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ROVER PROGRAM

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METALLIC SEAL

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COMPRESSION TESTS

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Figure 1. TEST SEAL DIMENSIONS

- (a) Omega Seal
- (b) Transition Seal Ring
- (c) X-Seal
- (d) Extended X-Seal

1. INTRODUCTION

- 1.1 Metallic seal rings having nominal diameters over 40 inches are used in the reactor vessel during experimental tests conducted at the Nuclear Rocket Development Station. The development of these seals at the Albuquerque Division of ACF Industries, Inc., has included gaseous, hydrostatic, and cryogenic pressure testing in a seal test fixture (1,3) and pressure vessels (2,3).
- 1.2 This report presents results of deflection versus load tests conducted on 5 inch long segments of each seal type to furnish additional seal design data. Of interest was the (1) characteristic curve of load versus deflection, (2) load required for "seating," (3) nature of seal lobe deformation and soft coating flow, and (4) magnitude of spring "recovery." The testing was accomplished at the ACF Alameda facility using an Instron test machine.

2. TESTING — GENERAL

- 2.1 Seal segments were taken from the following metal seal rings:

(a)	Omega Seal, Nozzle	ACF Drawing No. 508175
(b)	X-Seal, Nozzle	ACF Drawing No. 504909
(c)	Extended X-Seal, Nozzle	ACF Drawing No. 507676
(d)	Transition Ring Seal	ACF Drawing No. 510791

With the exception of the last seal listed, these seals are described in the references.

- 2.2 The Transition Ring Seal, fabricated of 6061-T6 aluminum, is employed at the interface of (1) the nozzle skirt and graphite transition ring, and (2) the transition ring and graphite reflector cylinder. To prevent damage to the seal grooves in these graphite components, this seal is designed to assemble with low loading. In contrast to the Omega Seal, the free ends of the legs do not close together permitting direct compressive loading through the seal lands. There is, as a result, no deformation of the seal base material and only a small flowing of the lead plating during the assembly sequence.
- 2.3 Figure 1 presents the four seal types tested and their general dimensions. To investigate the effect of lead plating, both plated and stripped samples of each seal type were prepared. The following dimensions were taken at both ends of each segment before and after plating or stripping:

(a)	Omega Seal, Nozzle:	Height at seal lobes (.252 shown) Height at each leg at seal lobe (not shown) Backbone thickness (.022 shown)
(b)	Transition Ring Seal	Height at seal lobes (.200 shown) Height of each leg at seal lobe (not shown) Backbone thickness (.022 shown)

a Extended X-Seal Segment
in Lower Seal Plate

b Seal Plates Bottomed

Figure 2. SEAL PLATE CONFIGURATION DURING TEST

Figure 3. OVER-ALL VIEW OF TEST SETUP

(c) X-Seal, Nozzle:	Height at I.D. (.292 shown)
Height at O.D. (.292 shown)
Width at top (.220 shown)
Width at bottom (.220 shown)
Leg thickness (.040 shown)
(d) Extended X-Seal Nozzle:	Height at I.D. (.322 shown)
Height at O.D. (.322 shown)
Width at top (.220 shown)
Width at bottom (.220 shown)
Leg thickness (.040 shown)

3. TESTING — PROCEDURE

- 3.1 Each seal segment was axially loaded and unloaded between two seal plates (Figure 2a) containing corresponding segments of seal grooves. Figure 3 is an over-all view of the test setup. Five such plates, fabricated of 6061-T6 aluminum, provided the combinations (Figure 4) necessary to test the four seal types. The upper seal plate was bolted to the machine crosshead. The lower plate was bolted to an adapter piece which screwed into the load cell located at the bottom on the machine.
- 3.2 Prior to the testing of each seal type, a calibration run was made with the plate combination and at the load range to be used during the actual test. The plates were brought together, bottomed (Figure 2b), and separated while the load versus deflection curve was traced on the chart. The result was a characteristic load-deflection curve of the particular seal plate combination and the test machine itself. This curve was later applied to the test run data for the corresponding seal and a curve of net deflection found.
- 3.3 The seal segment was placed in the lower seal plate (Figure 2a) and the crosshead lowered to a position just above the seal. Prior to seal compression the chart was zeroed, load range and crosshead speed checked, and crosshead control set on automatic. All testing was conducted at 0.010 inch per minute crosshead speed and 1.0 inch per minute chart speed.
- 3.4 Testing of each seal type included full and partial compression cycles. The purpose of these partial loadings was to study the width of seal land developed at points throughout an assembly sequence. This provided additional data as to sealing stress values for the seals investigated.

4. TEST RESULTS

- 4.1 Table 1 lists the seal segments tested, the test load per circumferential inch of seal, and the resultant seal deflection. The test load here is that load imposed by the test machine on the particular test configuration (seal sample and plates). This is not the "seating" load for the seal type. The deflection is the net amount found after applying the calibration curve previously mentioned to the test curve.

Seal Plate Configuration	Seal Tested
<p>Omega Seal</p> <p>Transition Ring Seal</p>
<p>Omega Seal</p>
<p>X-Seal</p>
<p>Extended X-Seal</p>

Figure 4. SEAL PLATE COMBINATIONS USED

- 4.2 Figures 5 through 9 show typical load and unload cycles for the four types tested. Each is a curve of load versus deflection for both plated and stripped seal segments. Elastic bending occurs until point "A" is reached. Bending yield then progresses to point "B" where compressive yield starts and continues to point "C" with the seal plates at zero gap. Since the free ends of the Transition Ring Seal do not come together, elastic bending is followed only by bending yield to the point of seal plate contact. The unloading portion of each cycle shows the spring recovery value to be 0.003 inch for the X-Seal, 0.004 inch for the Extended X-Seal, and 0.008 inch for the Omega Seal. Referring to the same Figures, the load required to seat each seal type is that value at point "C" on the loading curve. The values are: X-Seal, 1900 pounds per inch; Extended X-Seal, 1750 pounds per inch; and Omega Seal, 775 pounds per inch.
- 4.3 To investigate the effects of a possible tolerance stack-up, the Omega Seal was tested in a groove of 0.150 inch depth in addition to the normal 0.160 inch. The resultant curves of load versus deflection for this cycle are shown in Figure 6. This additional compression resulted in increased seal land width, buckling of the lower leg, and bearing at the ends of the backbone. These effects are shown in the photomacrograph of Figure 14b.
- 4.4 When tested in the normal depth groove, the Omega Seal demonstrated a spring recovery of 0.010 inch at a partial compression test load of 400 pounds per inch (Figure 13c) and 0.008 inch at a test load of 1000 pounds per inch (Figure 14a). In the 0.150 inch depth groove the recovery was 0.004 inch at 1000 pounds per inch test load (Figure 14b).
- 4.5 Figures 10, 11, and 12 are curves of load and stress versus developed seal land width for the Omega Seal, X-Seal, and Extended X-Seal, respectively. Such a curve for the Transition Ring Seal has been excluded here since there is no deformation of the base material and very little flow of the lead plating during the assembly sequence. The maximum seal land width shown for each seal type is that measured at the point of seal plate bottoming. The increase in the slope of each curve results from an increase of resistance to lateral material flow with increasing seal land width. The stress curve (dotted) for each seal type gives experimental results which greatly exceed yield strength for 6061-T4 aluminum, since the deformation is well into the plastic region for the material.
- 4.6 The photomacrographs shown in Figures 13 through 16 were taken at a 12X magnification. They were prepared by cross-sectioning, mounting, and polishing each sample shown. The lead plating shows up as the white area outlining each sample. It is seen that in each case the plating is heavier on the exterior surface of the seal, especially at the sealing surfaces. As an example, refer to the Omega Seal in Figure 13a. Here, there is less than 0.001 inch of plating on the internal portion of the seal while at the sealing surfaces there is better than 0.003 inch of plating.
- 4.7 Figures 15b and 16b show the X-Seal and Extended X-Seal cross-sections, respectively, as the legs first touch the corners of the groove. The load at this point is 632 pounds per inch for the X-Seal and 772 pounds per inch for the Extended X-Seal.

Table 1. SEAL SAMPLES TESTED

Seal Type	No.,	Condition	Test Load, lb/in.	Deflection, in.
Omega Seal	0-1	Plated	1000	.0938
	2-3	Plated	1000	.0942
	4-5	Plated	1000	.0985
	6-7	Plated	1000	.1178
	8-9*	Plated	1000	.1025
	10-11*	Plated	1000	.1046
	12-13*	Plated	27.8	.0487
	13-14*	Plated	400	.0850
	1-2	Stripped	1000	.0866
	3-4	Stripped	1000	.0923
	5-6*	Stripped	1000	.1003
	7-8*	Stripped	400	.0880
X-Seal	0-1	Plated	1800	.0449
	2-3	Plated	2000	.0501
	4-5	Plated	2000	.0522
	6-7	Plated	2000	.0493
	8-9	Plated	632	.0282
	1-2	Stripped	2000	.0443
	3-4	Stripped	2000	.0427
Extended X-Seal	0-1	Plated	2000	.0946
	2-3	Plated	2000	.083
	4-5	Plated	772	.0514
	6-7	Plated	2000	.076
	9-10	Plated	2000	.0833
	1-2	Stripped	2000	.0745
	3-4	Stripped	2000	.075
Transition Ring Seal	0-1	Plated	100	.0587
	2-3	Plated	100	.0632
	1-2	Stripped	100	.0523
	3-4	Stripped	100	.052

* Tested in .150 in. depth groove.

- 4.8 An effect of lead plating can be seen in Figures 7 and 8. Each presents load and un-load curves of seal-load versus deflection for plated and unplated samples of the X-Seal and Extended X-Seal, respectively. The plated sample exhibits a smooth curve while the unplated sample shows an irregular trace in the bending yield section of its curve (from point A to point B). This shows an advantage of plating in providing a smooth assembly. An unplated seal has a "stick-slip" action during this sequence, resulting in an uneven load application and possible twisting of the cross section. While the lead plating provides this lubrication, its primary responsibility is in filling flange surface asperities, providing a positive initial seal without disturbing the harder flange material.
- 4.9 Referring to the photomicrographs, it is noted that a thin coating of lead remains during deformation of the harder base seal material. This is most clearly seen in Figure 14 at the seal lands of the Omega Seal.

5. CONCLUSIONS

- 5.1 The testing described above has provided information valuable to future seal design, including seals for larger diameters and higher pressures. A characteristic load-deflection curve was obtained for each of the seals studied. Deformation behavior was observed in each case. The lead coating serves as a lubricant during assembly compression. A thin film remains with interface stresses observed as high as 55,000 psi. Experimental values obtained for seating load required and spring recovery are as follows:

	<u>X-Seal</u>	<u>Ext. X-Seal</u>	<u>Omega Seal</u>
Seating load, lb/in.	1900	1750	775
Spring recovery, in.	0.003	0.004	0.008

Figure 5. OMEGA SEAL, LOAD AND UNLOAD CYCLE (.160 Inch Deep Groove)

Figure 6. OMEGA SEAL, LOAD AND UNLOAD CYCLE (.150 Inch Deep Groove)

Figure 7. X-SEAL LOAD AND UNLOAD CYCLE

Figure 8. EXTENDED X-SEAL LOAD AND UNLOAD CYCLE

Figure 9. TRANSITION RING SEAL LOAD AND UNLOAD CYCLE

Figure 10. OMEGA SEAL, SEAL LOAD AND STRESS VERSUS SEAL LAND WIDTH

Figure 11. X-SEAL, SEAL LOAD AND STRESS VERSUS SEAL LAND WIDTH

Figure 12. EXTENDED X-SEAL, SEAL LOAD AND STRESS VERSUS SEAL LAND WIDTH

a Unloaded Sample

b After Loading to 0.050 Inch Deflection
(27.8 lb/inch of seal)

c After Loading to 400 lb/inch of Seal

Figure 13. OMEGA SEAL PHOTOMACROGRAPHS

a After Full Test Load in 0.160 Inch Deep Groove (1000 lb/inch of seal)

b After Full Test Load in 0.150 Inch Deep Groove (1000 lb/inch of seal)

Figure 14. OMEGA SEAL PHOTOMACROGRAPHS

a Unloaded Sample

b After Loading to 632 lb/inch of Seal
(legs have reached corners)

c After Full Test Load
(2000 lb/inch of seal)

Figure 15. X-SEAL PHOTOMACROGRAPHS

a Unloaded Sample

b After Loading to 772 lb/inch of Seal
(upper legs have reached corners)

c After Full Test Load
(2000 lb/inch of seal)

Figure 16. EXTENDED X-SEAL PHOTOMACROGRAPHS

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- (1) Progress Report — Omega Seal Development, Albuquerque Division, ACF Industries, Inc., ACF-431-47, Unclassified, March 1963.
- (2) Progress Report — X-Seal Development, Albuquerque Division, ACF Industries, Inc., ACF-431-60, Unclassified, August 1963.
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