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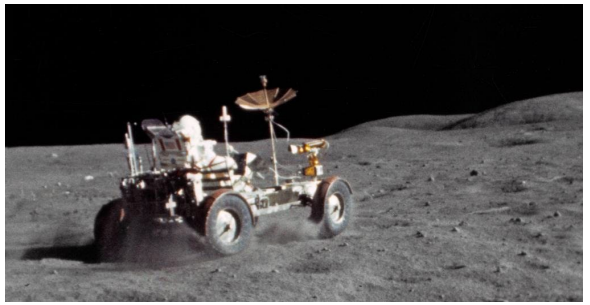
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Space Technology Mission Directorate
Game Changing Development Program

Phillip Abel | Lunar Dust Mitigation Guide - Sustainable Technologies in the Lunar Surface Environment Workshop | Nov. 2023

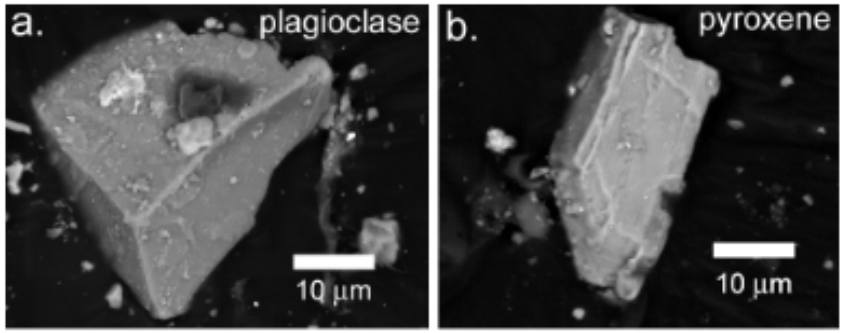
Dust Mitigation Best Practices Guide Motivation

- Why the concern about lunar surface dust effects - sustained ops?
  - Abrasive, adherent, sharp fine particulates - a problem for mechanisms?
  - Ubiquitous - as discovered by the Apollo astronauts, completely avoiding lunar dust during surface operations would be nearly impossible.
  - Electrostatics - potentially negatively or positively charged depending on solar illumination and charged particle flux, and in low gravity.
  - Particle reactivity - chemically reactive fracture surfaces possible in hard vacuum.



Lunar Roving Vehicle (LRV) spraying regolith during Apollo 16 mission, (NASA Photo S72-37002)

- What should you be testing?
  - Which dust effects are your primary failure concern? Mechanical wear? Optical effects / visibility? Thermal control? Combined effects?
  - How long *must* your asset operate? Should it degrade gracefully?
  - Are dust mitigation schemes to be tested? Measured & compared?

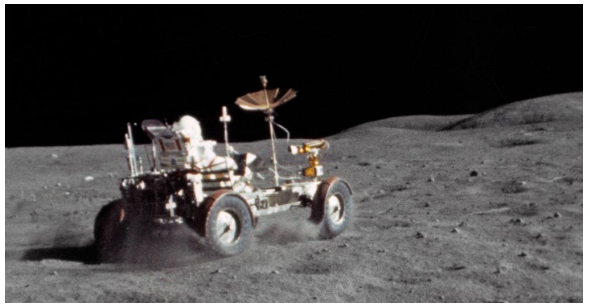


Mineral grains common in lunar soils of (a) highland material (b) mare soils, Christoffersen et al., NASA TP-2009-214786

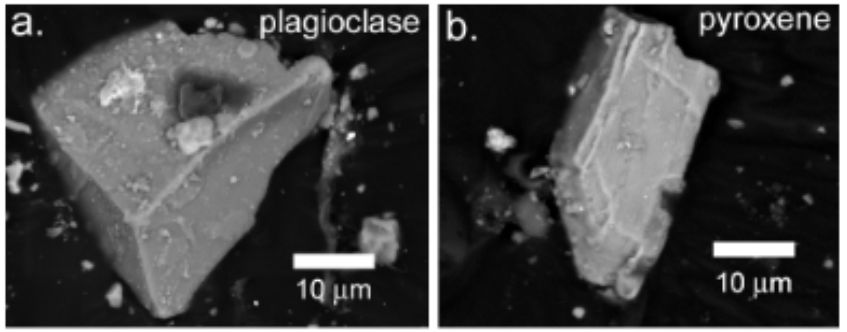
- How are you quantifying exposure / coverage / mitigations?
  - Lunar surface particle size distribution extends down to nanometer range - optical microscopy resolves at best to ~micrometers. Mass balance measurements typically cannot detect dust (<20 µm dia.) differences.

Dust Mitigation Best Practices Guide Overview

- Technology Product Capability
  - Develop an accessible, understandable, comprehensive, and refereed guide to avoiding lunar dust problems during surface operations, both for inexperienced mechanisms designers in academia or small companies *and* for seasoned mission veterans.
  - Extensive references into the detailed technical literature provide a “how to” lunar dust mitigation reference.
- Technical Capabilities
  - Interactions and input from potential Guidebook users in industry that are external to NASA during COVID 19, to be incorporated
  - Identification and availability of technical expertise across NASA
- Exploration & Science Applicability
  - Publication and distribution to NASA stakeholders, aerospace industry, and academic partners
    - For use by designers, commercial partners, and service providers
  - NASA missions targeted by the guidebook: CLPS, Artemis, Gateway, HLS



Lunar Roving Vehicle (LRV) spraying regolith during Apollo 16 mission, (NASA Photo S72-37002)



Mineral grains common in lunar soils of (a) highland material (b) mare soils, Christoffersen et al., NASA TP-2009-214786

[As presented > 1 yr. ago]

Dust Mitigation Best Practices Guide - Contents

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Key Take-Away:

To the extent possible -
by design, **avoid** dust exposure, or
if possible, **remove** the dust,
or just design to **tolerate** some
level of dust loading in operation.

Topics focused on lunar surface operation consequences, much less emphasis on cabin interior (filtration) / human health or on Conops mitigations.

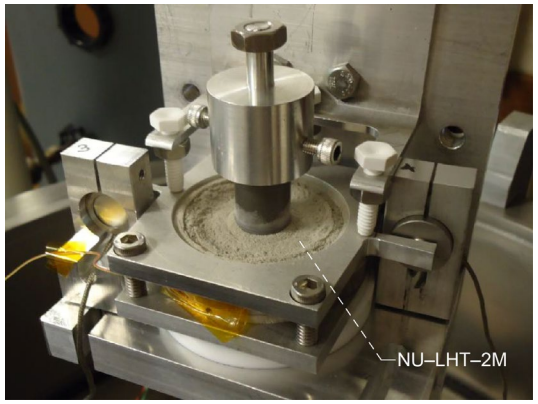
Dust Mitigation Best Practices Guide - Contents

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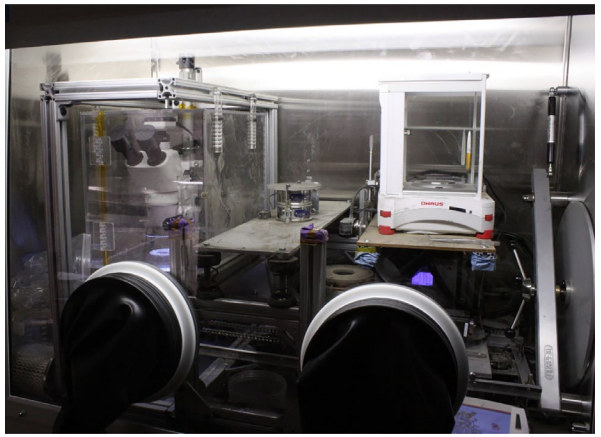
Appendix A - Lunar Dust - What Is It?	pp. 39 - 64	Synopsis of the Lunar Sourcebook, +
Appendix B - Measuring Lunar Dust and Simulants	pp. 65 - 75	Important to quantify testing amounts
Appendix C - Inertial Particle Removal	pp. 77 - 80	Basis for limited use on small particles
Appendix D - Terrestrial Dust Mitigation Best Practices	pp. 81 - 83	
Appendix E - Nomenclature	pp. 85 - 88	
References	pp. 89 - 94	Six pages long - a useful start!

Lunar Dust Tolerance - Terrestrial Testing Concerns

- Test fidelity
  - The simulant dust effects to be measured dictate the type and fidelity of testing needed, particularly if comparing mitigation scheme effectiveness.
  - If dust mitigation is to be used, the approaches involve either avoiding lunar dust exposure, removing particulates as possible, or tolerating particulates during surface operations - or some combination of those three general approaches.
- Fidelity determinants
  - Which simulant(s) to use, and particle size range of interest
    - LSIC, and other websites - e.g., Univ. of Central Florida, Colorado School of Mines.
    - *Classifications and Requirements for Testing Systems and Hardware To Be Exposed To Dust in Planetary Environments*, NASA Standard 1008 (2021), https://ntrs.nasa.gov
    - *Lunar Regolith Simulant User's Guide*, Schrader et al., NASA TM-2010-216446 (being updated!)
  - Vacuum level required / achievable with simulant, if relevant.
  - Simulant particle surface cleanliness / reactivity, if relevant.
  - Electrostatic field environment, if relevant.



Low temperature mechanism seal - dust tolerance testing, Delgado et al., NASA TM-2013-216587



Uniform Dust Deposition System, Gerdts et al., NASA TM-20210024128

Dust Mitigation Best Practices Guide

Additional resources:

- Levine, Joel S. (Ed.) (2021) "*The Impact of Lunar Dust on Human Exploration*" Newcastle: Cambridge Scholars Publishing
- And "*Lunar Dust and Its Impact on Human Exploration: A NASA Engineering and Safety Center (NESC) Workshop*" TM-2020-5008219
- NASA (2021) "*Classifications and Requirements for Testing Systems and Hardware To Be Exposed To Dust in Planetary Environments*" NASA-STD-1008
- Schrader, C.M., Rickman, D.L., McLemore, C.A., & Fikes, J.C. (2010) "*Lunar Regolith Simulant User's Guide*" TM-2010-216446
- Gaier, J.R. (2005) "*The Effects of Lunar Dust on EVA Systems During the Apollo Missions*" TM-2005-213610

NASA publications are available at https://ntrs.nasa.gov/search including:

- *"Lunar Dust Mitigation: A Guide and Reference First Edition (2021)"* as TP-20220018746

To all the Guide contributors - thank-you!



NASA/TP-20220018746

Lunar Dust Mitigation: A Guide and Reference
First Edition (2021)

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Dust Mitigation Best Practices Guide

Thank you!