

# Testbed for Lunar Extreme Environment Wear Tolerant Applications

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**Abstract:** The abrasive dust from lunar regolith poses significant long-term durability and performance challenges to materials, vehicles, mechanisms and structures that will be used for the next generation of lunar exploration. The development of advanced materials and device technologies that can withstand these abrasive particles and extreme environmental conditions is critical. However, the lack of standardized and accessible methods for evaluating such materials and devices in a facsimile of the harsh lunar environment hinders progress in dust-tolerant technologies. To address this challenge, NASA Langley Research Center is creating an extreme environment testbed. This reconfigurable testbed will allow rapid, repeatable wear testing of material and candidate mechanisms under vacuum conditions, facilitating the development of critical materials technologies for lunar exploration. Preliminary results from exposing an actuating mechanism similar to a pin joint to lunar regolith simulant under high vacuum are reported.

## Introduction: Opportunities and Challenges

### Lunar Environment

Enabling a sustainable human presence on the Moon requires technologies capable of withstanding the harsh lunar environment<sup>1-5</sup>:

- Atmospheric Pressure:  $2.25 \times 10^{-12}$  Torr ( $2.96 \times 10^{-15}$  atm)
- Ultraviolet (UV) radiation, galactic cosmic rays and solar particle events
- Temperature gradients:  $> 260^\circ\text{C}$  ( $500^\circ\text{F}$ )
- Lunar dust: Composition varies
  - Mixture of crystalline and amorphous
  - Abrasive, jagged morphology
  - Electrically charged

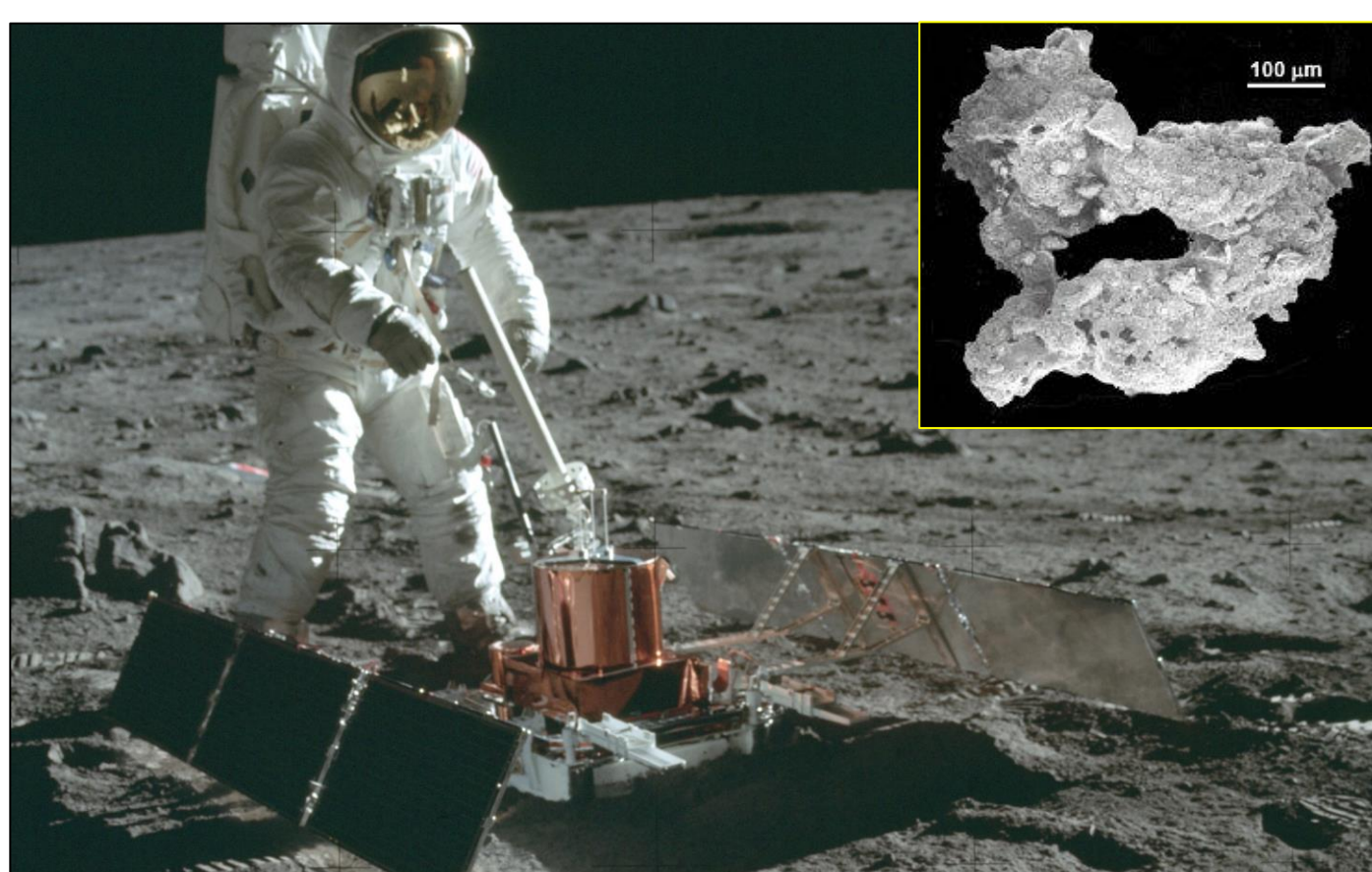


Fig. 1 Apollo 11 deployment of passive seismic experiment on lunar surface required displacement of regolith; inset image shows irregular, barb-like morphology of lunar dust particle

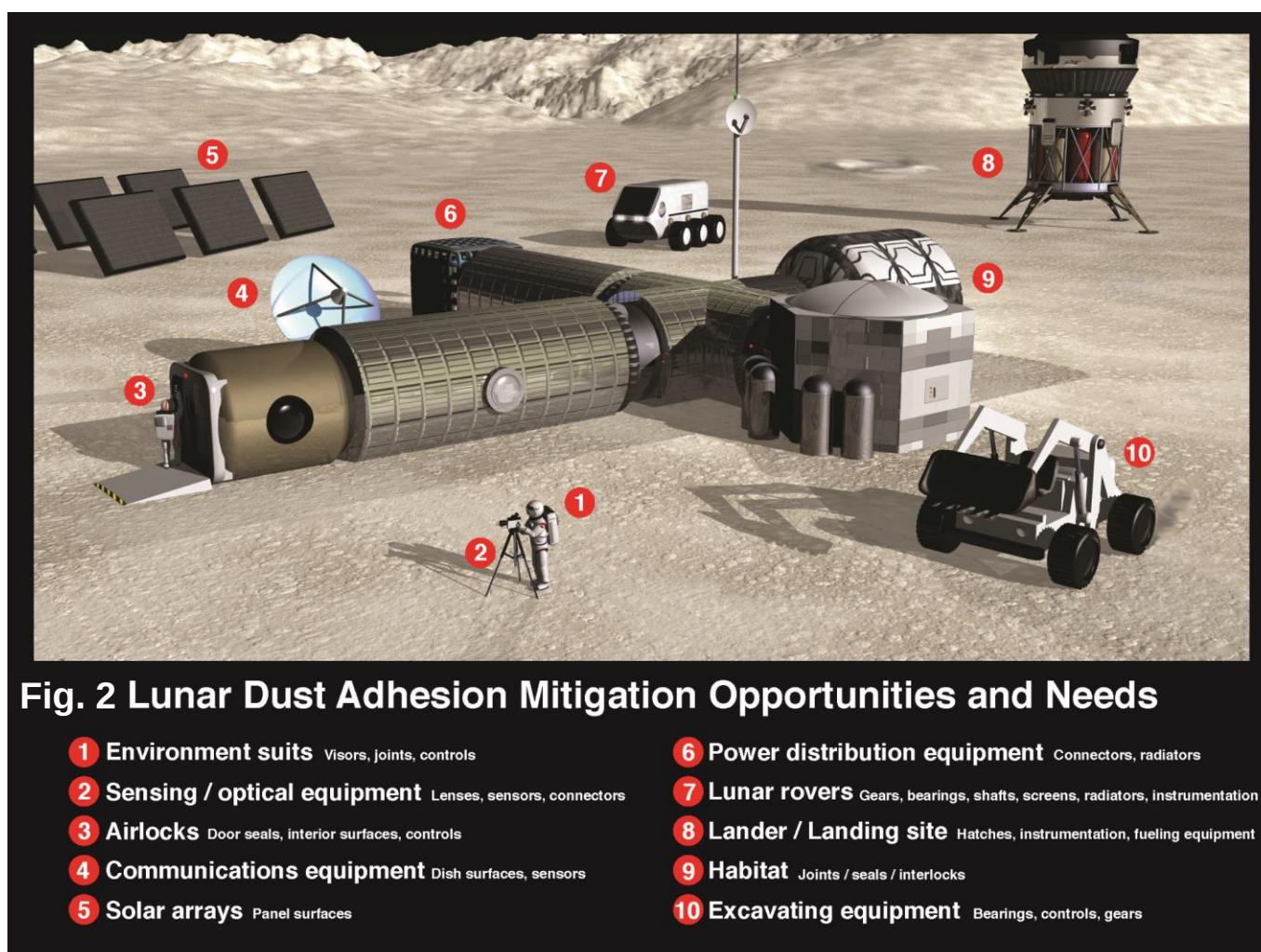


Fig. 2 Lunar Dust Adhesion Mitigation Opportunities and Needs

### Problem

- Dust threatens long-term durability of mechanisms operating on lunar and Martian surfaces
- Current ground-based tests do not capture combinatorial effects of lunar environment
- Flight experiments possess restrictions, such as duration, size, geometry and weight of specimens or on the type of exposure and access that limit test capabilities in authentic and controlled environments

A lack of standard, routine lab-based tests capable of subjecting materials to aspects of the lunar environment, such as wear by dust, large temperature gradients ( $>500^\circ\text{F}$ ), deep ultraviolet (DUV) radiation and vacuum of space, limit identification of durable materials technologies needed to enable a sustainable human presence on the Moon. Short of testing on the Moon, current test methods do not capture combinatorial effects of the lunar environment in a single, repeatable, lab-based approach.

## Surveying Lunar Dust Influence on Device Efficacy (SLIDE) Apparatus

### Goal

Construct and validate an extreme environment testbed for rapid, repeatable wear testing by dust under vacuum to vet and expedite critical materials technologies and mechanisms from concept to device.

### SLIDE Capabilities

- Simultaneously subject materials and mechanisms to:
  - Wear caused by dust (standard abrasives, lunar/Martian regolith simulants, etc.)
  - High vacuum  $>10^{-6}$  Torr ( $1.32 \times 10^{-12}$  atm)
  - Temperature fluctuations from room temperature to  $-190^\circ\text{C}$  ( $-310^\circ\text{F}$ )
  - DUV radiation ( $\sim 6\text{ eV}$ )
- Configurable to accommodate variety of materials, mechanisms and abrasives relevant to applications

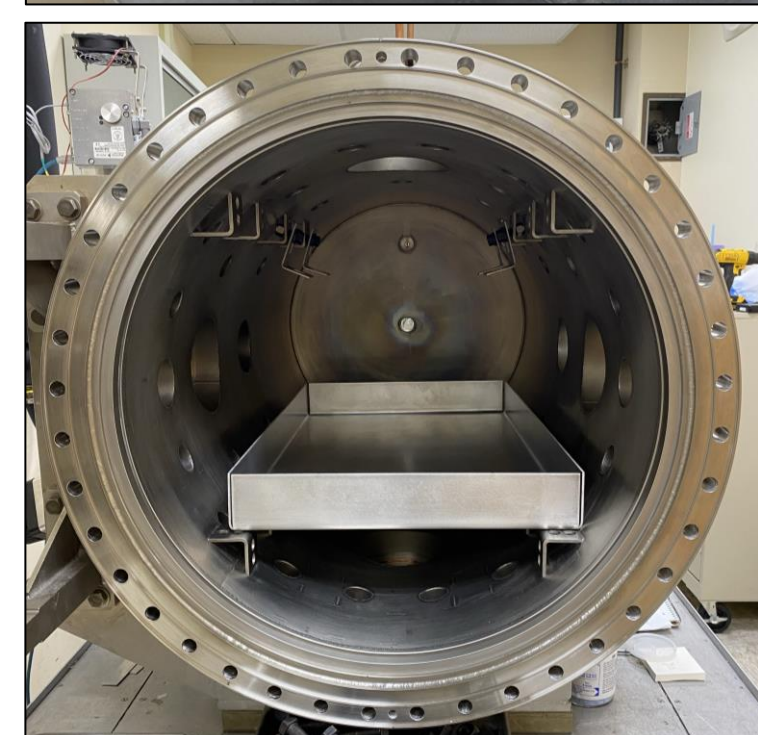
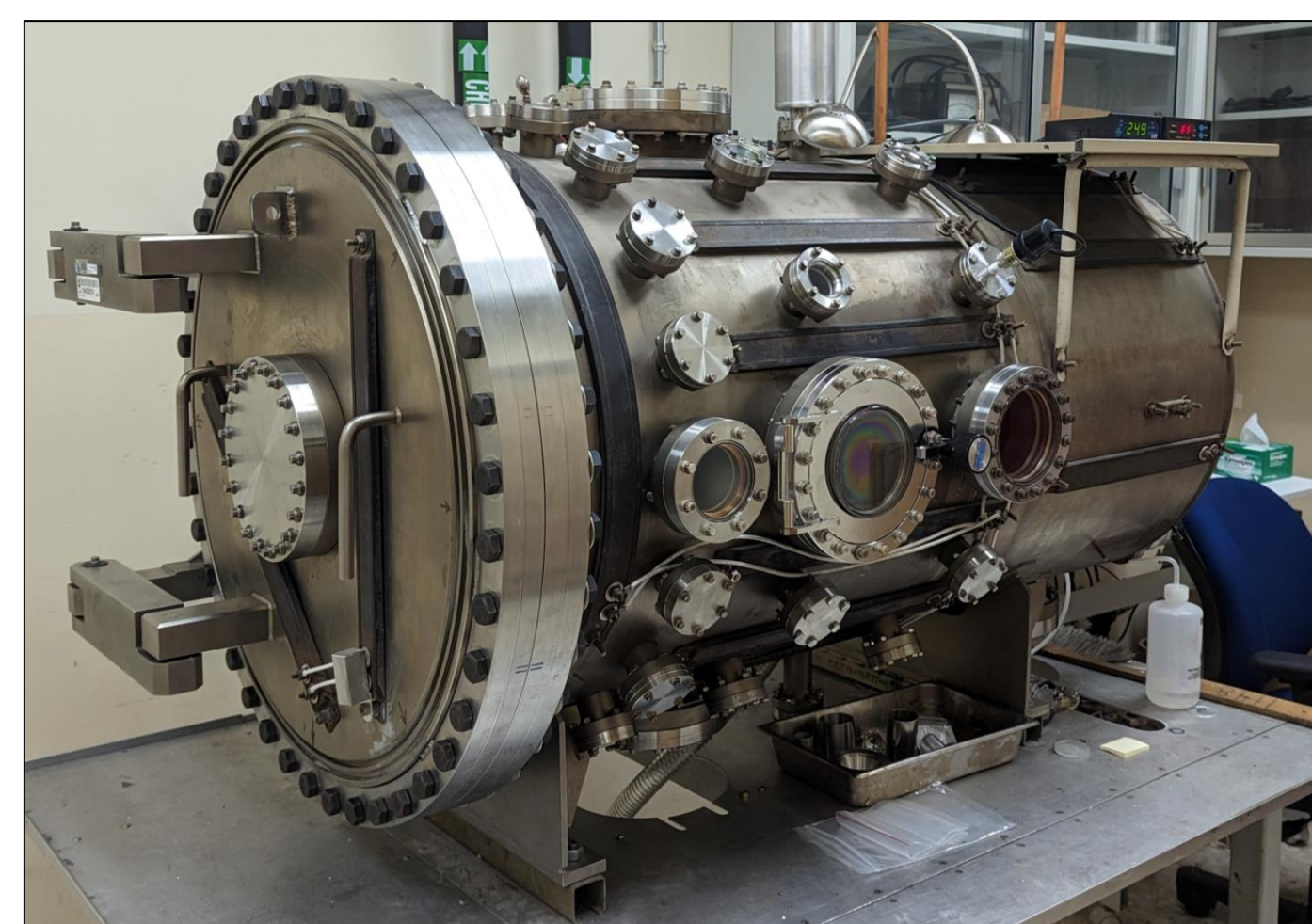


Fig. 3 (Top) SLIDE chamber with (left) interior view of chamber. Access door has diameter of 61 cm to accommodate a variety of mechanism sizes and geometries.

## SLIDE Apparatus Configuration

The SLIDE apparatus consisted of a stainless-steel vacuum chamber with multiple ports and feedthroughs.

### Pumping System

- Roughing pump to  $10^{-3}$  Torr ( $1.3 \times 10^{-6}$  atm) level
- Turbomolecular pump to approximately  $10^{-6}$  Torr ( $1.32 \times 10^{-12}$  atm)
  - Mounted on a 90-degree bend attached to a gate valve to mitigate dust incursion into the pump

### Interior Dimensions

- Diameter of primary chamber door is 61 cm and sealed using nuts, bolts and a copper gasket
- Approximate working volume: 86 cm (length) by 46 cm (width) by 51 cm (height)
- Optional containment housing minimizes dust contamination within the chamber

### Dust Shaker

A custom dust shaker (Fig. 5) was designed to release controlled amounts of lunar dust simulant.

- **Sieve:** Stainless steel mesh opening of  $106\text{ }\mu\text{m}$  with an acrylic cover secured to base plate using nylon bolts
- **Shaker support:** Aluminum base plate supported by four rubber boots that surrounded nylon bolts attached to chamber mounting plate
- **Shaker mechanism:** Rotating copper weight affixed to variable 24V-DC electric motor (maximum rotational rate of 5300 RPM) to induce vibration on base plate

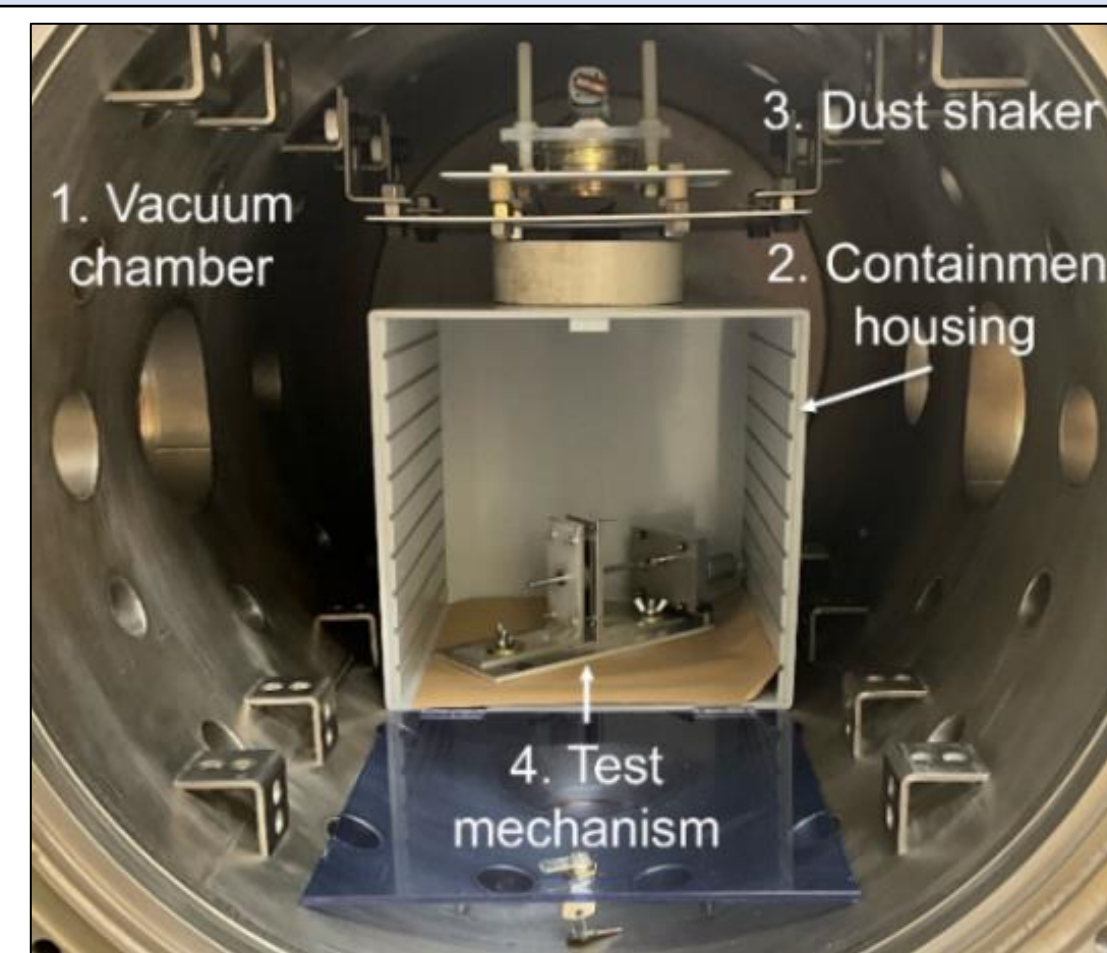


Fig. 4 Inside view of (1) vacuum chamber with (2) housing, (3) dust shaker and (4) test mechanism

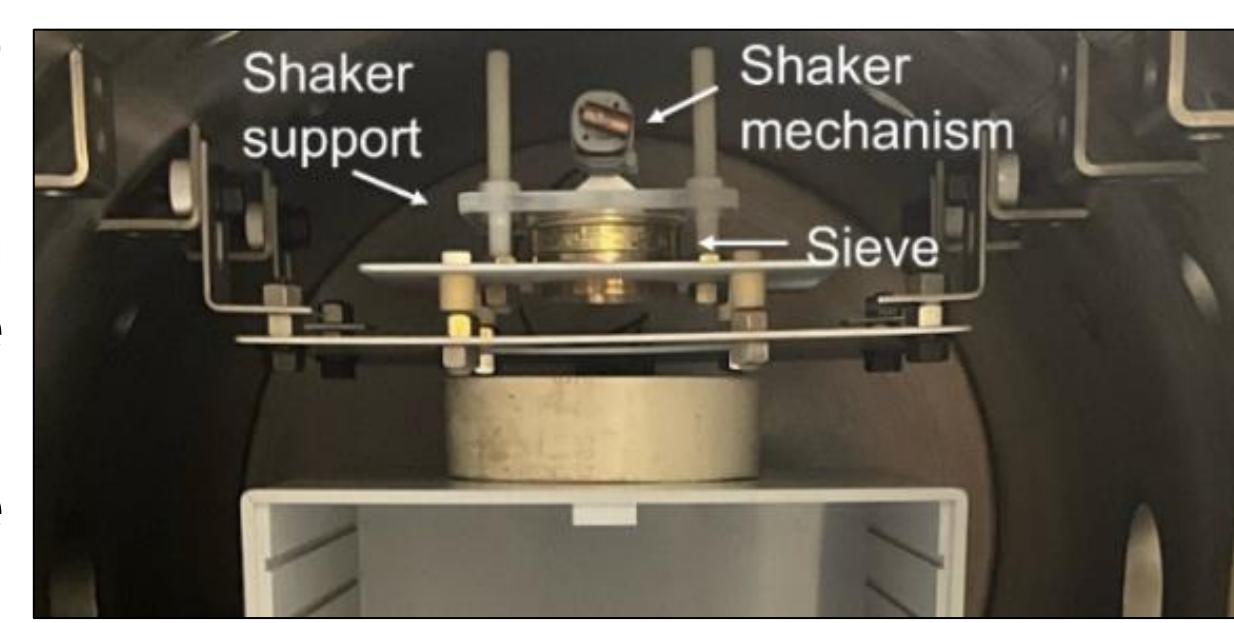


Fig. 5 Dust shaker device installed in SLIDE apparatus

## Pilot Assessment of Material Wear Performance

### Test Mechanism

A test mechanism was fabricated to replicate aspects of the three-body abrasive wear encountered by two dissimilar materials in a pin-joint-like configuration exposed to dust.

- Electric motor rotated drive shaft that ran through a hole in center of active disc (2.54-cm-diameter) that turned at a rate of 1.3 RPM
- Test coupon (3.8 cm x 3.3 cm) abraded through contact with active plate
- L-brackets aligned and secured such that test surface of the coupon was flush with the surface of the active disc.

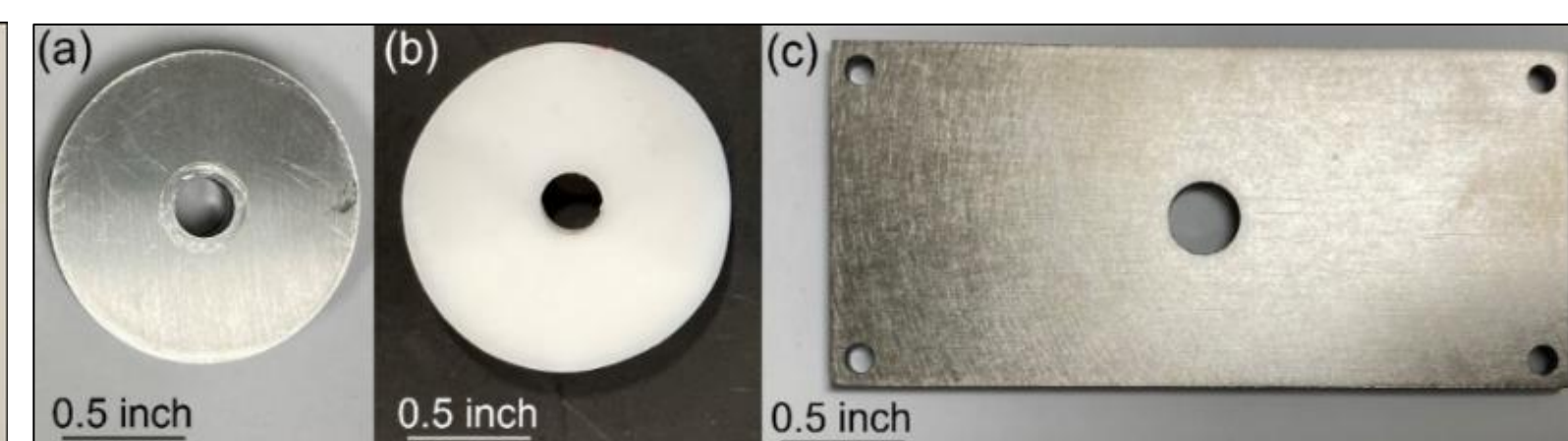
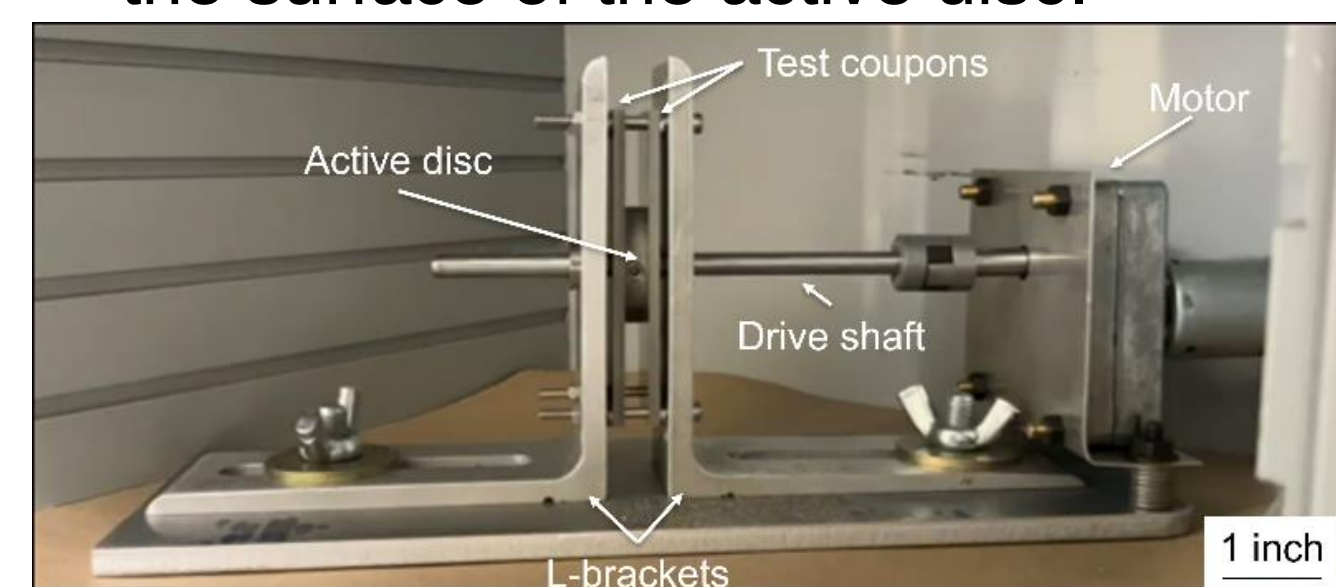


Fig. 6 (Left) Pilot test mechanism comprised of (a) Al6061 or (b) PTFE active plate and (c) Ti-6Al-4V test coupon

### Materials

- **Active plate:** Aluminum 6061 alloy (Al6061) or polytetrafluoroethylene (PTFE)
- **Test coupon:** Titanium-aluminum-vanadium alloy (Ti-6Al-4V)
- **Simulant:** Pre-sieved LHS-1D (Exolith Lab, Oviedo, Florida) particles  $<45\text{ }\mu\text{m}$

### Procedure

- Pump down of vacuum chamber until  $< 10^{-4}$  Torr ( $1.32 \times 10^{-7}$  atm) reached ( $\sim 15\text{ min.}$ )
- Preliminary roughness parameters of test coupon surface calculated using FormFactor FRT Microprof 100 profilometer (Livermore, CA) before and after test

## Preliminary Results

### Dust Shaker Surface Dust Accumulation Loading

The deposition rate of lunar dust simulant at ambient pressure was determined through a series of dust shaker trials by powering the electric motor at 6 V and 24 V. A programmable 30 V power supply (KORAD KA3305P) was used. The dust shaker loaded with 5 g of lunar dust simulant was actuated. Dust simulant that was collected was weighed using a high-precision scale to calculate the surface accumulation loading averaged over three deposition cycles at each electric motor voltage level.

- Human-generated surface transported dust<sup>2</sup>:  $< 40\text{ g/m}^2$
- SLIDE dust shaker:  $\sim 40\text{ g/m}^2$  after 15 sec.

### Results of Pilot Study on Assessment of Material Wear

Preliminary optical and profilometry results for a Ti-6Al-4V coupons tested in contact with an Al6061 active disc after wear testing with lunar dust simulant ( $\sim 141.8\text{ g/m}^2$ ) in vacuum are shown in Figure 7. The circular wear pattern was evident in optical and profilometry data of the coupon tested without and with lunar dust simulant compared with the starting surface.



### Without Dust (Control)

- **PTFE Active Plate:** No appreciable change in roughness of Ti-6Al-4V coupon
- **Al6061 Active Plate:** Statistically significant increase in  $R_a$  and  $R_q$  parameters compared to those of starting Ti-6Al-4V coupon

### With Dust

- **PTFE Active Plate and Al6061 Active Plate:** Statistically significant increase in surface roughness parameters

Table 2. Summary of Selected Surface Roughness Parameters for Ti-6Al-4V Test Coupons before and after Wear Testing in SLIDE with or without Dust.

| Test Coupon Material | Active Disc Material | Lunar Dust Simulant | $R_a$ ( $\mu\text{m}$ ) | $R_q$ ( $\mu\text{m}$ ) |
|----------------------|----------------------|---------------------|-------------------------|-------------------------|
| Ti-6Al-4V            | N/A (Control)        | N/A                 | $0.005 \pm 0.001$       | $0.006 \pm 0.001$       |
| Ti-6Al-4V            | PTFE                 | No                  | $0.006 \pm 0.001$       | $0.007 \pm 0.001$       |
| Ti-6Al-4V            | PTFE                 | Yes                 | $0.012 \pm 0.003$       | $0.014 \pm 0.003$       |
| Ti-6Al-4V            | Al6061               | No                  | $0.008 \pm 0.001$       | $0.010 \pm 0.001$       |
| Ti-6Al-4V            | Al6061               | Yes                 | $0.014 \pm 0.002$       | $0.019 \pm 0.002$       |

- Introduction of lunar dust simulant resulted in a higher degree of wear of the Ti-6Al-4V surface than in wear tests without lunar dust simulant

## Summary and Continuing Efforts

SLIDE testbed was developed to enable rapid advancement of critical technologies from conceptual stages to practical device implementation for lunar applications.

- Designed and installed dust shaker that yields appropriate flow rate of dust onto test article in SLIDE chamber
  - Dust shaker allows continuous or cyclical deposition of dust onto test article
- Performed materials pilot mechanism testing under high vacuum with lunar dust simulant in SLIDE chamber
  - Preliminary results showed increased surface roughness of Ti-6Al-4V coupons tested with dust compared to that of the coupons tested without dust exposure
- Compounding environmental effects, such as thermal gradients, cryogenic exposure, UV radiation and electrostatic exposure are being explored for SLIDE
- Testing using aspects of other extraterrestrial environments, such as Mars, by utilizing Martian dust, regulating pressure and incorporating carbon dioxide