	111.7	52.0	18.7	99	-78	24.6	21.7	46.3	DURATION
"	467	"	"	6.02	30000	385.0	21.0	-229	-282	109.6	50.0	15.2	95	-82	26.2	19.0	45.2	DURATION
"	468	"	"	3.80	29520	385.0	21.8	-237	-290	114.6	50.0	17.0	91	-87	24.5	20.9	45.4	ACCELEROMETER CUTOFF
"	469	"	2-28-77	0.57	31080	392.5	23.9	-236	-280	116.5	56.2	19.1	94	-8	28.0	21.4	49.4	ERRONEOUS LOW SPEED CUTOFF
"	470	"	"	6.10	30960	398.5	21.4	-234	-290	111.2	51.4	19.1	91	-70	24.7	22.2	46.9	DURATION
"	471	"	"	6.08	31040	397.5	21.8	-230	-286	111.7	50.6	18.1	91	-70	24.7	22.3	47.0	DURATION
"	472	"	"	6.03	32360	401.5	18.0	-220	-285	96.8	50.4	15.5	93	-73	25.2	21.8	47.0	DURATION

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL					HELIUM SEAL							REMARKS
						U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM	U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM			
															LOX SIDE	TURB SIDE	TOTAL	
23	473	ACCELERATION TESTS PHASE III 400 PSI LOX	2-28-77	6.03	31720	403.5	17.5	-224	-290	93.3	50.0	15.7	92	-79	26.4	20.8	47.2	DURATION
"	474		"	5.82	31120	398.5	21.2	-230	-299	106.8	51.2	17.9	92	-80	24.7	22.5	47.3	ERRONEOUS CUTOFF
"	475		"	6.03	31680	400.0	18.8	-224	-284	98.8	50.6	17.3	96	-74	26.3	21.1	47.4	DURATION
"	476	"	"	6.05	32280	402.5	17.3	-224	-290	92.4	49.4	16.0	92	-80	25.9	20.7	46.7	DURATION
"	477	"	"	6.03	32480	402.5	17.1	-221	-290	90.3	48.0	15.5	93	-82	25.8	20.7	46.6	DURATION
"	478	"	"	6.07	31680	401.0	17.6	-224	-287	93.4	49.6	15.4	95	-78	25.9	20.7	46.6	DURATION
"	479	"	"	0.22	27480	-	-	-	-	-	-	-	-	-	-	-	-	LOW TURBINE PRESSURE
"	480	"	"	6.05	31440	397.5	18.5	-224	-285	96.8	49.8	17.0	95	-76	27.2	20.1	47.3	DURATION
"	481	"	"	6.08	31920	399.5	17.7	-220	-283	93.2	50.0	16.5	97	-74	26.9	20.1	47.0	DURATION
"	482	"	"	6.03	31800	400.0	17.8	-223	-285	93.6	50.0	16.4	94	-74	26.8	20.4	47.2	DURATION
"	483	"	"	6.05	31800	400.0	18.0	-224	-289	93.8	50.0	16.5	91	-78	2[illegible].6	20.6	47.2	DURATION
"	484	"	"	6.07	31880	397.5	17.8	-222	-285	93.4	50.2	15.8	90	-70	27.2	20.2	47.4	DURATION
"	485	"	"	6.05	31800	400.0	17.4	-220	-284	92.1	50.4	16.0	90	-73	26.7	20.9	47.7	DURATION
"	486	"	"	6.10	31760	400.0	17.6	-224	-290	92.4	50.6	16.1	87	-76	26.6	21.2	47.8	DURATION
"	487	"	"	6.03	31960	397.0	17.0	-227	-290	90.5	48.6	15.0	82	-80	25.9	20.3	46.2	DURATION
"	488	"	"	6.05	31840	398.0	17.7	-224	-287	93.8	49.2	14.8	83	-80	24.8	21.3	46.2	DURATION
"	489	"	"	6.02	31840	396.5	17.7	-224	-287	93.0	49.0	14.6	83	-80	25.3	21.0	46.3	DURATION
"	490	"	"	7.13	31960	397.0	17.0	-220	-285	91.2	49.4	14.4	84	-80	25.2	21.1	46.3	DURATION, TESTER REMOVED FOR SCHEDULED INSPECTION AFTER ADDITIONAL 6.11 HOURS (15.28 HOURS TOTAL).

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY, PHASE IV

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL U/S PR. PSIG	LOX SEAL D/S PR. PSIG	LOX SEAL U/S TEMP F	LOX SEAL D/S TEMP F	LOX SEAL LEAKAGE SCFM	HELIUM SEAL U/S PR. PSIG	HELIUM SEAL D/S PR. PSIG	HELIUM SEAL U/S TEMP F	HELIUM SEAL D/S TEMP F	HELIUM SEAL LEAKAGE SCFM LOX SIDE	HELIUM SEAL LEAKAGE SCFM TURB SIDE	HELIUM SEAL LEAKAGE SCFM TOTAL	REMARKS
1	1	PHASE IV RAYLEIGH STEP LOX SEAL, 6 SEG HE SEAL CHECKOUT TEST	6-12-78	.2	-	-	-	-	-	-	-	-	-	-	-	-	-	NO SPEED TRACE
"	2		"	2.8	30360	140	9	-283	-289	-	35.6	0.1	60	-	-	-	-	OVERSPEED CUTOFF
"	3		"	0.9	29760	150	34	-277	-284	-	33.4	12.6	58	-	-	-	-	LOX ORIFICE OVER PRESSURE
"	4		"	2.8	29800	135	18	-281	-284	90.2	36.6	.4	59	-	-	-	-	LOW SPEED CUTOFF
"	5	"	"	15	29760	120	21	-281	-282	91.4	33.6	.5	62	-	1.87	0.90	2.77	DURATION, TEST POINT 1
"	6	"	"	10	29440	263	18	-282	-285	101.1	37.0	1.0	63	-	2.29	1.33	3.62	DURATION, TEST POINT 2
"	7	"	"	10	30000	325	20	-280	-283	100.7	91.2	1.6	60	-	11.07	1.67	12.74	DURATION, TEST POINT 3
"	8	"	"	.6	32000	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED CUTOFF
"	9	"	"	.03	32000	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED CUTOFF
"	10	"	"	10	30080	365	22	-277	-283	110.8	75.6	1.8	62	-	10.77	1.66	12.43	DURATION, TEST POINT 4 COMPLETED CHECKOUT TESTING. REMOVED TESTER FOR INSPECTION. SEALS IN EXCELLENT CONDITION.
2	11	PHASE IV CRYOGENIC ACCELER-ATION RAYLEIGH STEP LOX SEAL, 6 SEG HE SEAL	7-6-78	.03	-	-	-	-	-	-	-	-	-	-	-	-	-	CUT IN ERROR AT START.
"	12		"	6.0	30080	365	22.5	-277	-286	116.5	96.0	.6	70	-	3.28	1.15	4.43	DURATION
"	13		"	.13	-	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED CUTOFF
"	14		"	3.7	30400	370	22.5	-277	-285	117.9	87.6	.4	70	-	3.81	0.90	4.72	OVERSPEED CUTOFF
"	15		"	.13	-	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED CUTOFF
"	16	"	"	.77	30040	375	25.0	-277	-285	130.9	101.0	.6	69	-	5.30	1.14	6.44	LOW SPEED CUTOFF
"	17	"	"	.17	-	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED CUTOFF
"	18	"	"	.11	-	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED CUTOFF
"	19	"	"	6	29880	400	24.5	-277	-285	123.0	89.6	1.8	67	-	4.09	2.13	6.23	DURATION
"	20	"	"	.41	7000	415	5.5	-286	-293	52.0	93.6	.8	69	-	1.35	1.34	2.70	LOW SPEED CUTOFF
"	21	"	"	.15	-	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED CUTOFF
"	22	"	"	6.0	29880	387.5	23.0	-278	-283	117.6	81.6	.2	68	-	5.05	0.61	5.66	DURATION
"	23	"	"	6.0	30000	382.5	23.0	-277	-283	116.1	91.2	.2	69	-	5.08	0.61	5.68	DURATION
"	24	"	"	.11	-	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED CUTOFF

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY, PHASE IV

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL					HELIUM SEAL							REMARKS
						U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM	U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM			
															LOX SIDE	TURB SIDE	TOTAL	
2	25	PHASE IV CRYOGENIC	7-6-78	.28	-	-	-	-	-	-	-	-	-	-	-	-	-	LOW SPEED CUTOFF
"	26	ACCELER-ATION	"	.13	-	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED CUTOFF
"	27	RAYLEIGH STEP LOX	"	.15	-	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED CUTOFF
"	28	SEAL, 6 SEG	"	.11	-	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED CUTOFF
"	29	HE SEAL	"	6.0	30000	395.0	24.0	-277	-280	121.4	31.0	2.0	74	-	1.38	2.26	3.64	DURATION. HE SEAL PR REDUCED FROM 85 PSIG TO 35 PSIG.
"	30	"	"	6.0	30080	395.0	22.5	-277	-281	114.2	34.0	1.8	75	-	0.66	2.12	2.78	DURATION
"	31	"	"	6.0	29960	395.0	23.0	-277	-281	113.7	38.0	2.0	75	-	1.62	2.26	3.88	DURATION
"	32	"	7-19-78	6.0	30280	365.0	22.5	-277	-286	124.2	32.0	7.1	69	-	-	-	-	DURATION
"	33	"	"	6.0	30040	380.0	23.0	-276	-286	123.4	47.0	2.7	69	-	1.65	1.52	3.17	DURATION
"	34	"	"	6.0	30040	375.0	22.5	-277	-287	119.6	32.4	2.4	66	-	2.59	1.52	4.11	DURATION
"	35	"	"	6.0	30000	375.0	23.5	-277	-287	119.8	33.6	2.15	67	-	2.92	0.90	3.82	DURATION
"	36	"	"	6.0	30080	375.0	22.5	-277	-287	116.1	33.8	2.0	67	-	3.00	0.60	3.60	DURATION
"	37	"	"	6.0	30040	375.0	23.0	-276	-289	111.8	30.0	1.7	67	-	2.65	0.60	3.25	DURATION
"	38	"	"	6.0	29960	375.0	18.5	-276	-289	109.9	31.0	2.1	66	-	2.68	0.60	3.28	DURATION
"	39	"	"	6.0	30080	372.5	22.0	-277	-287	113.6	36.8	2.4	67	-	2.50	1.03	3.54	DURATION
"	40	"	"	6.0	30000	370.0	21.5	-277	-287	112.1	33.4	2.5	66	-	2.78	1.03	3.81	DURATION
"	41	"	"	6.0	30080	370.0	21.5	-278	-287	113.1	36.4	2.6	66	-	2.72	1.12	3.83	DURATION
"	42	"	"	1.3	30120	365.0	21.5	-278	-287	113.3	31.4	3.0	66	-	2.30	1.50	3.80	OVERSPEED CUTOFF
"	43	"	"	6.0	30080	380.0	22.0	-277	-287	113.1	31.8	2.7	66	-	2.67	1.32	3.99	DURATION
"	44	"	"	6.0	30040	380.0	22.5	-277	-287	113.7	31.6	2.5	66	-	2.76	1.32	4.08	DURATION
"	45	"	"	6.0	30080	377.5	22.5	-277	-287	111.2	35.0	3.1	66	-	3.23	1.66	4.89	DURATION
"	46	"	"	6.0	30040	375.0	22.0	-277	-287	111.7	39.0	2.6	66	-	3.08	1.31	4.40	DURATION
"	47	"	"	6.0	29960	375.0	22.5	-277	-287	111.8	38.8	2.6	66	-	2.91	1.12	4.02	DURATION
"	48	"	"	6.0	30080	375.0	21.5	-277	-289	109.6	39.8	2.95	67	-	2.91	1.49	4.41	DURATION
"	49	"	7-20-78	7.3	28600	300.0	22.0	-266	-287	124.3	37.8	1.35	66	-	2.91	1.15	4.06	DURATION

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY, PHASE IV

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL					HELIUM SEAL							REMARKS
						U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM	U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM			
															LOX SIDE	TURB SIDE	TOTAL	
2	50	PHASE IV CRYOGENIC	7-20-78	1.4	30000	317.5	24.0	-268	-286	127.2	35.1	2.4	65	-	1.66	2.16	3.82	OVERSPEED CUTOFF
"	51	ACCELER-ATION	"	.1	-	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED CUTOFF
"	52	RAYLEIGH STEP LOX SEAL,	"	.55	29760	320.0	24.0	-264	-286	135.2	33.8	3.25	65	-	0.98	2.53	3.52	P3 REDLINE CUTOFF - VALVE FAILED
"	53	6 SEG HE SEAL	"	.13	-	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED CUTOFF
"	54	"	"	6.0	30040	370.0	27.0	-259	-285	134.6	37.2	3.9	65	-	1.84	2.50	4.34	DURATION
"	55	"	"	6.0	29800	365.0	26.5	-261	-285	132.2	35.5	3.1	65	-	1.86	1.98	3.84	DURATION
"	56	"	"	6.0	29760	370.0	26.0	-261	-285	126.6	36.8	2.85	65	-	2.53	1.68	4.21	DURATION
"	57	"	"	6.0	29960	370.0	26.0	-259	-285	124.4	34.1	2.75	67	-	2.29	1.67	3.96	DURATION
"	58	"	"	6.0	30000	365.0	25.5	-259	-285	123.3	35.3	2.7	67	-	2.61	1.50	4.12	DURATION
"	59	"	"	6.0	30120	365.0	25.5	-259	-286	122.2	36.8	2.65	66	-	2.85	1.50	4.35	DURATION
"	60	"	7-25-78	6.0	29760	410.0	25.5	-277	-285	127.5	31.8	2.3	78	-	3.17	1.14	4.31	DURATION
"	61	"	"	6.0	29880	410.0	25.5	-277	-285	126.7	35.2	3.45	79	-	2.28	1.69	4.31	DURATION
"	62	"	"	6.0	29880	395.0	26.0	-277	-285	127.1	35.8	3.4	77	-	2.48	1.68	4.16	DURATION
"	63	"	"	6.0	29920	402.5	24.5	-277	-285	120.8	34.2	2.8	75	-	2.85	1.13	3.98	DURATION
"	64	"	"	6.0	29920	402.5	24.5	-277	-285	120.4	35.9	2.1	75	-	3.66	0.60	4.26	DURATION
"	65	"	"	6.0	29720	402.5	24.5	-277	-285	122.3	33.8	2.1	73	-	1.84	2.36	4.20	DURATION
"	66	"	"	6.0	29880	402.5	24.5	-277	-285	120.4	32.8	2.5	74	-	1.93	2.11	4.04	DURATION
"	67	"	"	6.0	30200	402.5	24.5	-277	-287	117.8	33.3	2.55	73	-	2.33	2.11	4.44	DURATION
"	68	"	"	6.0	29920	400.0	24.5	-277	-287	118.2	34.0	2.5	70	-	2.47	2.11	4.58	DURATION
"	69	"	"	6.0	30280	400.0	24.5	-277	-286	118.0	29.7	2.5	71	-	2.00	2.10	4.11	DURATION
"	70	"	"	6.0	29800	400.0	24.5	-276	-286	117.1	31.9	2.85	70	-	2.97	2.36	5.33	DURATION
"	71	"	"	6.0	29880	407.5	25.0	-277	-285	122.6	35.8	3.55	69	-	3.05	2.93	5.98	DURATION
"	72	"	"	6.2	29600	395.0	24.5	-277	-286	119.5	33.4	3.05	66	-	2.81	2.72	5.53	DURATION
"	73	"	"	6.0	30200	395.0	24.5	-277	-285	119.0	35.1	3.05	66	-	2.92	2.60	5.52	DURATION

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY, PHASE IV

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL					HELIUM SEAL							REMARKS
						U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM	U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM LOX SIDE	LEAKAGE SCFM TURB SIDE	LEAKAGE SCFM TOTAL	
2	74	PHASE IV CRYOGENIC	7-25-78	6.0	29760	395.0	24.0	-276	-287	-	36.3	2.95	66	-	3.34	2.49	5.82	DURATION
"	75	ACCELER-ATION	"	6.0	29800	392.5	24.5	-276	-286	-	37.2	3.25	66	-	3.58	2.83	6.40	DURATION
"	76	RAYLEIGH STEP LOX	"	6.0	29400	392.5	23.5	-276	-287	-	33.8	2.55	65	-	2.90	2.49	5.39	DURATION
"	77	SEAL, 6 SEG HE SEAL	"	6.0	29600	390.0	23.5	-276	-287	-	35.8	2.70	65	-	3.12	2.60	5.72	DURATION. COMPLETED 5 HOURS. TESTER REMOVED FOR INSPECTION. SEALS IN EXCELLENT CONDITION.
3	78	"	8-21-78	.05	-	-	-	-	-	-	-	-	-	-	-	-	-	NOISY ACCELERATION CUTOFF.
"	79	"	"	.4	-	-	-	-	-	-	-	-	-	-	-	-	-	NO ACCELERATION TRACE.
"	80	"	"	6	30040	382.5	25.0	-277	-285	173.2	35.0	5.5	105	108	1.20	3.34	4.55	DURATION
"	81	"	"	6	29960	380.0	23.5	-277	-287	162.9	37.0	5.15	103	102	2.07	2.98	5.05	DURATION
"	82	"	"	4.9	30040	375.0	23.0	-277	-285	158.8	33.4	5.2	102	97	1.35	2.99	4.34	FACILITY CUTOFF
"	83	"	"	1	29920	375.0	25.5	-280	-287	177.6	31.8	5.6	104	100	0.60	3.46	4.05	VISICORDER LOST POWER
"	84	"	"	6	29960	375.0	23.5	-276	-286	163.6	30.8	5.65	105	97	1.67	3.19	4.86	DURATION
"	85	"	"	6	29600	372.5	23.0	-276	-287	156.5	33.3	5.4	106	93	2.31	3.10	5.41	DURATION
"	86	"	"	6	29920	370.0	22.5	-277	-287	149.0	32.8	5.45	106	90	2.15	3.11	5.26	DURATION
"	87	"	"	6	29920	370.0	22.0	-277	-289	148.6	32.0	5.45	105	88	2.05	3.12	5.17	DURATION
"	88	"	"	.17	-	-	-	-	-	-	-	-	-	-	-	-	-	OVERSPEED CUTOFF
"	89	"	"	6	30080	370.0	24.5	-276	-287	164.9	34.4	5.3	105	87	2.00	3.02	5.02	DURATION
"	90	"	"	6	28880	365.0	22.5	-276	-287	154.[illegible]	34.3	4.65	105	86	1.92	2.70	4.63	DURATION
"	91	"	8-24-78	6	29680	365.0	24.0	-272	-284	156.6	38.3	4.9	86	96	2.09	3.09	5.18	DURATION
"	92	"	"	6	29680	400.0	25.0	-276	-283	171.3	32.1	5.1	86	91	1.06	2.91	3.97	DURATION
"	93	"	"	6	29640	400.0	24.0	-276	-284	168.8	31.9	5.1	88	87	1.46	2.70	4.16	DURATION
"	94	"	"	6	29720	400.0	23.5	-277	-285	165.9	32.7	4.95	88	84	1.79	2.60	4.38	DURATION
"	95	"	"	6	29760	395.0	23.5	-280	-287	164.0	33.7	4.95	90	82	1.99	2.60	4.59	DURATION
"	96	"	"	6	29720	395.0	25.0	-276	-282	170.9	32.5	5.1	92	86	1.74	3.02	4.76	DURATION
"	97	"	"	6	29520	395.0	23.5	-276	-284	163.7	31.8	4.85	94	83	1.96	2.82	4.78	DURATION

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY, PHASE IV

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL					HELIUM SEAL							REMARKS
						U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM	U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM LOX SIDE	LEAKAGE SCFM TURB SIDE	LEAKAGE SCFM TOTAL	
3	98	PHASE IV CRYOGENIC	8-24-78	6	30000	395.0	24.0	-276	-285	169.6	31.8	4.9	95	82	2.07	2.71	4.79	DURATION
"	99	ACCELER-ATION	"	6	29720	395.0	24.0	-276	-285	168.0	32.5	4.6	95	82	2.06	2.71	4.77	DURATION
"	100	RAYLEIGH STEP LOX	"	6	29600	395.0	24.5	-273	-285	184.2	33.3	4.6	97	81	2.25	2.72	4.96	DURATION
"	101	SEAL, 6 SEG	"	6	29000	390.0	23.5	-276	-285	175.0	33.6	4.15	98	81	2.76	2.60	5.36	DURATION
"	102	HE SEAL	"	6	29200	390.0	27.0	-277	-285	179.7	34.3	5.0	105	99	2.88	3.09	5.96	DURATION
"	103	"	"	6	29480	360.0	24.5	-273	-286	158.1	36.9	4.5	105	95	3.92	2.68	6.61	DURATION
"	104	"	"	6	29880	385.0	26.0	-273	-285	170.59	33.4	4.8	105	91	2.88	2.69	5.57	DURATION
"	105	"	"	6	29880	390.0	26.0	-273	-285	171.9	32.8	4.85	103	90	2.42	2.90	5.33	DURATION
"	106	"	"	6	29800	390.0	26.0	-273	-286	171.9	33.3	4.5	105	88	2.78	2.70	5.48	DURATION
"	107	"	"	1.77	29920	390.0	25.5	-276	-287	170.9	32.6	4.75	105	87	3.04	2.81	5.85	RAN OUT VISICORDER PAPER
"	108	"	"	6	29760	380.0	26.0	-277	-285	177.5	36.2	4.45	104	95	4.33	3.10	7.43	DURATION
"	109	"	"	6	29680	382.5	25.0	-275	-285	170.1	34.2	4.3	103	91	3.92	2.80	6.72	DURATION
"	110	"	"	6	29560	382.5	25.0	-273	-286	172.4	38.0	4.1	104	88	4.88	2.70	7.58	DURATION
"	111	"	"	6	29600	380.0	24.5	-273	-285	171.2	38.8	4.15	103	86	4.57	2.70	7.28	DURATION
"	112	"	"	6	29840	380.0	25.5	-273	-285	173.9	38.0	4.0	103	83	4.82	2.71	7.53	DURATION
"	113	"	"	6	29720	380.0	25.0	-275	-285	169.2	37.5	4.0	103	82	5.07	2.71	7.78	DURATION
"	114	"	"	6	29720	380.0	24.5	-275	-286	168.5	38.8	4.0	103	81	5.26	2.60	7.87	DURATION
"	115	"	"	6	29480	380.0	24.0	-273	-285	164.1	37.6	2.95	103	79	6.16	1.98	8.14	DURATION
"	116	"	"	6	29680	390.0	25.0	-275	-278	177.8	37.3	3.0	103	79	5.67	2.12	7.79	DURATION
"	117	"	"	.4	27480	377.5	29.5	-271	-284	192.7	36.3	3.4	99	82	6.05	3.03	9.09	P4 CUT OFF
"	118	"	"	6	29680	380.0	26.0	-275	-278	172.8	36.4	4.1	100	81	4.57	2.93	7.50	DURATION
"	119	"	"	6	29480	382.5	25.5	-273	-282	174.6	34.8	3.65	100	81	4.41	2.60	7.01	DURATION
"	120	"	"	6	29480	380.0	25.5	-273	-282	174.9	35.8	3.6	99	79	4.87	2.61	7.48	DURATION
"	121	"	"	6	29400	380.0	24.5	-272	-280	171.8	34.9	3.85	98	79	4.46	2.61	7.07	DURATION
"	122	"	"	6	29880	380.0	24.5	-272	-282	172.4	36.7	3.65	98	78	5.05	2.38	7.42	DURATION

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY, PHASE IV

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL					HELIUM SEAL							REMARKS
						U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM	U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM LOX SIDE	LEAKAGE SCFM TURB SIDE	LEAKAGE SCFM TOTAL	
3	123	PHASE IV CRYOGENIC	8-24-78	6	29720	380.0	24.5	-273	-281	174.4	36.0	3.65	98	78	4.69	2.37	7.06	DURATION
"	124	ACCELER-ATION	"	6	29400	380.0	24.5	-273	-285	170.6	33.6	3.5	97	77	4.46	2.38	6.84	DURATION
"	125	RAYLEIGH STEP LOX	"	6	29600	380.0	24.5	-273	-285	168.6	35.9	3.6	98	76	4.99	2.38	7.36	DURATION
"	126	SEAL, 6 SEG	"	6	29640	375.0	24.0	-272	-283	168.6	34.0	3.65	97	76	4.99	2.38	7.36	DURATION
"	127	HE SEAL	"	6	29120	380.0	24.5	-273	-284	171.2	35.3	3.85	98	76	5.26	2.38	7.63	DURATION
"	128	"	"	6	29200	377.5	24.5	-271	-285	169.3	34.9	3.85	97	76	5.00	2.38	7.39	DURATION
"	129	"	"	6	29680	375.0	24.5	-272	-285	170.2	33.8	3.85	95	75	4.88	2.38	7.26	DURATION
"	130	"	"	6	29720	372.5	24.0	-272	-285	167.5	32.5	3.85	93	74	4.54	2.38	6.92	DURATION
"	131	"	"	6	29680	375.0	25.0	-272	-285	168.2	34.9	3.9	94	74	5.68	2.38	8.06	DURATION
"	132	"	"	6	29720	375.0	25.5	-271	-285	171.0	36.7	3.9	95	74	5.88	2.38	8.27	DURATION
"	133	"	"	6	29480	375.0	25.5	-272	-285	171.0	34.4	3.9	95	74	5.53	2.26	7.79	DURATION.COMPLETED 10 HOURS. TESTER REMOVED FOR INSPECTION. SEALS IN EXCELLENT CONDITION.
4	134	PHASE IV SPIRAL GROOVE LOX SEAL	12-11-78	.03	19480	340.0	24.0	-296	-281	151.0	35.9	17.4	102	95	.04	8.32	8.36	HIGH VIBRATION 20G P-P DRAIN T DIPPED TO -297 F AT START.
"	135	SEGMENTED HE SEAL	"	.08	-	-	-	-	-	-	-	-	-	-	-	-	-	NO SPEED TRACE. DRAIN TEMP DROPPED AT START. LOX PR SPIKED UP AT START.
"	136	"	"	.23	28000	330.0	28.5	-292	-292	173.0	31.6	17.2	98	92	0	.83	.83	SPEED ERRATIC-DROPPED TO ZERO AS LOX PR INCREASE, DRAIN TEMP DIPPED FROM +40 F TO -15 F AT START.
"	137	"	"	.08	5520	332.0	20.0	-289	-289	200.0	30.0	29.7	99	87	0	.82	.82	LOW SPEED CUT-OFF.
"	138	"	"	0	-	-	-	-	-	-	-	-	-	-	-	-	-	TESTER DID NOT START WITH NORMAL TURBINE PRESSURE.
"	139	"	"	.08	31960	250.0	33.0	-276	-246	210.0	34.1	29.4	99	87	0	.85	.85	OVERSPEED AT START WITH INCREASED TURBINE PR.

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY, PHASE IV

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL					HELIUM SEAL							REMARKS
						U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM	U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM LOX SIDE	LEAKAGE SCFM TURB SIDE	LEAKAGE SCFM TOTAL	
4	140	PHASE IV SPIRAL GROOVE LOX SEAL SEGMENTED HE SEAL	12-11-78	1.22	27600	337.0	30.5	-280	-276	182.0	35.6	45.0	99	86	0	.87	.87	LOW SPEED CUT-OFF. DRAIN TEMP DIPPED TO -200 F AT START GRADUALLY INCREASED TO -80 F.
"	141-1		"	6	29720	340.0	19.0	-284	-268	127.0	36.3	24.6	97	85	0	.88	.88	SPEED ERRATIC. LOX PR DROPPED GRADUALLY FROM 340 PSIG TO 210 PSIG.
	141-2	"	"		31240	227.0	22.5	-285	-264	140.0	37.1	33.5	93	83	0	.89	.89	
"	142-1	"	"	2.8	28320	142.0	29.0	-280	-271	185.0	33.3	33.4	95	84	0	.85	.85	EXCESSIVE LEAKAGE. LOX POURING OUT DRAIN. LOX PR COULD NOT BE INCREASED ABOVE 177 PSIG. LEAK ORI ΔP PEGGED OUT. INSPECTION REVEALED HEAVY RUBBING & WEAR ON SPIRAL GROOVE SURFACE.
	142-2				31000	177.0	69.0	-261	-262	326.0 +	33.7	50.0	94	84	0	.85	.85	
5	143	PHASE IV MOD I SPIRAL GROOVE LOX SEAL. SEGMENTED HE SEAL	4-19-79	.03	16760	175.0	28.5	-297	-296	303.0 +	34.4	23.9	82	82	0	3.4	3.4	EXCESSIVE LOX LEAKAGE PRETEST AND DURING TEST. CUTOFF DUE TO VIBRATION REDLINE 20 gs.
"	144		"	.05	15600	145.0	16.0	-296	-297	132.0	37.3	11.6	79	79	0	3.01	3.01	CUTOFF DUE TO VIBRATION REDLINE 20 gs.
"	145	"	"	.25	32000	152.5	42.0	-280	-297	210.0	40.4	31.7	79	81	0	2.98	2.98	OVERSPEED CUTOFF. EXCESSIVE LOX LEAKAGE POST TEST. TESTER WOULD NOT START WITH MAX TURB PR. TESTER TORQUE HIGH & ERRATIC. INSPECTION REVEALED RUBBING & WEAR ON SPIRAL GROOVE SURFACE.
6	146	PHASE IV MOD II SPIRAL GROOVE LOX SEAL SEGMENTED HE SEAL	8-29-79	.05	-	145.0	1.0	-218	-303	15.4	35.9	.25	82	83	5.564	0.60	6.16	ACCELEROMETER REDLINE. NO SPEED TRACE.
"	147		"	.05	-	137.5	1.0	-218	-300	17.6	35.8	7.15	82	90	3.961	4.43	8.40	ACCELEROMETER REDLINE. NO SPEED TRACE.
"	148		"	.15	33080	185.0	.5	-290	-286	22.3	25.0	16.2	83	91	4.246	7.10	11.34	OVERSPEED CUT-OFF
"	149	"	"	.23	37080	190.0	.5	-261	-276	19.5	34.0	20.5	86	95	4.069	8.22	12.29	OVERSPEED CUT-OFF
"	150	"	"	.12	32320	150.0	3.0	-310	-286	42.8	28.0	10.0	86	94	5.691	5.62	11.31	OVERSPEED CUT-OFF
"	151	"	"	.27	32000	152.5	.5	-259	-276	29.4	30.0	13.3	86	95	5.027	6.27	11.30	OVERSPEED CUT-OFF
"	152	"	"	.28	33280	150.0	.5	-292	-290	21.8	37.0	15.0	86	95	5.321	6.833	12.15	OVERSPEED CUT-OFF

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY, PHASE IV

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL U/S PR. PSIG	LOX SEAL D/S PR. PSIG	LOX SEAL U/S TEMP °F	LOX SEAL D/S TEMP °F	LOX SEAL LEAKAGE SCFM	HELIUM SEAL U/S PR. PSIG	HELIUM SEAL D/S PR. PSIG	HELIUM SEAL U/S TEMP °F	HELIUM SEAL D/S TEMP °F	HELIUM SEAL LEAKAGE SCFM LOX SIDE	HELIUM SEAL LEAKAGE SCFM TURB SIDE	HELIUM SEAL LEAKAGE SCFM TOTAL	REMARKS
6	153	PHAS IV MOD II	8-29-79	.80	35760	155.0	.5	-259	-280	22.2	23.0	11.3	86	95	4.459	5.860	10.32	OVERSPEED CUT-OFF
"	154	SPIRAL GROOVE	"	.53	37440	197.5	.5	-298	-267	19.6	33.4	20.9	86	96	3.948	8.182	12.13	OVERSPEED CUT-OFF
"	155	LOX SEAL SEGMENTED	"	.50	33920	202.5	.5	-271	-253	18.8	32.1	19.5	86	95	5.365	7.843	13.21	OVERSPEED CUT-OFF
"	156	HE SEAL	"	.30	33200	180.0	.5	-258	-259	18.7	31.0	13.5	86	95	5.526	6.099	11.63	OVERSPEED CUT-OFF
"	157	"	"	.38	39200	185.0	.5	-299	-258	16.1	33.4	15.3	86	96	4.249	6.608	10.86	OVERSPEED CUT-OFF
"	158	"	"	.05	33200	157.5	1.0	-299	-283	24.7	31.2	9.0	86	95	4.909	5.159	10.07	OVERSPEED CUT-OFF
"	159	"	"	2.80	32440	185.0	.5	-259	-277	19.4	33.5	7.7	86	92	4.218	4.612	8.83	OVERSPEED CUT-OFF
"	160	"	"	.1	32800	85.0	3.0	-293	-286	18.5	30.0	10.0	86	92	5.232	5.371	10.60	OVERSPEED CUT-OFF
"	161	"	"	.17	27000	85.0	1.5	-292	-290	13.0	34.5	10.0	86	92	4.381	5.371	9.75	ACCELEROMETER CUT-OFF. TURBINE HOUSING LOOSE.
"	162	"	9-5-79	.12	30920	100.0	9.0	-310	-264	43.46	24.0	9.5	105	116	3.52	5.13	8.65	ACCELEROMETER CUT-OFF
"	163	"	"	.10	30640	100.0	11.0	-310	-266	41.45	31.5	13.0	105	113	4.51	5.89	10.40	ACCELEROMETER CUT-OFF
"	164	"	"	.13	36080	100.0	5.5	-307	-266	30.66	34.5	12.3	105	113	4.59	5.89	10.47	OVERSPEED CUT-OFF ACCELEROMETER CUT-OFF
"	165	"	"	2.50	32920	100.0	4.0	-303	-264	26.93	34.7	4.5	105	109	4.70	3.34	8.04	OVERSPEED CUT-OFF
"	166	"	"	.52	32320	90.0	2.5	-307	-267	21.83	35.3	6.7	105	108	3.91	4.14	8.04	OVERSPEED CUT-OFF
"	167	"	"	.42	33080	77.5	2.0	-307	-272	19.30	32.8	6.2	106	110	3.38	4.13	7.50	OVERSPEED CUT-OFF
"	168	"	"	10.02	30080	157.5	1.0	-170	-270	10.94	39.0	6.9	104	104	3.56	4.07	7.63	TEST REQUIREMENT COMPLETED
"	169	"	"	13.72	30000	225.0	5.5	-245	-280	19.52	34.3	5.8	105	99	3.63	3.72	7.35	HIGH LOX SEAL DRAIN PRESSURE AND LEAKAGE. INSPECTION REVEALED RUBBING & WEAR ON SPIRAL GROOVE SURFACE.
7	170	PHASE IV MOD III	1-22-80	0.06	32320	110.0	56.5	-284	-263	74.3	61.0	40.00	88	100	0	.79	.79	OVERSPEED CUT-OFF
"	171	SPIRAL GROOVE	"	15.00	29880	180.0	7.5	-261	-286	23.5	38.5	6.15	84	93	3.56	3.25	6.81	TEST REQUIREMENT COMPLETED
"	172	LOX SEAL	"	15.00	29800	250.0	5.0	-273	-300	20.1	38.6	4.85	90	90	3.64	3.11	6.75	TEST REQUIREMENT COMPLETED
"	173	"	"	15.00	29880	340.0	6.5	-272	-299	22.3	37.9	5.65	90	84	3.76	3.22	6.99	TEST REQUIREMENT COMPLETED
"	174	"	"	.10	31960	375.0	9.5	-280	-302	28.5	35.3	3.95	88	82	3.69	1.67	5.36	OVERSPEED CUT-OFF

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY, PHASE IV

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL					HELIUM SEAL							REMARKS
						U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM	U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM			
															LOX SIDE	TURB SIDE	TOTAL	
7	175	PHASE IV MOD III SPIRAL GROOVE LOX SEAL	1-22-80	.13	17000	375.0	13.0	-280	-300	34.0	31.8	10.65	88	83	3.11	5.15	8.26	LOW SPEED CUT-OFF
"	176		"	.10	19000	375.0	-	-	-	-	-	-	-	-	-	-	-	EXPLOSION AND FIRE

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY, PHASE V

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL U/S PR. PSIG	LOX SEAL D/S PR. PSIG	LOX SEAL U/S TEMP °F	LOX SEAL D/S TEMP °F	LOX SEAL LEAKAGE SCFM	HELIUM SEAL U/S PR. PSIG	HELIUM SEAL D/S PR. PSIG	HELIUM SEAL U/S TEMP °F	HELIUM SEAL D/S TEMP °F	HELIUM SEAL LEAKAGE SCFM LOX SIDE	HELIUM SEAL LEAKAGE SCFM TURB SIDE	HELIUM SEAL LEAKAGE SCFM TOTAL	REMARKS
1	1	PHASE	6-26-81	.05	20,000	130	.05	-296	-328	0.92	35.2	2.5	101	99	2.11	1.00	3.11	OVERSPEED CUT-OFF
1	2	V SPIRAL	"	.10	12,800	130	.05	-298	-328	1.11	35.0	1.4	99	96	1.61	0.59	3.20	"
1	3	GROOVE LOX	"	.11	22,800	130	.05	-298	-328	0.95	34.6	1.5	100	97	2.03	1.31	3.34	"
1	4	SEAL SEGMENTED		.11	24,000	135	.05	-296	-328	1.09	34.0	1.5	95	96	1.66	0.88	2.54	"
1	5	He SEAL	"	.40	26,000	135	4.00	-298	-319	8.36	34.0	1.4	95	95	1.45	1.65	3.10	"
1	6	"	"	.10	100	135	2.00	-298	-319	5.30	34.0	1.5	99	97	1.52	1.31	2.82	"
1	7	"		.60	24,920	145	5.00	-298	-318	9.61	34.0	1.0	99	95	1.32	1.21	2.53	"
1	8	"	"	.55	27,600	135	4.00	-298	-322	6.94	34.2	1.0	97	89	1.51	1.32	2.83	"
1	9	"	"	.35	22,000	135	1.00	-298	-322	1.11	34.2	1.2	99	89	1.65	0.89	2.54	"
1	10	"	"	.60	25,600	135	.05	-298	-319	1.12	34.2	1.1	99	89	1.60	.59	2.19	"
1	11	"	"	.65	14,400	135	6.00	-298	-319	10.81	34.4	0.75	99	89	1.21	1.32	2.53	"
1	12	"	"	1.45	20,000	135	5.00	-298	-322	9.26	34.0	1.3	100	89	2.27	0.27	2.54	INSTRUMENTATION MALFUNCTION
1	13	"	"	.65	21,600	150	6.0	-298	-319	9.48	35.0	0.75	99	88	1.65	0.89	2.54	OVERSPEED CUT-OFF
1	14	"	"	1.50	29,200	120	4.0	-298	-328	5.00	35.0	0.50	100	93	2.26	0.26	2.52	"
1	15	"	"	.96	24,800	150	6.0	-298	-322	9.35	35.0	0.50	99	93	1.93	0.26	2.19	"
1	16	"	"	1.83	30,600	135	6.0	-298	-319	9.35	35.0	0.40	100	92	1.92	0.27	2.19	"
1	17	"	"	.15	26,400	135	5.0	-298	-319	8.13	34.0	0.40	100	92	1.92	0.27	2.19	"
1	18	"	7-8-81	.08	21,600	140	12.0	-302	-254	16.88	31.4	2.5	104	108	1.41	1.93	3.34	"
1	19	"	"	.36	30,000	140	4.0	-302	-328	7.43	30.8	2.4	104	108	1.19	0.87	2.06	INSTRUMENTATION MALFUNCTION
1	20	"	"	.73	30,000	140	7.0	-302	-328	11.18	36.2	2.35	104	106	1.42	0.74	2.16	OVERSPEED CUT-OFF
1	21	"	"	1.08	30,000	140	2.0	-302	-227	5.28	36.0	2.35	105	107	2.12	0.58	2.70	"
1	22	"	"	.90	30,000	140	2.0	-302	-280	5.13	44.6	2.35	105	107	2.44	0.58	3.02	"
1	23	"	"	1.15	29,080	135	7.0	-302	-328	12.2	36.4	2.25	104	107	1.59	0.58	2.17	ACCELEROMETER CUT-OFF
1	24	"	"	1.22	30,000	140	2.0	-302	-280	5.65	30.8	3.0	105	106	1.41	1.30	2.71	OVERSPEED CUT-OFF
1	25	"	"	.75	28,000	130	7.0	-302	-328	10.96	35.0	3.0	105	106	1.84	0.87	2.71	ACCELEROMETER CUT-OFF
1	26	"	"	.83	29,800	140	4.0	-302	-328	7.02	43.4	3.1	102	105	1.98	0.39	2.37	INSTRUMENTATION MALFUNCTION

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY, PHASE V

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL U/S PR. PSIG	LOX SEAL D/S PR. PSIG	LOX SEAL U/S TEMP °F	LOX SEAL D/S TEMP °F	LOX SEAL LEAKAGE SCFM	HELIUM SEAL U/S PR. PSIG	HELIUM SEAL D/S PR. PSIG	HELIUM SEAL U/S TEMP °F	HELIUM SEAL D/S TEMP °F	HELIUM SEAL LEAKAGE SCFM LOX SIDE	HELIUM SEAL LEAKAGE SCFM TURB SIDE	HELIUM SEAL LEAKAGE SCFM TOTAL	REMARKS
1	27	PHASE V SPIRAL	7-8-81	1.75	30,000	140	6.0	-302	-328	9.59	44.0	3.1	102	105	2.33	0.39	2.72	OVERSPEED CUT-OFF
1	28	GROOVE LOX SEAL	"	1.48	30,000	140	5.0	-302	-328	8.30	36.6	3.0	105	105	2.35	0.39	2.74	ACCELEROMETER CUT-OFF
1	29	SEGMENTED He SEAL	"	2.18	30,000	140	4.0	-302	-328	8.30	37.0	3.0	102	104	2.35	0.39	2.74	"
1	30	"	"	1.48	30,000	140	6.0	-302	-328	10.76	37.0	3.0	102	102	2.35	0.39	2.74	"
1	31	"	7-9-81	.16	-	-	-	-	-	-	-	-	-	-	-	-	-	SPEED TRACE FAILURE
2	32	"	2-3-82	1.05	30,000	80	0.1	-311	-305	20.17	1.6	0.15	95	97	0.85	0.39	1.24	SEAL DAMAGE INSTRUMENTATION MALFUNCTION
2	33	"	"	0.216	31,200	150	12.0	-311	-302	25.53	7.6	0.10	95	97	0	1.34	1.34	OVERSPEED CUT-OFF
2	34	"	"	7.72	29,880	140	9.0	-311	-305	22.32	39.0	0.10	94	99	0	1.83	1.83	UNDERSPEED CUT-OFF
2	35	"	"	1.00	30,400	140	10.0	-311	-305	31.42	5.8	0.95	95	99	0	1.19	1.19	OVERSPEED CUT-OFF
2	36	"	"	0.70	31,400	140	10.0	-311	-305	33.35	4.0	0.90	97	103	0	1.19	1.19	" "
2	37	"	"	0.45	31,120	30	3.0	-311	-305	11.64	7.0	0.50	99	103	1.63	0.87	2.50	" "
2	38	"	"	5.30	29,000	140	12.0	-311	-305	13.27	35.6	0.10	97	103	0	1.73	1.73	TEST REQUIREMENT COMPLETED
2	39	"	"	0.53	32,360	260	26.0	-311	-305	30.49	26.0	1.00	97	105	0	2.95	2.95	OVERSPEED CUT-OFF
2	40	"	"	1.58	30,480	240	22.0	-311	-306	23.02	32.6	0.35	97	105	0	2.35	2.35	" "
2	41	"	2-5-82	0.33	28,800*	240	28.0	-271	-295	42.87	7.6	2.00	91	97	0	1.66	1.66	" "
2	42	"	"	0.28	28,720*	240	32.0	-271	-295	53.38	16.0	3.10	89	103	0	1.70	1.70	" "
2	43	"	"	0.32	26,800*	240	32.0	-280	-297	42.32	15.6	1.75	89	103	0	1.69	1.69	" "
2	44	"	"	2.22	27,000*	220	24.0	-271	-297	18.83	30.4	0.60	89	100	0	1.71	1.71	" "
2	45	"	"	0.10	26,000*	240	2.0	-245	-234	9.16	4.8	0.40	94	103	0	1.10	1.10	" "
2	46	"	2-9-82	0.40	31,800	240	8.0	-271	*	35.73	8.8	2.35	105	103	0	1.22	1.22	" "
2	47	"	"	9.82	30,400	230	4.0	-271	-238	44.52	31.8	2.40	103	103	2.06	1.79	3.85	TEST REQUIREMENT COMPLETED
2	48	"	"	2.27	31,600	340	16.0	-253	-302	50.80	18.8	2.25	97	97	0	2.09	2.09	OPERATOR CUT -ERRATIC SPEED TRACE, INBOARD SLAVE SEAL FAILED.
3	49	"	4-7-82	.39	14,000	340	16.0	-290	-253	86.4	36.0	1.0	78	82	1.19	.89	2.08	SPEED CONTROL
3	50	"	"	.06	16,000	250	20.0	-300	-	44.4	35.6	1.75	78	82	2.02	1.67	3.69	LOX SEAL PR REDLINE
3	51	"	"	.03	17,000.	100	30.0	-	-	51.9	35.4	1.75	78	80	1.50	1.83	3.34	LOX SEAL PR REDLINE
3	52	"	"	.7	25,400	320	34.0	-271	-	188.4	36.0	1.0	78	82	4.80	1.12	2.93	BEARING CAV FLOW REDLINE

*. INSTRUMENTATION MALFUNCTION READINGS IN ERROR

TABLE C-1. NASA CRYOGENIC SEAL TEST SUMMARY, PHASE V

BUILD NO.	TEST NO.	OBJECTIVE	DATE	TIME MIN.	SPEED RPM	LOX SEAL					HELIUM SEAL							REMARKS
						U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM	U/S PR. PSIG	D/S PR. PSIG	U/S TEMP °F	D/S TEMP °F	LEAKAGE SCFM LOX SIDE	LEAKAGE SCFM TURB SIDE	LEAKAGE SCFM TOTAL	
3	53	PHASE V SPIRAL	4-7-82	.4	21,120	300	29.0	-	-290	187.1	36.0	1.15	78.0	84	1.88	1.32	3.21	SPEED CONTROL
3	54	GROOVE LOX SEAL	"	.23	32,000	380	58.0	-245	-245	190.5	46.0	1.25	75.8	82	.21	1.32	1.54	OVERSPEED
3	55	SEGMENTED He SEAL	"	.13	32,800	320	26.0	-228	-290	138.9	36.0	1.25	75.8	82	2.37	1.32	3.70	OVERSPEED
3	56	"	"	.15	23,680	300	22.0	-237	-290	128.7	38.0	1.45	75.8	82	.97	.89	1.86	ACCEL REDLINE
3	57	"	"	.15	24,000	360	28.0	-267	-290	143.5	40.0	.9	75.8	82	1.74	.89	2.63	ACCEL REDLINE
3	58	"	"	4.8	31,000	360	18.0	-245	-290	102.8	46.0	.5	86.8	-	1.65	.97	2.63	LOW SPEED REDLINE
3	59	"	"	.85	32,200	360	20.0	-262	-290	116.4	42.0	1.25	73.6	78	2.62	1.33	3.95	OVERSPEED
3	60	"	"	.12	32,200	360	20.0	-245	-290	111.5	44.0	2.5	78.0	78	.35	1.68	2.03	OVERSPEED
3	61	"	"	.1	32,200	345	6.0	-245	-295	52.2	44.6	1.15	73.6	78	1.43	1.42	2.85	OVERSPEED
3	62	"	"	.12	32,120	340	12.0	-245	-290	80.2	48.0	1.65	73.6	78	.69	1.33	2.02	OVERSPEED
3	63	"	"	.1	32,000	340	10.0	-245	-290	75.0	46.0	1.15	73.6	78	1.52	1.33	2.85	OVERSPEED
3	64	"	"	6.7	30,160	340	6.0	-245	-262	50.3	46.0	.5	73.6	78	1.51	1.51	3.03	TEST REQUIREMENT COMPLETED
3	65	"	"	2.3	34,520	400	10.0	-228	-245	60.5	58.0	1.9	69.1	73	2.31	1.98	4.30	LOW SPEED REDLINE
3	66	"	"	.7	32,320	400	14.0	-221	-228	81.9	52.0	1.0	73.6	73	1.08	1.02	2.10	OVERSPEED
3	67	"	"	.18	31,920	400	8.0	-213	-228	55.3	51.4	1.5	73.6	73	1.63	1.33	2.97	OVERSPEED
3	68	"	"	.28	31,680	400	6.0	-213	-221	49.8	58.0	.5	73.6	73	1.71	1.60	3.32	OVERSPEED
3	69	"	"	2.1	31,600	340	6.0	-187	-177	44.3	56.0	.5	73.6	73	1.20	.90	2.10	OVERSPEED
3	70	"	"	.83	31,680	300	4.0	-173	-163	37.3	60.0	.6	64.6	69	1.72	.40	2.12	OVERSPEED
3	71	"	4-8-82	3.8	30,600	80	2.0	-119	-128	19.9	36.4	4.0	129.4	91	.86	.88	1.74	LOW LOX SEAL CAV PR.