An Overview of the NASA LO-DuSST Project

(Lunar Occupancy Dust Surface Separation Technologies)

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Why is Lunar Dust so Problematic?

Apollo missions demonstrated that dust was a limiting factor for lunar surface operation and posed a health concern when it penetrated habitable spaces. Dust mitigation (DM) is required to enable ARTEMIS.

- The Problem: Hazards associated with hard, sharp, fine, chemically reactive lunar dust
  - Impact on people:
    - Potential inhalation health hazard
    - Embeds in, abrades soft materials
    - Reduces visibility through optical surfaces by scatter and scratching
  - Impact on habitats, equipment, and mission operations:
    - Reduces performance efficiency of solar arrays and radiators
    - Compromises sealing of critical, gas-tight surfaces
    - Accelerates wear on and increases jamming of moving surfaces
    - Variable with lunar locations and specific dust characteristics

Apollo astronaut glove covered in lunar dust
Image credit: NASA

- The Need:
  - Reduce health hazard associated with incidental exposure
  - Improve functioning and increase equipment lifetime
  - Expand lunar surface mission options, longer lifetime for deployed systems, minimize risk of lunar system capability loss (i.e., magnitude and duration) and increase system reliability, and create a greater probability of mission success
  - DM is needed to support NASA's Plan to Return to the Moon by 2024 and Lunar Sustainability by 2028 (LSII project)

Quantitative Impact: preliminary studies show adhesion reductions of 80% to 95% for various removal techniques.

Flanagan and Goree, Dust release from surfaces exposed to plasma, Physics of Plasma 13, 123504, 2006. Schwan, J., et al., The charge state of electrostatically transported dust on regolith surfaces, Geophy. Res. Lett., 44, 3059, 2017. Godyak. V,. Ferromagnetic enhanced inductive plamsa source. J. Phys. D: Appl. Phys., 46, 283001, 2013. Wang. X et al. https://sservi.nasa.gov/articles/video-dust-charging-and-mobilization/

Where is Lunar Dust Mitigation Important?

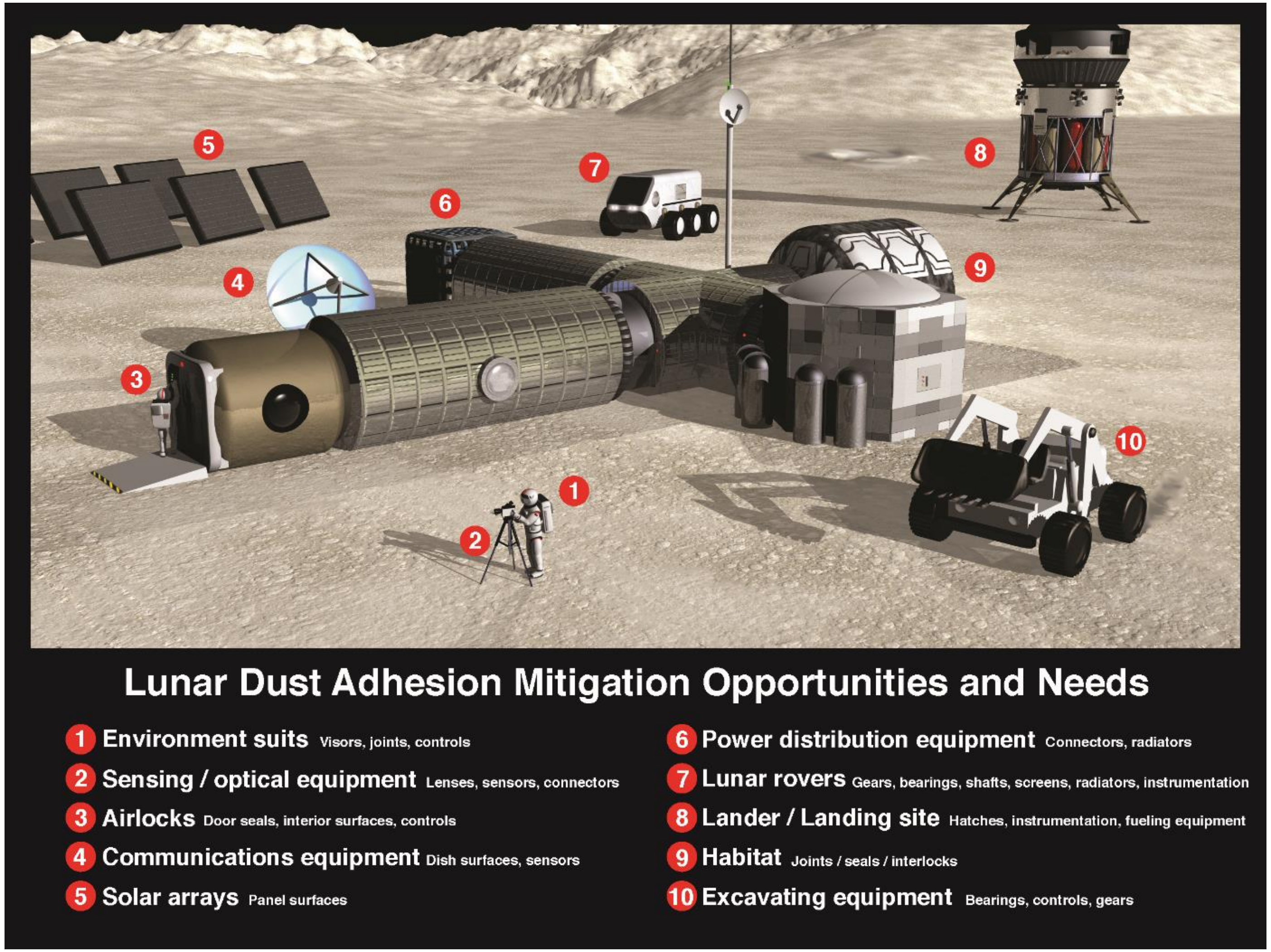
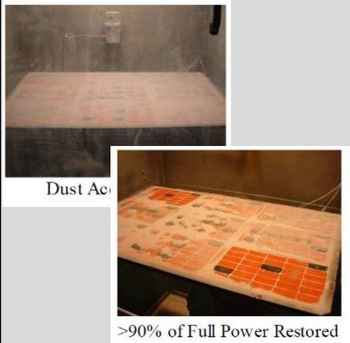


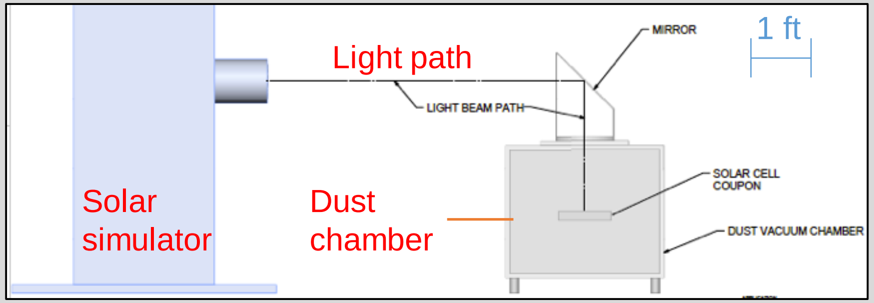
Image credit: NASA

LO-DuSST Focal Areas

Active-Solar Panel Array Protection

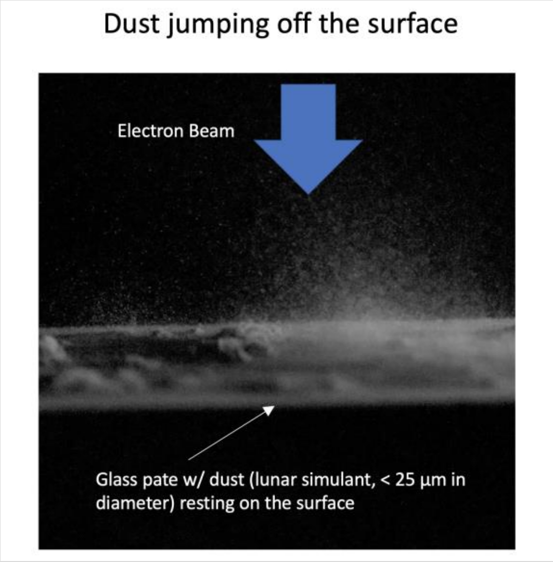
- Integration of Piezoelectric and other active/passive technologies to realize reliable and resilient power generation at mission-relevant scales
- Technologies evaluated through high fidelity ground testing





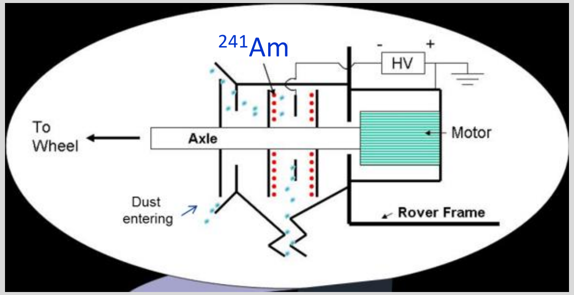
Active-Lunar Dust Lofting

- Patched charge model
- Dust exposed to focused electron beam
- Negative charge buildup arising from absorption of secondary emission electrons within micro-cavities
- Repulsion results in observed dust lofting and ejection



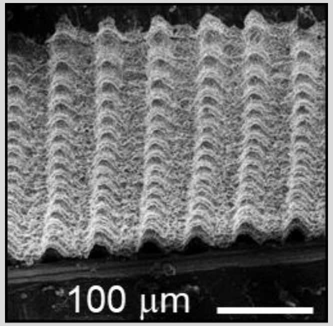
Active-Electrostatic Repulsion in Confined Geometries

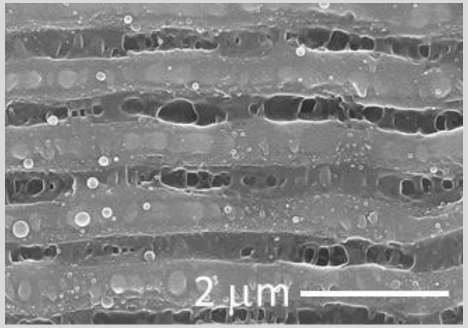
- Prevention of infiltration of lunar dust in critical locations using electrostatic repulsion



Passive-Complementary Adhesion Mitigation Materials

- Surface chemical, topographical, and mechanical properties
- Metals, ceramics, polymers





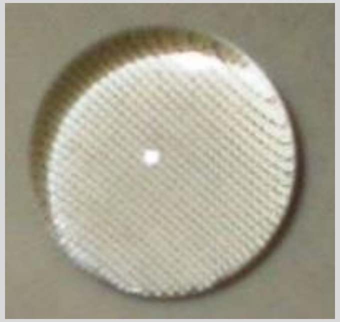


Image credit: NASA

Connectivity with Other Lunar Research Activities

VIPER-like Vehicles

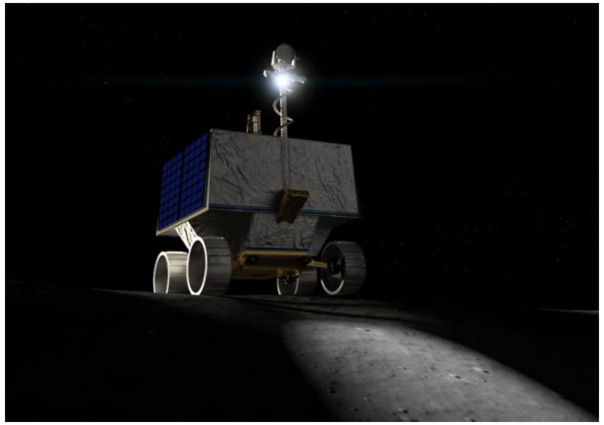


Image credit: ARC, Daniel Rutter

Safe Haven Inflatable Structures

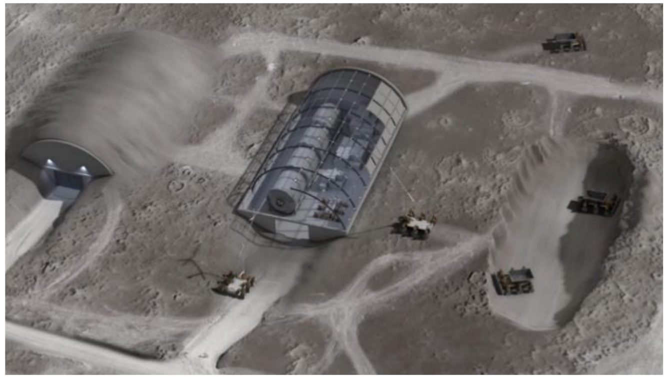


Image credit: NASA

Patch Plate Materials Assessment

LO-DuSST

Plume-Surface Interactions

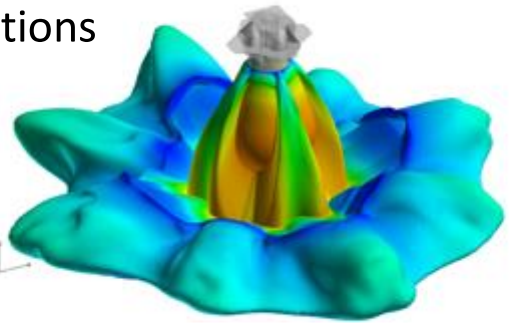


Image credit: Peter Liever/NASA MSFC/2019

Lunar Surface Manipulation Systems

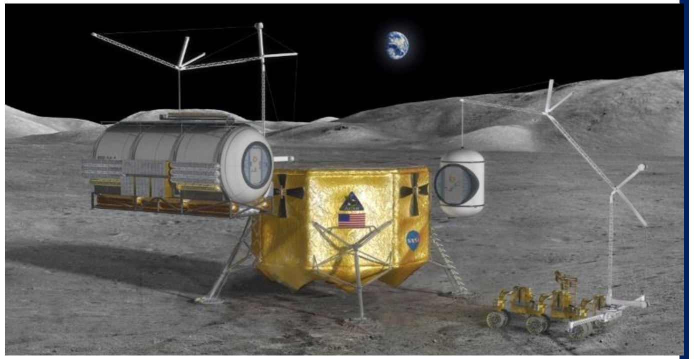


Image credit: LaRC, AMA, Tom Jones

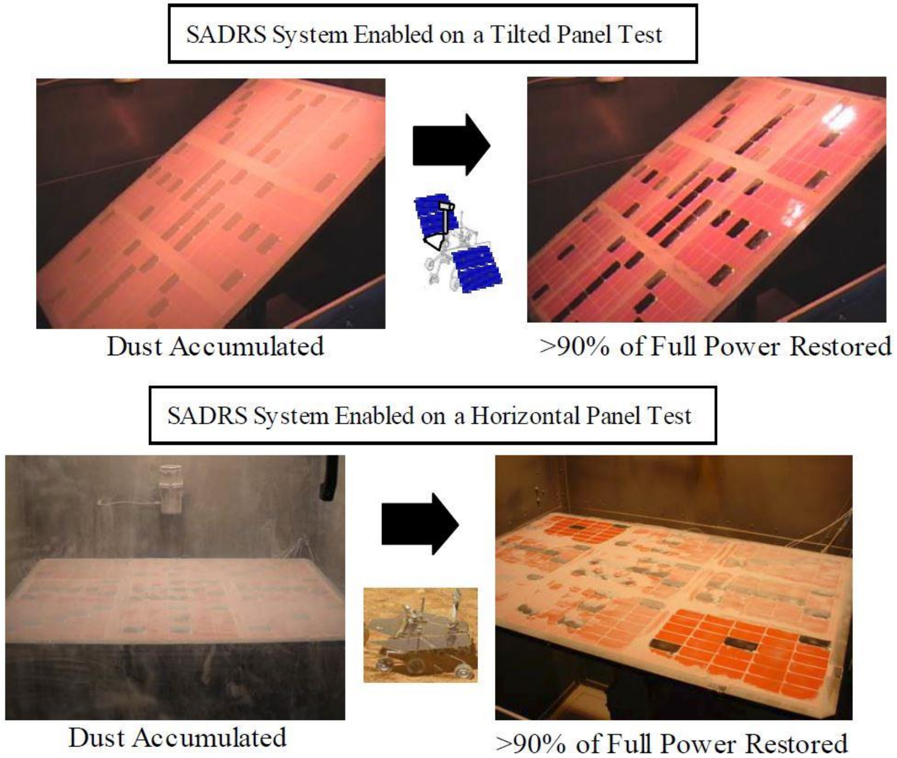
LO-DuSST Team

- Project Lead
  LaRC
  - Electrostatics/ Inorganic Materials
    GRC
    - Inorganic Materials
    - Electrostatics
  - Polymeric Materials/ Quantitative Adhesion
    LaRC
    - Polymeric Materials
    - Simulant Studies
    - High Wear Ceramics
  - Plasma Dust Lofting
    JPL
    - Mobile System
    - Habitat System
  - Solar Arrays
    JPL
    - Solar Panels
    - Piezoelectrics

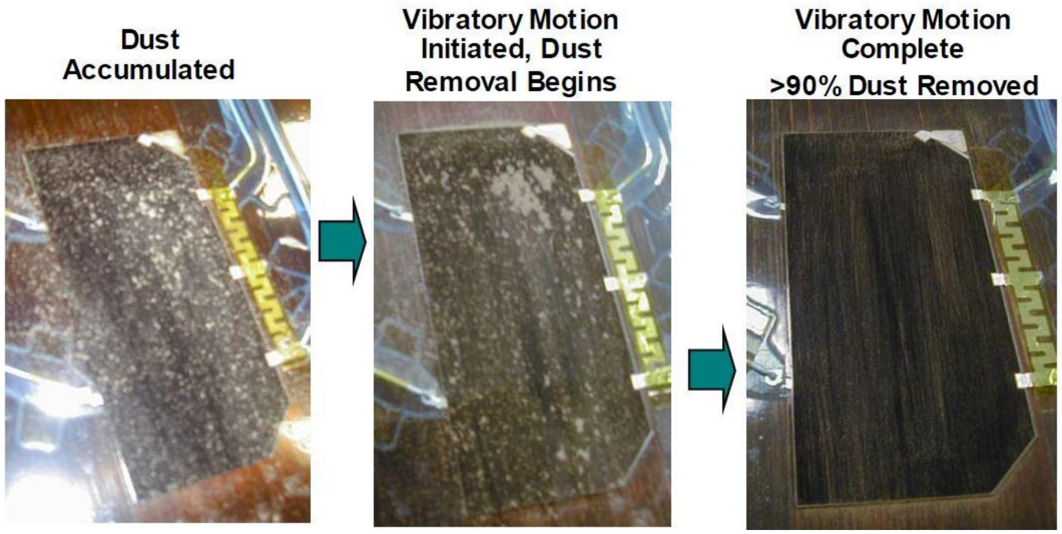
Solar Array Protection

Previous Research-Solar Array Dust Removal System (SADRS)

Indium Tin Oxide (ITO) Dependency ITO-coated Surfaces Clean Better



SADRS using Mars simulant and piezoelectric activation

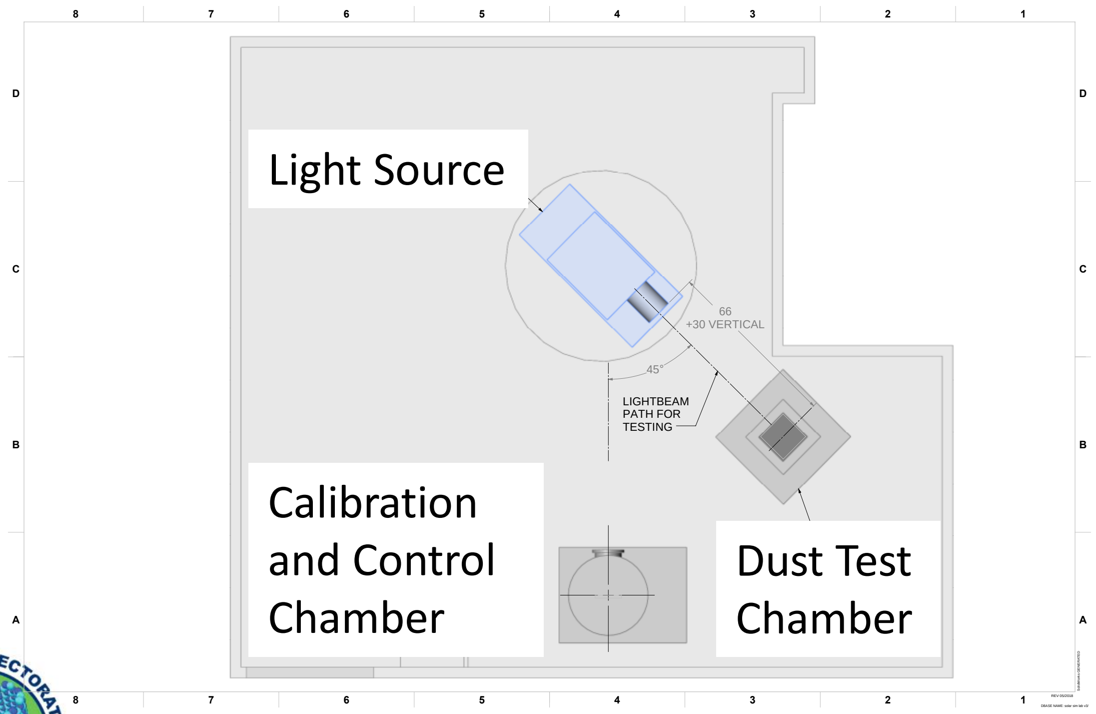


**Mars dust simulant used in all tests shown.*

Image credit: NASA

Solar Array Protection
Recent Activities

Laboratory Reconfiguration



Evaluation Chamber Design

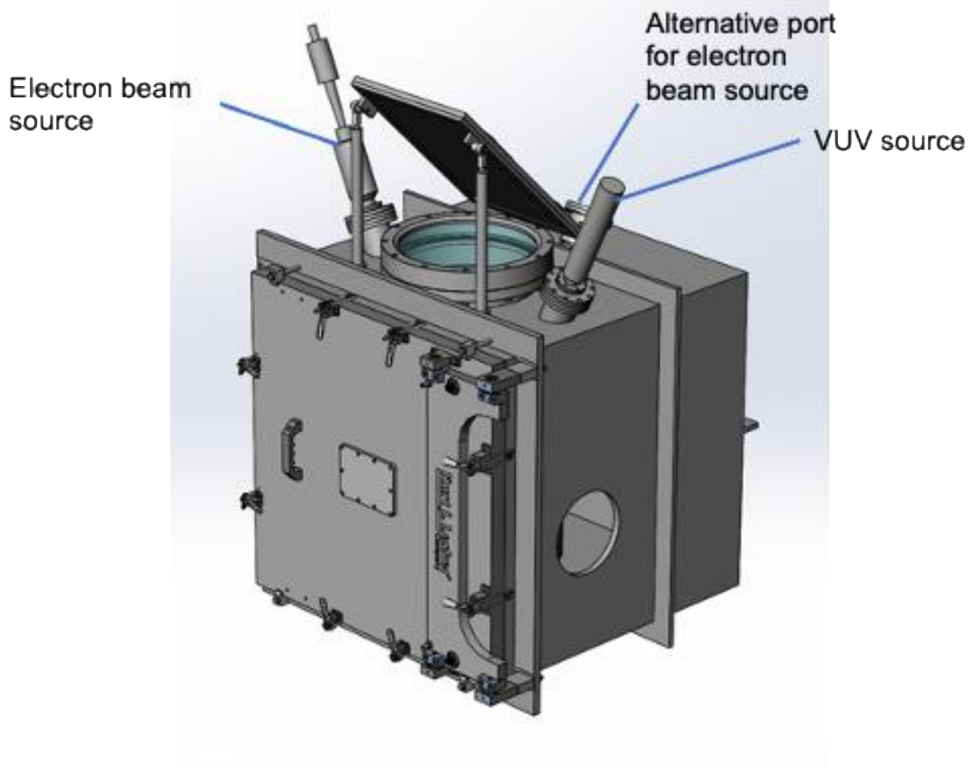


Image credit: NASA JPL

Dust Lofting Technique

Previous Research

Plasma Dust Lofting from Extra-Vehicular Activity (EVA) Suit

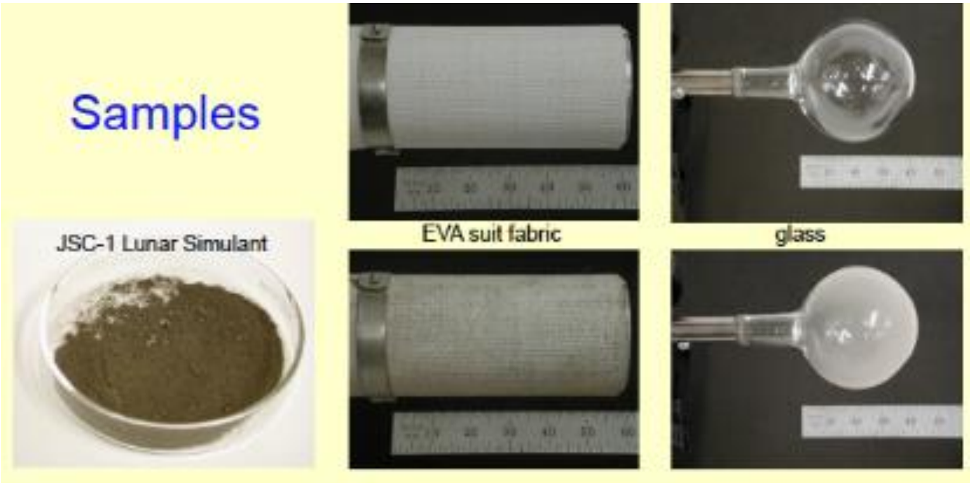
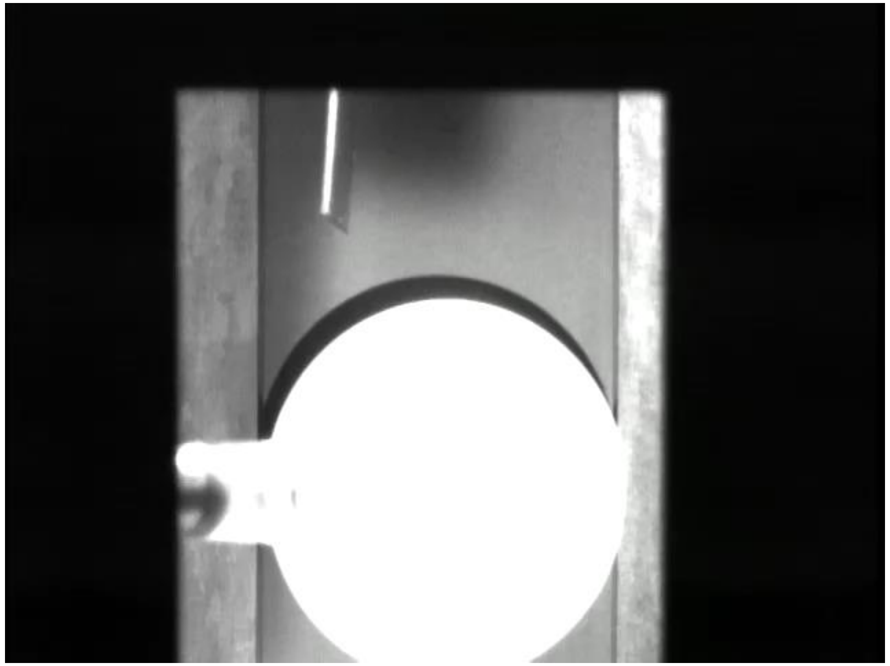


Image credit: J. Goree, "Iowa Dust Mitigation Scheme for EVA Suits in a Lunar Habitat" NASA Dust Mitigation Technology Focus Group Workshop, Golden, CO, 2005

Test System with Light in Dust Vacuum Chamber

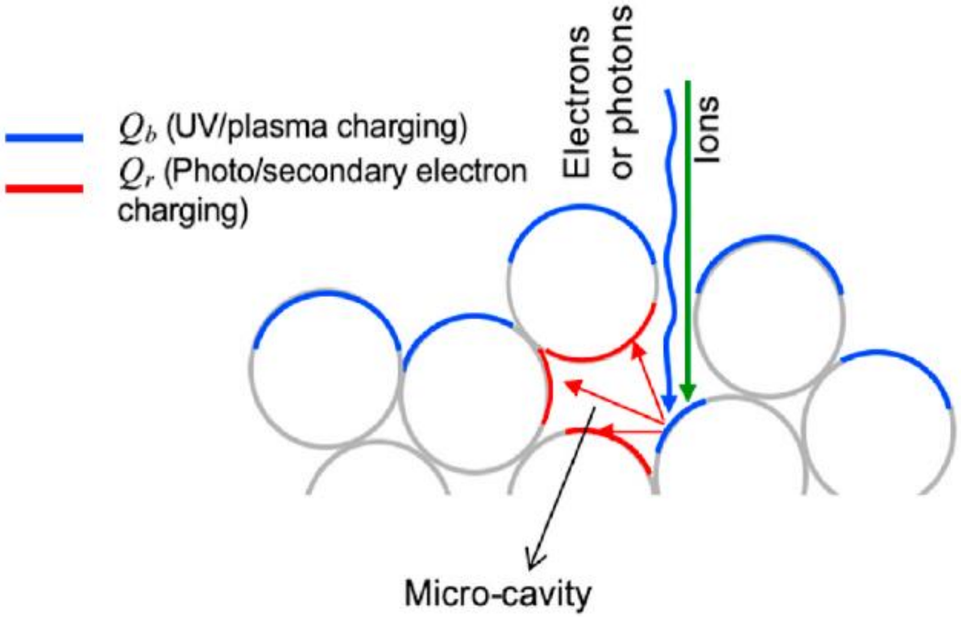


Movie credit: Flanagan & Goree, Phys. Plasmas 13, 123504, 2006

Dust Lofting Technique

Recent Activities

Determination of Dust Lofting Mechanism



Test System with Light in Dust Vacuum Chamber

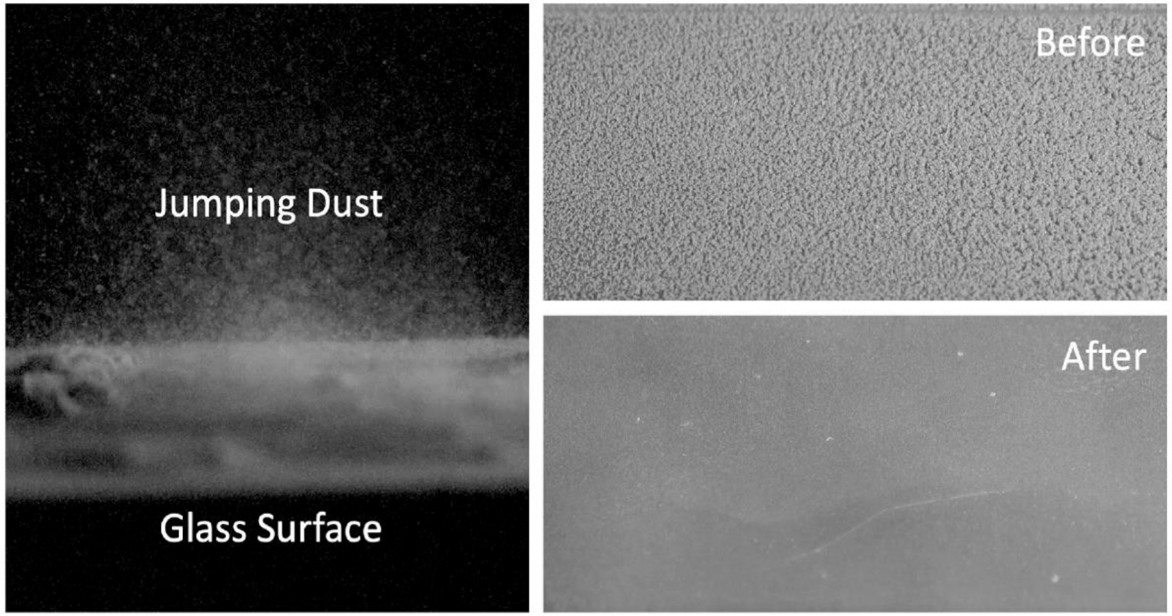


Image credit: B. Farr, X. Wang, J. Goree, I. Hahn, U. Israelsson, M. Horányi, Acta Astronautica 2020, 177, 405-409.
https://doi.org/10.1016/j.actaastro.2020.08.003

Electrostatic Attraction/Repulsion
Concept

- Alpha particle charging of dust particles from Americium-241 (used in smoke detectors) …
- … in combination with electrodes to electrostatically clear dust particles
- Harnesses lunar vacuum environment
- Envisioned to prevent infiltration of lunar dust into sensitive environments such as bearings, shafts, and housings for sensitive equipment

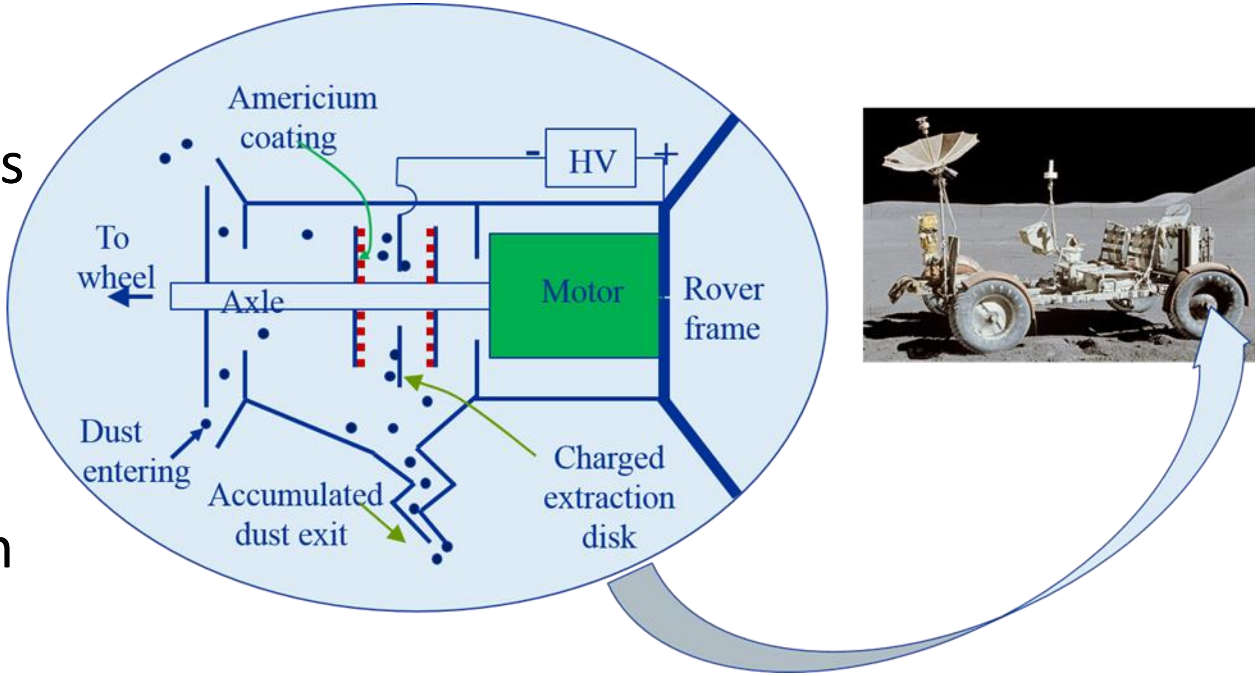


Image credit: NASA

Electrostatic Attraction/Repulsion

Recent Activities

Test Chamber

Experimental Design

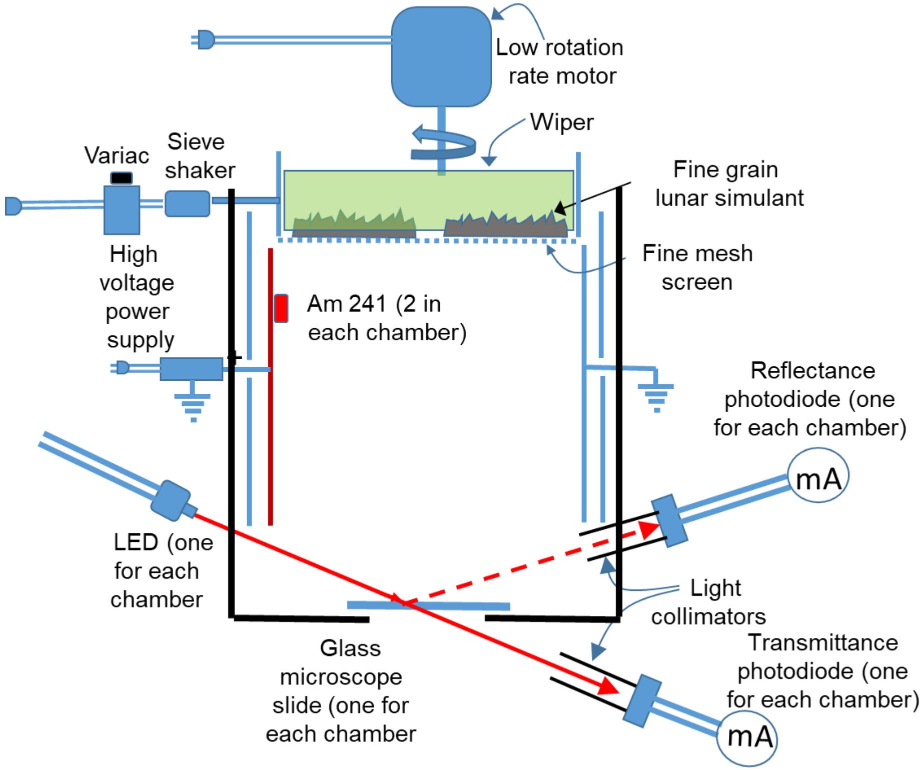


Image credit: NASA

Adhesion Mitigation Materials

Spectrum of Necessity

Dust Mitigation-
Must Remove

Image credit: NASA

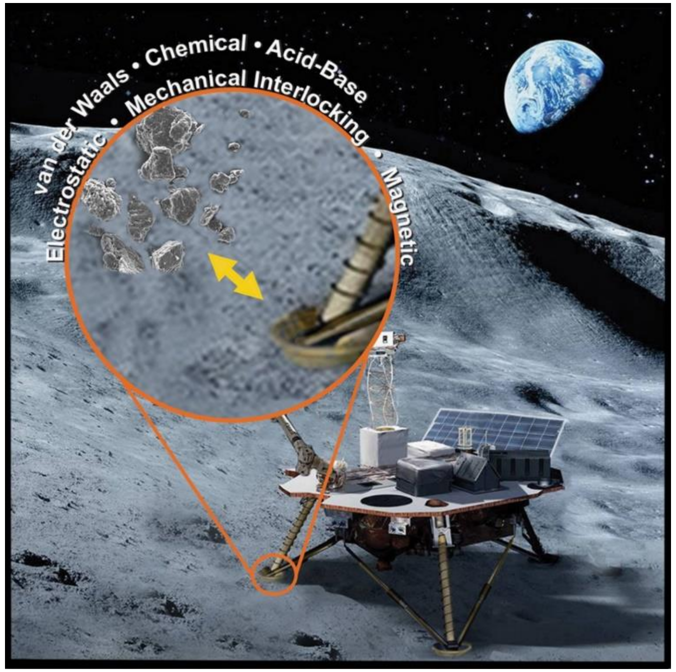
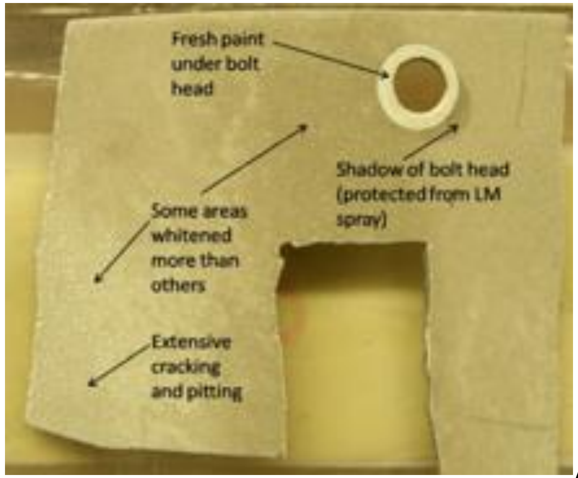
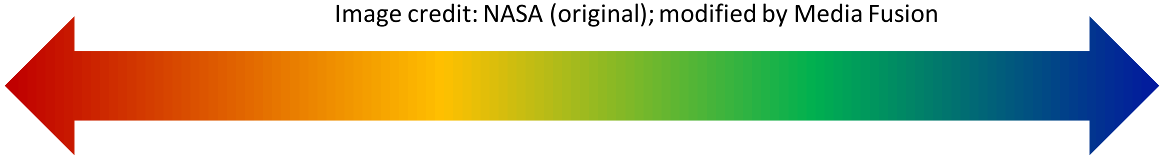


Image credit: NASA (original); modified by Media Fusion

Dust Management-
Must Tolerate





From lunar dust mitigation to management

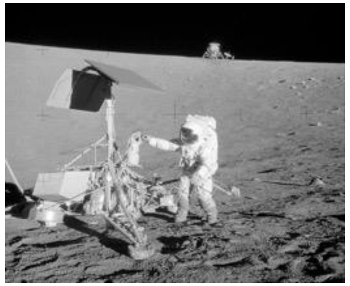
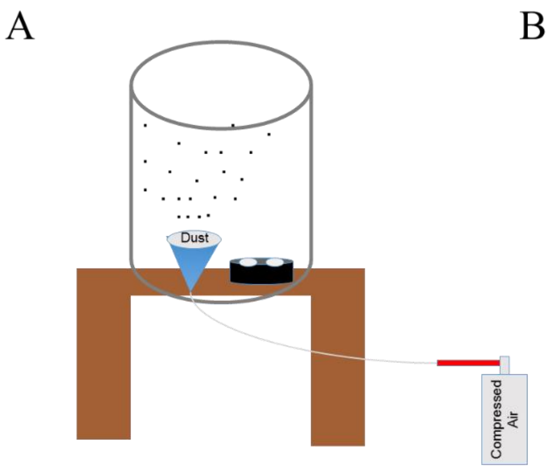
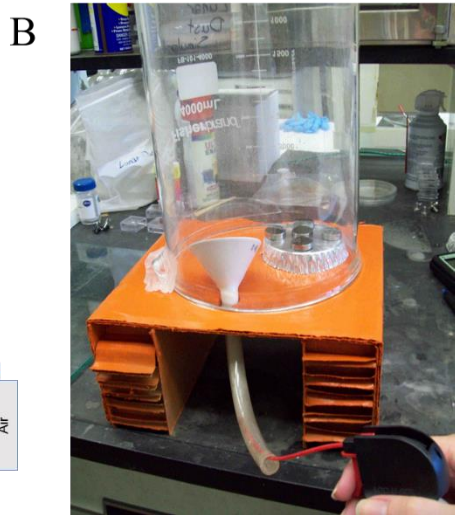


Image credit: NASA

Lunar Dust Adhesion Testing
Deposition Chambers

Previous Approach





Current Focus

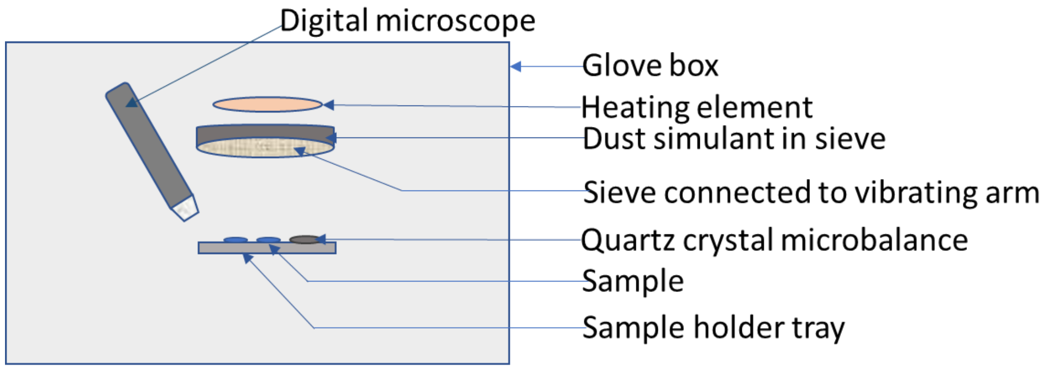


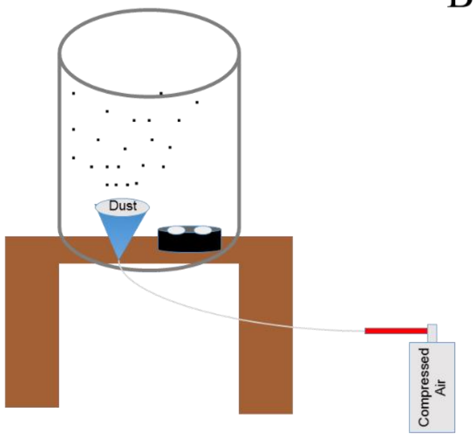
Image credit: NASA

Lunar Dust Adhesion Testing

Deposition Chambers

Previous Approach

A



B

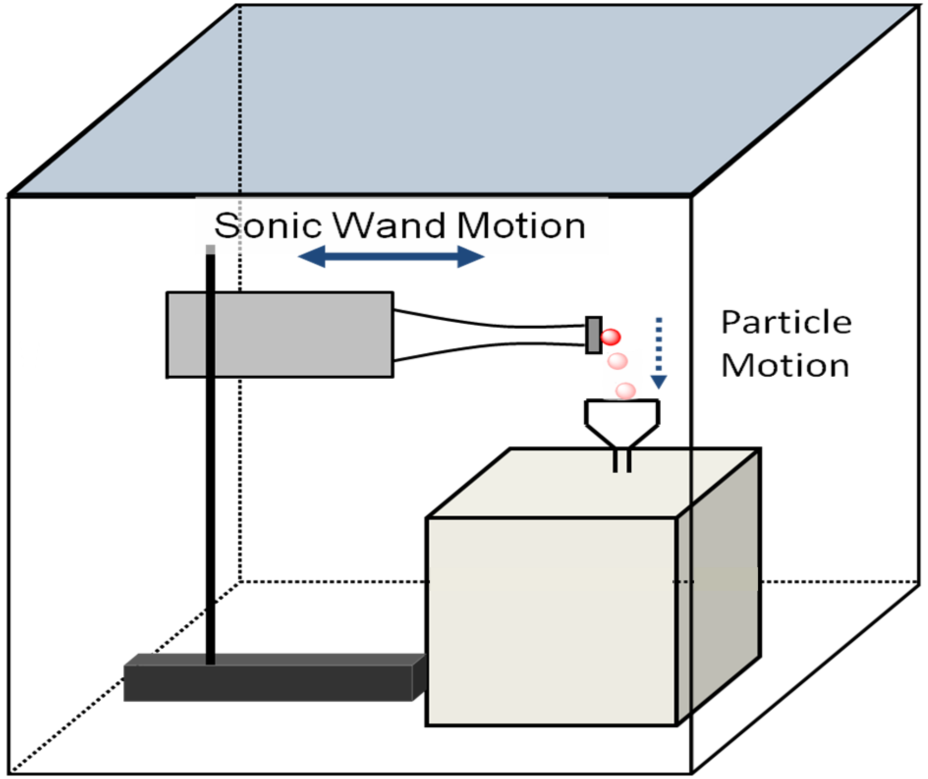
Current Focus

Image credit: NASA

Lunar Dust Adhesion Testing

Adhesion Test Chamber

Schematic



Actual Instrument

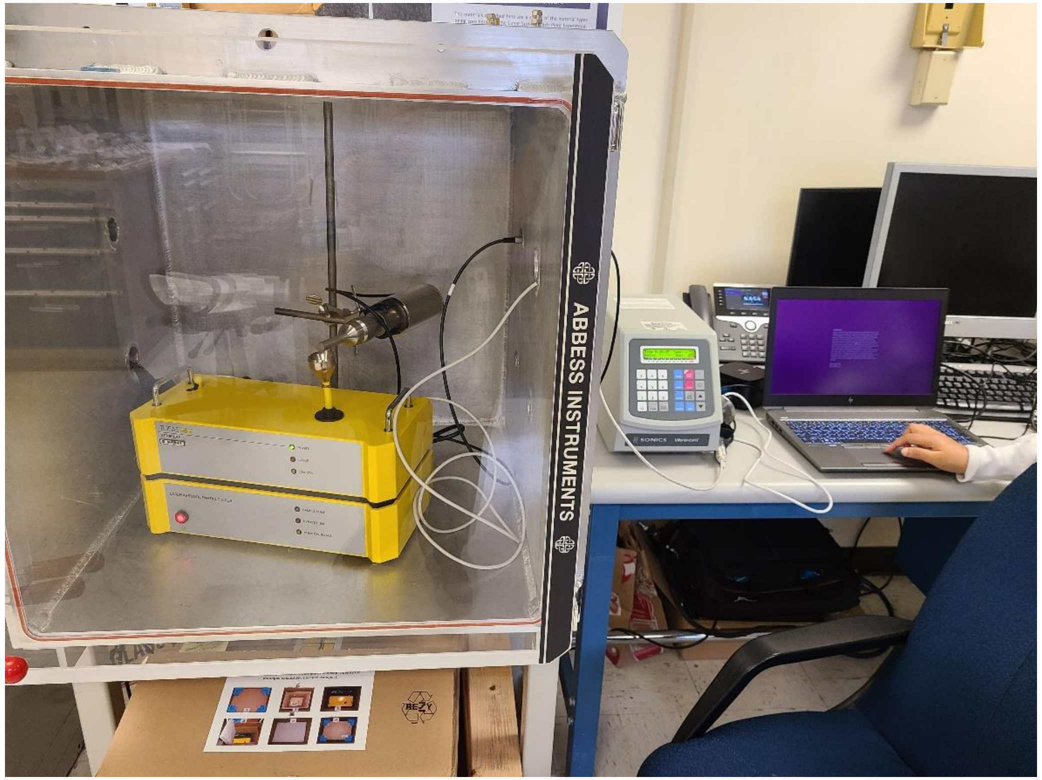
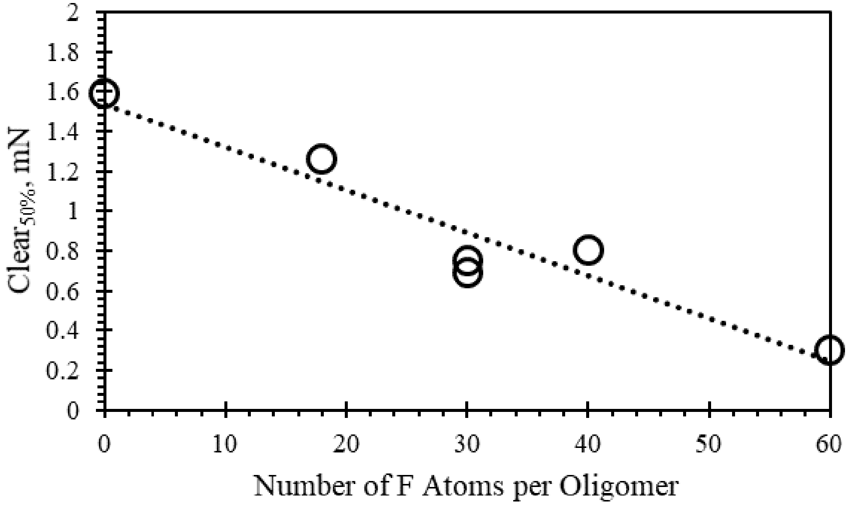


Image credit: NASA

Lunar Dust Adhesion Testing

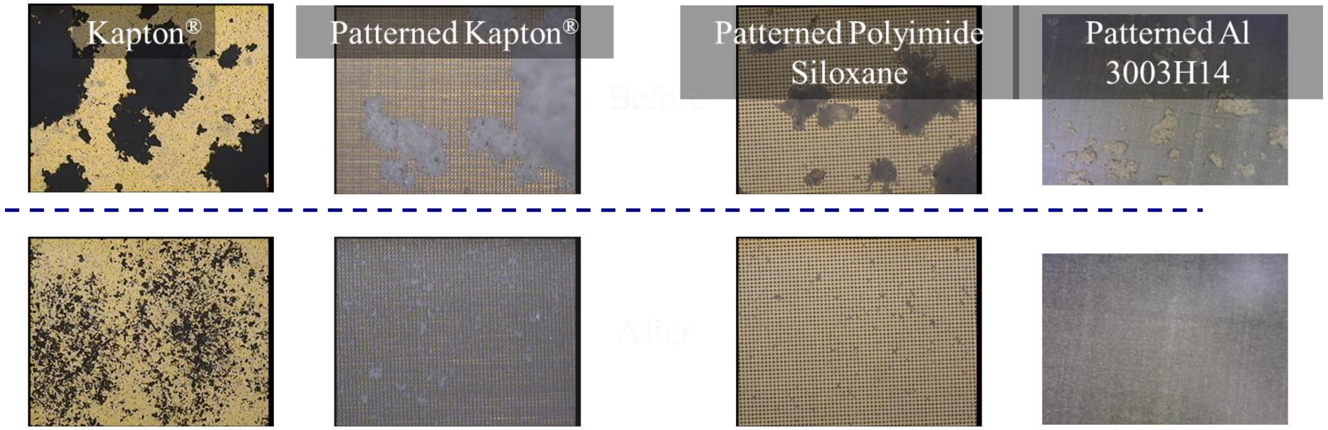
Previous Results



Wohl, C., et. al. "Lunar Dust Simulant Particle Adhesion on Copolyimide Alkyl Ethers" in The Impact of Lunar Dust on Human Exploration, ed. Joel S. Levine, Cambridge Scholars Publishing, February, 2021.

Reduction in microparticulate adhesion strength upon increasing low surface energy additive.

Laser ablation patterning reduced Lunar dust simulant retention. Top and bottom images were before and after a tilt and tap experiment, respectively.

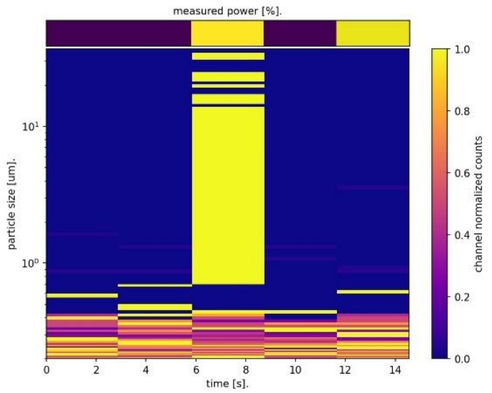


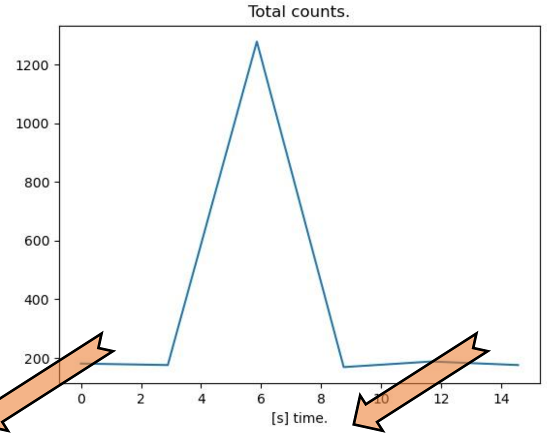
Wohl, C., et. al. Langmuir 2010, 26(13), 11469.

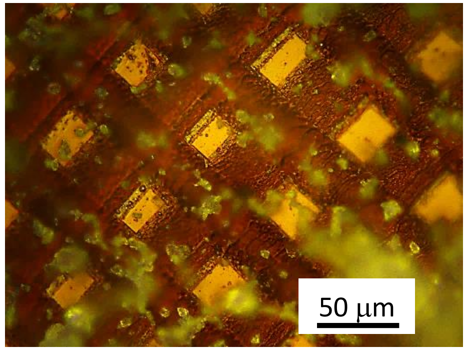
Lunar Dust Adhesion Testing

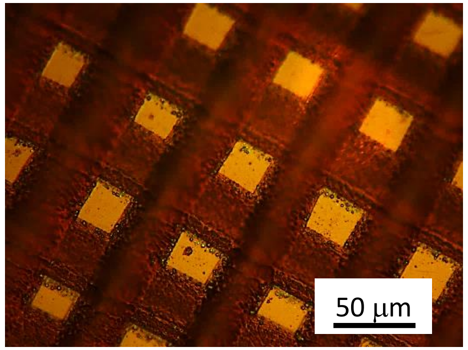
Recent Activities

Refined Simulant Particle Detection

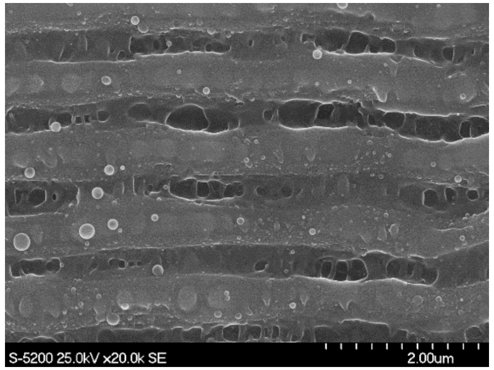








Hierarchical Topography on Metals



Nanometer-scaled Laser-Induced Period Surface Structure (LIPSS)

Micrometer-scaled Direct-write Laser Patterning

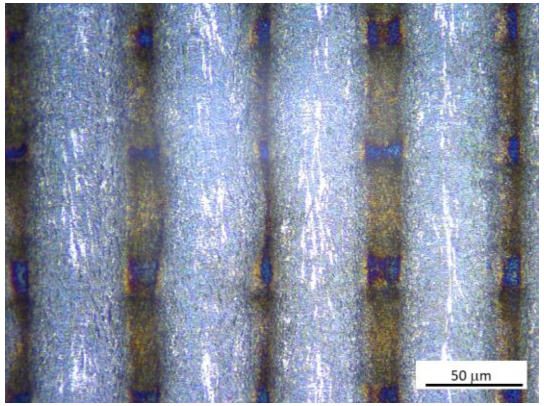
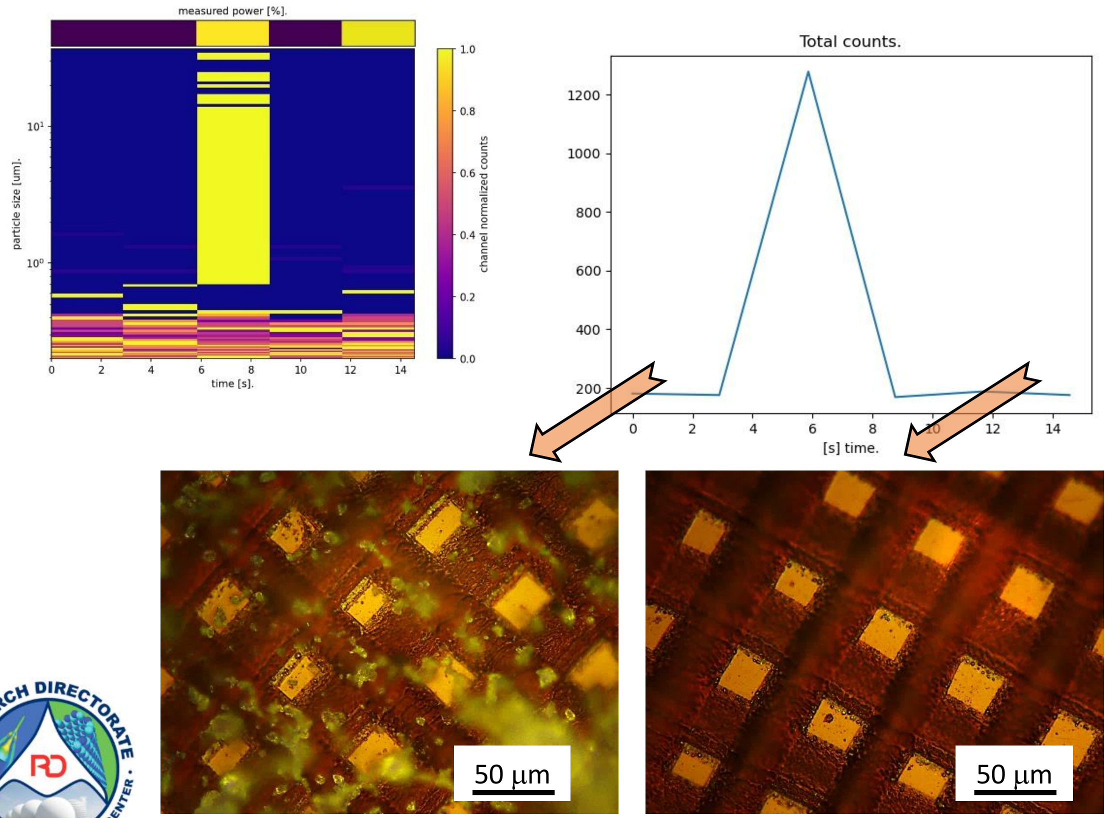


Image credit: NASA

Lunar Dust Adhesion Testing
Recent Activities

Refined Simulant Particle Detection



Hierarchical Topography on Metals

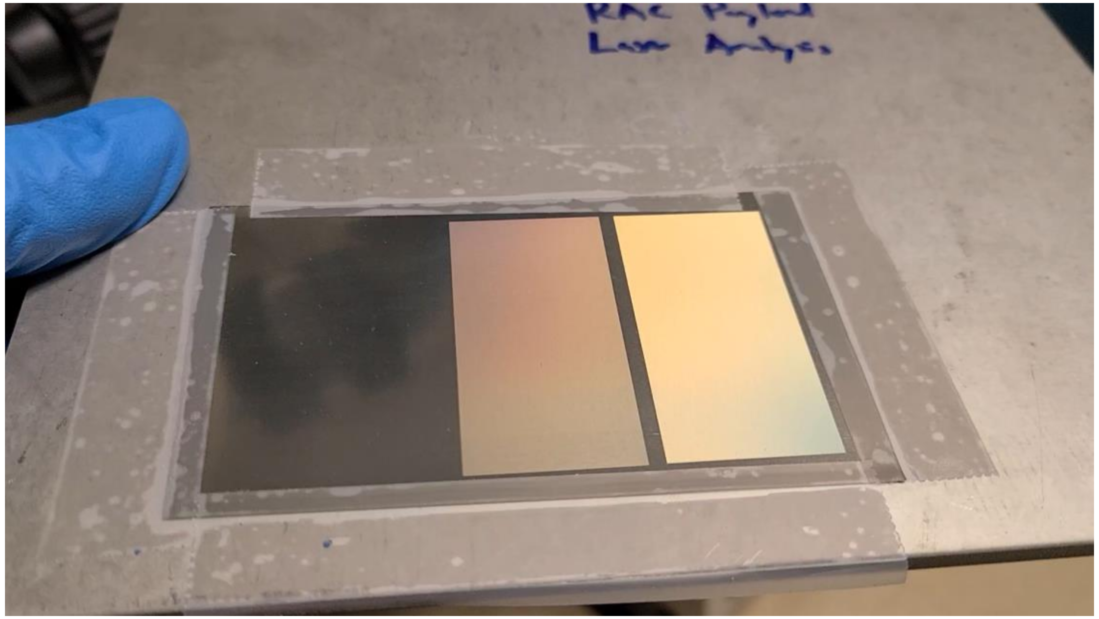


Image credit: NASA

Lunar Dust Wear-Resilient Materials

Particle Surface Interactions (PSI)

<u>Ejecta from PSI can be traveling up to 2000 m/s</u>

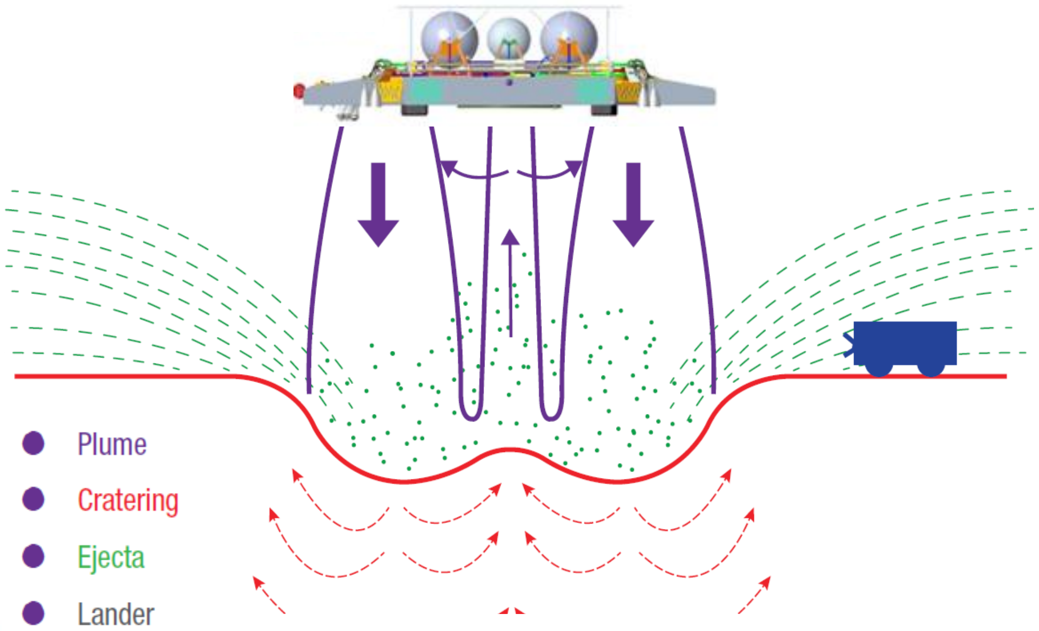
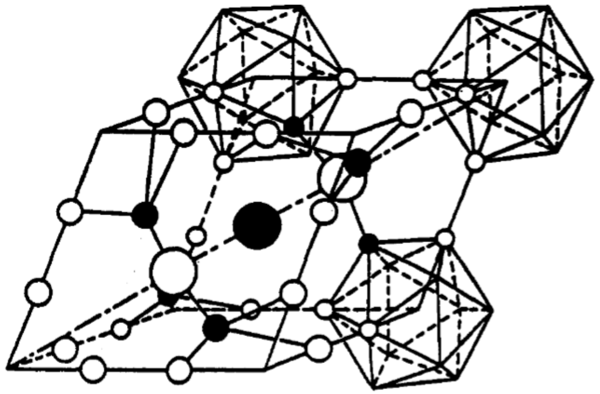


Image credit: Michelle Munk, NASA LaRC

Lunar Lander Legs … Can they be Reusable

https://plumesurfacewearmap.larc.nasa.gov/



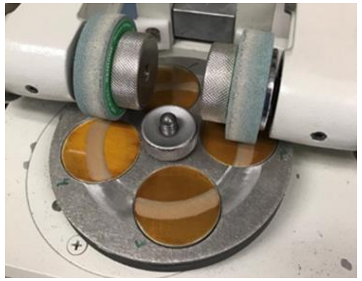


Image credit: NASA

Conclusions/Next Steps

- Risk reduction for long duration lunar exploration missions will require an entire suite of dust mitigation materials, tools, and techniques.
- Synergistic development of active and passive mitigation strategies will enable the greatest integration of material and device technologies.

- Next Steps
  - Develop top-coat materials for solar array and dust lofting applications
  - Establish benchmark for lunar particulate wear studies
  - Identify most promising scalable topographic modification technique
  - Next-Next Step-Identify a lunar surface mission and Commercial Lunar Payload Service (CLPS) lander to deliver LO-DuSST technologies to the lunar surface

Acknowledgements

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  - ❖John W. Connell
- ❖**NASA Lunar Surface Innovation Initiative**
  - ❖Niki WerkHeiser, Michael Johansen, Erica Montbach, Cameron Hartman
- ❖**NASA Internship, Fellowship, Scholarship (NIFS) /STEM Takes Flight (STF) Programs**

George Blackwell, Dylan Lew, Nicholas Fransen
Summer, 2020

Image credit: NASA