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Preliminary Assessment of Seals for Dust Mitigation of Mechanical Components for Lunar Surface Systems

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Abstract

Component tests were conducted on spring-loaded Teflon seals to determine their performance in keeping lunar simulant out of mechanical component gearbox, motor, and bearing housings. Baseline tests were run in a dry-room without simulant for 10,000 cycles to determine wear effects of the seal against either anodized aluminum or stainless steel shafts. Repeat tests were conducted using lunar simulants JSC-1A and LHT-2M. Finally, tests were conducted with and without simulant in vacuum at ambient temperature. Preliminary results indicate minimal seal and shaft wear through 10,000 cycles, and more importantly, no simulant was observed to pass through the seal-shaft interface. Future endurance tests are planned at relevant NASA Lunar Surface System architecture shaft sizes and operating conditions.

Introduction and Background

NASA's Constellation program currently calls for an eventual return to the moon. During the Apollo Missions astronauts sited multiple problems with lunar dust. This included accelerated visor wear, false instrumentation readings, seal failures, abrasion of materials and degradation of mechanisms. Lunar dust has been characterized to be very abrasive with sharp angular features and ranging in diameter from tens to hundreds of micrometers (Ref. 1). With NASA's current plans for an extended stay on the lunar surface, dust mitigation of gearbox, motor, and bearing housings is especially critical. One technology currently under development is a spring-loaded Teflon seal which could potentially be used for dust mitigation of mechanical housings. These types of seals have seen use as dust mitigation components in the Mars Exploration Rover (MER) Instrumentation Deployment Device (IDD) as shown in Figure 1. The IDD is responsible for the deployment, placement, and control of various measurement devices including a Mossbauer Spectrometer, Alpha Particle X-ray Spectrometer, Microscopic Imager, and Rock Abrasion Tool (Ref. 2). The MER uses canted, spring-preloaded sliding Teflon seals manufactured by Bal Seal to keep small dust particles out of the rover mechanisms (Ref. 3). Because of MER's continued successful long-term operation on the Martian surface, baseline experiments were run on this type of dust seal using lunar simulant to determine their potential performance on mitigating dust in lunar mechanisms.

Experimental Procedure

A series of rotating shaft tests were run against spring-loaded Teflon seals to determine their performance in preventing lunar simulant from passing through the seal-shaft interface. Baseline tests without simulant were run in ambient dry-room conditions to determine wear of the Teflon seal against both stainless steel and anodized aluminum shafts. Then, these tests were repeated using lunar simulants

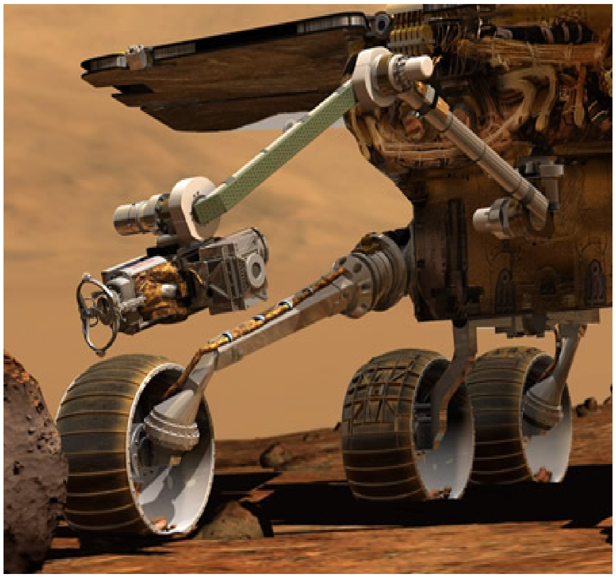


Figure 1.—Mars Exploration Rover (MER) Instrument Deployment Device or IDD.

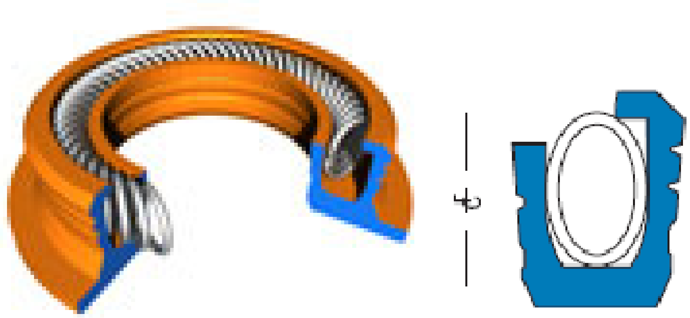


Figure 2.—Bal-Seal Cross-Section Main Body.

JSC-1A and LHT-2M. Finally, these tests were repeated in vacuum. Shaft rotation was constant at 20 rpm per lunar rover technology demonstrator requirements. The number of cycles was limited to 10,000 to determine initial feasibility of the seals. Note that with NASA's planned extended operations on the lunar surface, the seals are expected to last for millions of cycles. Thus, endurance tests on these seals are planned for design validation. Table 1 shows the matrix of tests completed for this feasibility study. In addition, a secondary study on the initial wear rate of the seal was performed for 0.375-, 0.75-, and 1.5-in. diameter seals where the seals were weighed after 1000, 3000, and 10,000 cycles.

The simulants JSC-1A and LHT-2M were synthetically manufactured such that their physical and chemical properties, as well as composition, simulate lunar regolith. JSC-1A simulates lunar regolith found in the mare, or dark regions of the lunar surface while LHT-2M simulates lunar regolith found in the highland, or light regions of the lunar surface (Ref. 4).

TABLE 1.—BAL-SEAL TEST MATRIX

Seal ID	Seal Diameter [in.]	Atm	Shaft	Shaft ID	Simulant
A22, A23	0.375	Dry Room	anodized Al	SA22, SA23	none
B7, B20	0.75	Dry Room	anodized Al	SB7, B20	none
C17, C18	1.5	Dry Room	anodized Al	SC17, SC18	none
B12	0.75	Dry Room	stainless steel	T6	none
A12	0.375	Dry Room	anodized Al	SA51	JSC-1A
B10	0.75	Dry Room	anodized Al	SB10	JSC-1A
C6	1.5	Dry Room	anodized Al	SC51	JSC-1A
B13	0.75	Dry Room	stainless steel	T8	JSC-1A
A17	0.375	Dry Room	anodized Al	SA55	LHT-2M
A18	0.375	Dry Room	stainless steel	S-10	LHT-2M
A13	0.375	4x10^-7 torr	anodized Al	SA52	none
B11	0.75	4x10^-7 torr	anodized Al	SB51	none
A15	0.375	3x10^-7 torr	anodized Al	SA53	JSC-1A
A16	0.375	4x10^-7 torr	anodized Al	SA54	LHT-2M

Test Article Description

An example of the spring-loaded Teflon seal, manufactured by Bal Seal, is shown in Figure 2.

The seal is composed of a Polytetrafluoroethylene (PTFE) ring with a U-shaped cross-section. A stainless steel canted coil-spring is inserted into the U-shaped cross-section thereby energizing the seal (Ref. 5). Seal sizes of 0.375-, 0.75-, and 1.5-in. inner diameter were selected to test against either stainless steel or anodized aluminum shafts of the same diameter.

Test Equipment Description

The test set-up is composed of a test stand, motor, seal housing, seal, and shaft as shown in Figure 3. The assembly is arranged in a vertical orientation to allow lunar simulant to enter the seal-shaft interface through the top of the assembly. The top of the seal housing is designed with a coned interior to funnel simulant towards the seal-shaft interface.

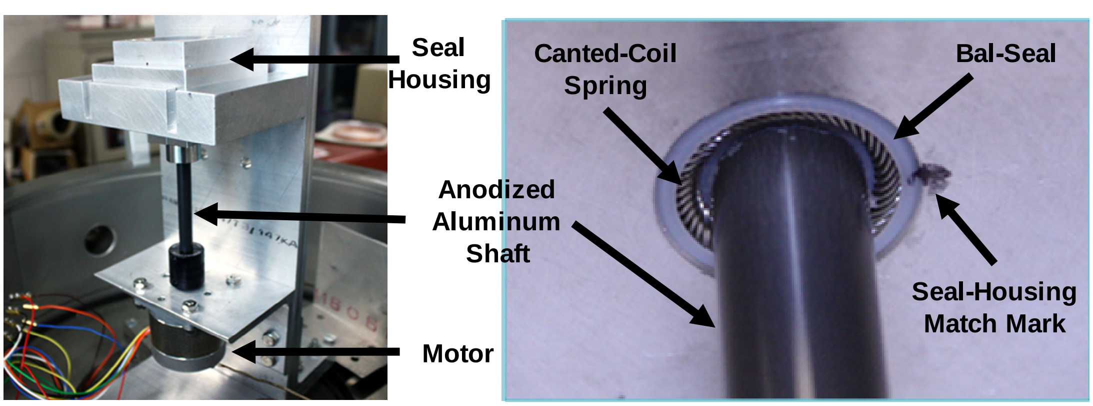


Figure 3.—Rotary seal rig test set-up and view of underside of seal within seal holder.

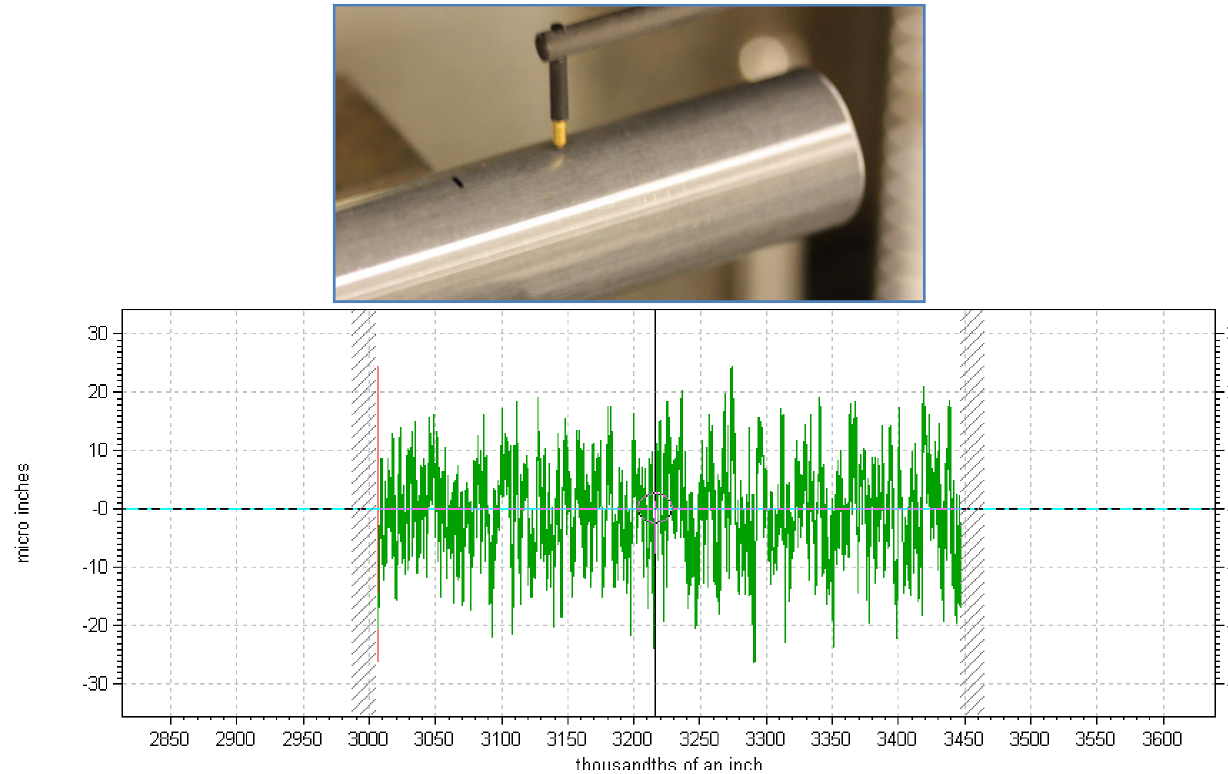


Figure 4.—Profilometer stylus measuring anodized aluminum shaft surface and sample shaft roughness profile.

Procedure

Prior to testing, the seals were first cleaned with Alconox, rinsed with ethanol alcohol and dried to remove any residual oils or other residue. Pre-test photos were taken of the seals and weight and inner-diameter measurements were recorded. Pre-test photos were taken of the shafts as well, and their surface roughness profiles were recorded. Shaft roughness averaged 4.020 ± 0.514 µin. for the stainless steel shafts and 5.691 ± 0.758 µin. for the anodized aluminum shafts. A representative profilometer plot of the surface roughness measured around the shaft circumference is shown in Figure 4.

Prior to installation, the seal and shaft were allowed to sit in the dry-room overnight to remove any residual moisture. The seal was then installed in the seal holder with a slight interference fit and oriented with the U-shaped channel opening of the seal facing downward. Note that simulant would be introduced at the top of the rotary seal rig. The seal was match-marked with respect to its orientation in the seal holder to determine if the seal rotated during testing. The top and bottom pieces next to the seal holder were installed using socket head cap screws, SHCS. Attention was given to ensure that no misalignment occurred when tightening the SHCS that bolt the three pieces of the seal holder together. The assembled seal holder was placed on the seal cartridge holder of the rotary seal rig, Figure 3. Depending upon the test seal size, the appropriately sized coupling adapter was used to mate the test shaft to the motor. The test shaft was carefully inserted into the top opening of the seal cartridge and gently pushed downward until seated inside the coupling adapter. After securing the shaft to the coupling, match-marks were made on the shaft and coupling adapter to determine if any slippage occurred during testing. For baseline tests with no lunar simulant added the motor was run for 10,000 cycles. For tests with either JSC-1A or LHT-2M, approximately 20 ml of simulant was added to the top of the seal cartridge prior to test start-up. In addition, a secondary platform was attached to the shaft just below the seal cartridge holder to contain any simulant that may pass through the seal-shaft interface.

After testing was completed, the seal cartridge along with the shaft were removed from the rotary seal rig. Observations were made as to the amount of seal and shaft wear. Post-test analyses included shaft profilometry, seal weight loss, and microscopic examination of both seal and shaft surfaces. For tests with lunar simulant, any simulant remaining at the top of the seal cartridge was removed prior to disassembly and examination of the test seal and shaft. More importantly, observations were made to determine if simulant had passed through the seal-shaft interface. The seal cartridge was disassembled starting from the bottom of the cartridge to determine the extent to which simulant had passed through the seal-shaft interface, if any.

For tests in vacuum, a vacuum-rated motor was used in place of the dry-room motor. The rotary seal rig was placed within a bell jar capable of 10^{-7} Torr, Figure 5. The chamber was then pumped down overnight until approximately $4{\times}10^{-7}$ Torr was reached. Tests were also run at 10,000 cycles and 20 rpm. Disassembly and examination procedures of both the test seal and shaft were identical to dry-room post-test procedures.

Results and Discussion

For all tests run in the dry-room or in vacuum with either JSC-1A or LHT-2M, no simulant was observed to pass through the seal-shaft interface, as shown in Figures 6(a) and (b). Note that only Teflon flakes were observed on the downstream side of the seal-shaft interface. This is indicative of some seal wear as will be quantified later in the discussion. Also note that the simulant was observed to go no further than approximately half-way down the inner diameter of the Bal-Seal.

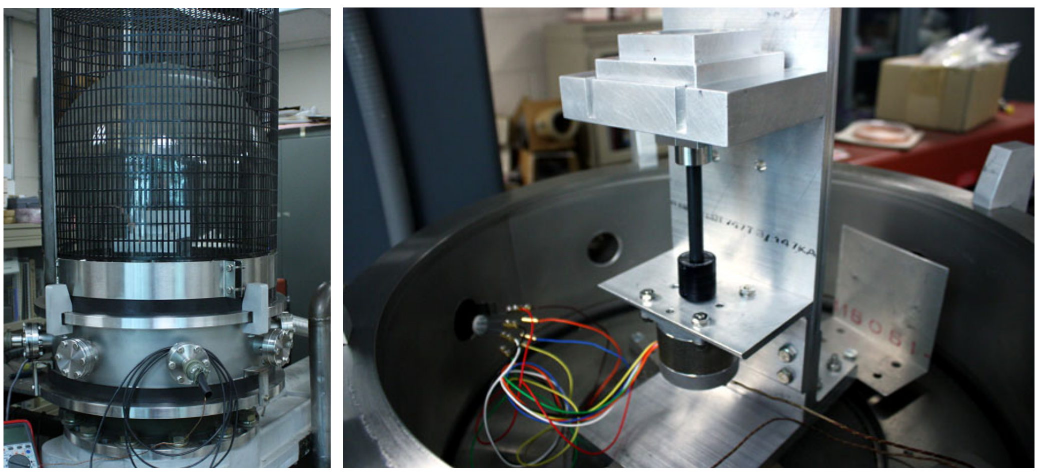
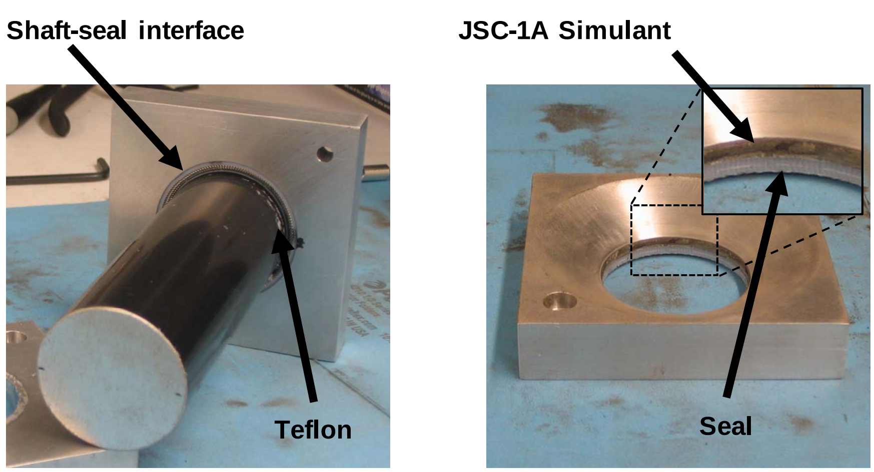


Figure 5.—Bell Jar vacuum chamber containing rotary seal rig test set-up.



a. Downstream side. **b. Seal cartridge holder. Upstream side.**

Figure 6.—Typical seal-shaft observations for tests run with either JSC-1A or LHT-2M.

Table 2 shows results of Bal-Seal tests through 10,000 cycles. In general, seal weight loss was greater for increasingly larger seal diameters due to a larger contact area and increased surface speed due to increased circumference. For example, for dry- room tests run without simulant, the average seal weight loss ranged from 0.11 to 0.33 percent for the 0.375 in. diameter seals, from 0.07 to 0.66 percent for the 0.75 in. diameter seals and from 2.63 to 3.0 percent for the 1.5 in. diameter seals. Post-test roughness profiles for dry-room test shafts run without simulant (Tests A22, A23, B7, B20, C17, C18) were inconclusive ranging from -7.34 percent (smoother surface) to 2.72 percent (rougher surface). In comparison, these same tests run with JSC-1A (Tests A12, B10, C6, A17) showed a more definitive roughness change of 15 percent (rougher surface) on average. Preliminary tests in vacuum show minimal seal weight loss through 10,000 cycles. In fact seal weight loss was identical at -0.11 percent for the 0.375 in. diameter seal tested without and with JSC-1A (Tests A13 and A15, respectively). Seal weight loss was doubled at -0.22 percent for the same sized seal tested with LHT-2M (Test A16). Although the vacuum test results are encouraging, repeat tests are necessary to validate these results. Unfortunately, a malfunction in the vacuum motor occurred after these four tests. Thus further testing was postponed. Post-test surface roughness profiles for the vacuum tested seals were again inconclusive with results ranging from -13.87 percent (smoother surface) to 6.90 percent (rougher surface). Preliminary tests of Bal-Seals against stainless steel shafts show seal weight losses comparable to the anodized aluminum shafts. However, the large change in surface roughness for shaft S-10 does not appear to be consistent with the -0.11 percent seal weight loss of Seal ID A18. In fact, this inconsistency between seal weight loss and change in shaft surface roughness is apparent for a large portion of the test results. Further analysis in data and procedures is necessary to reconcile these differences in surface roughness with seal weight loss. Supplementary testing was performed to determine cycles versus wear for three seal sizes. Results are shown in Figure 7. As expected, the larger contact surface area of the 1.5 in. seals incurred more wear through 10,000 cycles than the 0.75- or 0.375-in. seals. Further long-term testing is necessary to determine if the seal wear rate remains constant, increases, or possibly stabilizes to some final seal weight loss. Note that these tests were run at constant speed and that future tests may involve start-stop cycles, ramp-up and ramp-down in speed, etc. Finally, infrared microscopy has confirmed the presence of Teflon being transferred to the anodized aluminum shaft surface. The presence of Teflon on the rotating surface provides additional lubrication between the shaft and seal which could potentially increasing seal-shaft life. Further tests are needed to assess the performance of this lubricating layer through extended operations.

TABLE 2.—WEAR RESULTS FOR BAL-SEAL TESTS THROUGH 10,000 CYCLES

Seal ID	Environ.	Seal Diameter [in.]	% Wt Change	Simulant	Shaft	Shaft ID	%ΔRa
A22	Dry Room	0.375	-0.24	none	Anod. Al	SA22	2.16
A23	Dry Room	0.375	-0.33	none	Anod. Al	SA23	-1.25
B7	Dry Room	0.75	-0.61	none	Anod. Al	SB7	-5.20
B20	Dry Room	0.75	-0.87	none	Anod. Al	SB20	-7.34
C17	Dry Room	1.5	-3.00	none	Anod. Al	SC17	0.04
C18	Dry Room	1.5	-2.63	none	Anod. Al	SC18	2.72
B12	Dry Room	0.75	-0.13	none	SS	T6	5.32
A12	Dry Room	0.375	-0.27	JSC-1A	Anod. Al	SA51	12.14
B10	Dry Room	0.75	-0.54	JSC-1A	Anod. Al	SB10	13.73
C6	Dry Room	1.5	-1.46	JSC-1A	Anod. Al	SC51	19.55
B13	Dry Room	0.75	-0.66	JSC-1A	SS	T8	-0.39
A17	Dry Room	0.375	-0.17	LHT-2M	Anod. Al	SA55	14.81
A18	Dry Room	0.375	-0.11	LHT-2M	SS	S-10	30.48
A13	4x10^-7 torr	0.375	-0.11	none	Anod. Al	SA52	-13.87
B11	4x10^-7 torr	0.75	-0.07	none	Anod. Al	SB51	5.70
A15	3x10^-7 torr	0.375	-0.11	JSC-1A	Anod. Al	SA53	-8.03
A16	4x10^-7 torr	0.375	-0.22	LHT-2M	Anod. Al	SA54	6.90

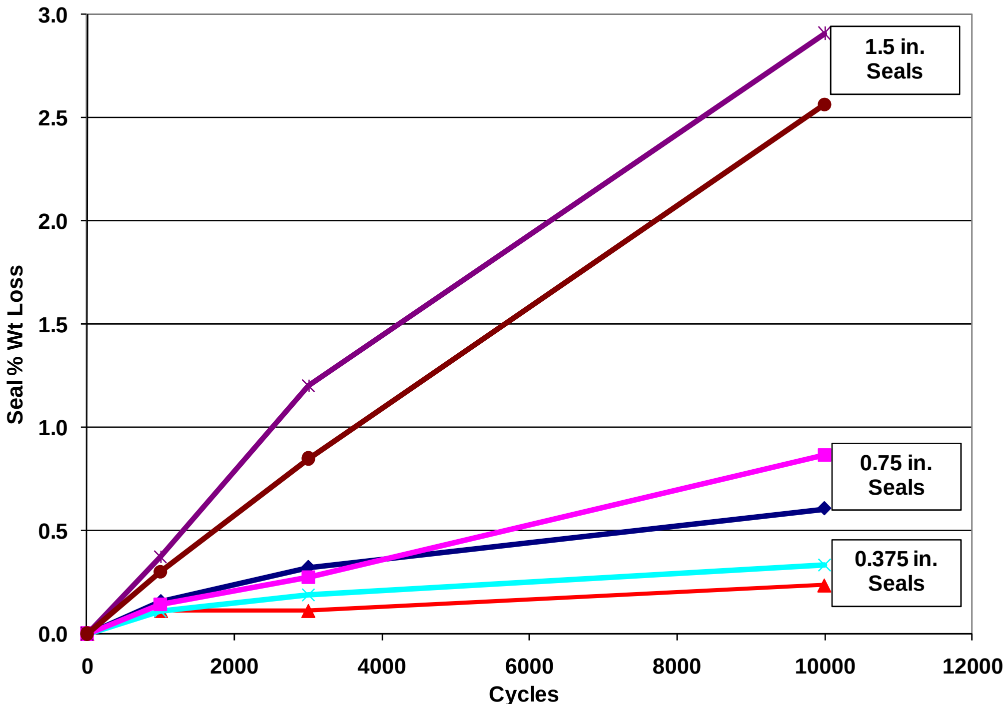


Figure 7.—Seal percent weight loss versus cycles.

Conclusions and Recommendations

Seals of three different diameters were tested: 0.375-, 0.75-, and 1.5-in. Tests were conducted at 20 rpm up to 10,000 cycles in dry-room and vacuum conditions using lunar simulants JSC-1A and LHT-2M. For the tests conducted:

- No simulant was observed to pass through the seal-shaft interface.
- A minimal amount of wear was observed on both seal and shaft. Seal weight loss was minimal with only Teflon ‘flakes’ observed on the downstream side of the seal.
- Shaft profilometery generally show a slight deterioration in shaft surface roughness with simulant use. Inconsistencies between surface roughness and seal weight loss require further analysis.
- Infrared microscopy of the anodized aluminum shaft surface has revealed the presence of Teflon which is beneficial as a lubricant between the seal and shaft during operation.

Based on these results, further tests are planned including effects of temperature and extended cycles in vacuum. Efforts are also underway to integrate the seal tests with NASA Lunar Surface Systems architectures.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT
Component tests were conducted on spring-loaded Teflon seals to determine their performance in keeping lunar simulant out of mechanical component gearbox, motor, and bearing housings. Baseline tests were run in a dry-room without simulant for 10,000 cycles to determine wear effects of the seal against either anodized aluminum or stainless steel shafts. Repeat tests were conducted using lunar simulants JSC-1A and LHT-2M. Finally, tests were conducted with and without simulant in vacuum at ambient temperature. Preliminary results indicate minimal seal and shaft wear through 10,000 cycles, and more importantly, no simulant was observed to pass through the seal-shaft interface. Future endurance tests are planned at relevant NASA Lunar Surface System architecture shaft sizes and operating conditions.

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