An Update on NASA's Lunar Dust Mitigation Strategy. M. R. Johansen[1], [1]NASA Space Technology Mission Directorate, Technical Integration Manager

Introduction: It is well known that the Apollo lunar surface missions experienced a number of issues related to dust – which are sometimes referred to as "The Dust Problem". The jagged, electrostatically charged lunar dust particles can foul mechanisms and alter thermal properties. They tend to abrade textiles and scratch surfaces. NASA and other interested parties require an integrated, end-to-end dust mitigation strategy to enable sustainable lunar architectures.

Dust Mitigation Strategies – A Three Pronged Approach: An effective dust mitigation strategy includes three components: Operational and architecture considerations, passive technologies, and active technologies.

By far, the component that can have the biggest impact on dust exposure is operational and architecture considerations. With proper planning, this component of the integrated strategy can also be the most cost effective. An example of an architecture and operational consideration is lessening the risk of astronauts falling on the lunar surface through changing EVA procedures and adjusting tool design to accommodate better balance.

Active and passive technologies can be used to close the gap between expected dust exposures and system dust tolerance limits. Passive technologies include nanomaterials and other surface modification techniques and simple tools. Active technologies typically require non-negligible power consumption and/or some form of mechanical actuation.

This three pronged approach to a dust mitigation strategy can be viewed from an architecture element perspective or a capability need perspective.

Dust mitigation strategies are needed for optical systems (viewports, camera lenses, space suit visors), thermal surfaces (thermal radiators, thermal painted surfaces), fabrics (space suit fabrics, soft wall habitats, mechanism covers), mechanisms (linear actuators, bearings, quick disconnects), seals and soft goods (space suit interfaces, hatches, connectors), and gaseous commodities (spacecraft atmospheres, ISRU processes).

With these considerations, NASA is forming an integrated dust mitigation strategy.

An Integrated Dust Mitigation Strategy: Nearly every system, on the lunar surface or on orbit, will experience deleterious effects due to lunar dust. Thus, every system should be responsible for a piece of the integrated dust mitigation strategy.

A notional integrated dust mitigation strategy may have the following features:

Lunar Surface Operations

- Architecture and Operational Considerations
  - Slow, methodical movements
  - Removable dust covers for high exposure regions
  - Adequate time for dust mitigation protocols
  - Ground preparation or a dust tarp
  - Materials compatibility
  - Passive technologies and tools
    - Dust brushes
    - Boot scrapers
    - Dust tolerant mechanisms and quick disconnects
    - Nanocoatings
  - Active Technologies
    - Electrostatic dust removal
    - Magnetic dust removal
    - Compressed gas dust removal

Lunar Surface Habitats

- Architecture and operational considerations
  - Dust airlock or 'Mudroom'
  - Single or staged 'Softwall'
  - Materials compatibility
- Passive technologies and tools
  - Dust brushes and wipes
  - Two stage cabin filtration (inertial separation and media filtration)
  - Nanocoatings
- Active technologies
  - Electrostatic or magnetic dust removal
  - Compressed gas shower
  - Dust vacuum

Lunar Ascent/Descent

- Architecture and operational considerations
  - Descent/ascent trajectories
  - Prepared and unprepared landing surfaces
  - Landing proximity to other surface assets
  - Blast ejecta in lunar orbit
- Passive technologies and tools
  - Capped connectors and docking mechanisms
  - Dust brushes and wipes
  - Two stage cabin filtration

    - Nanocoatings
- Active technologies
    - Dust vacuum
    - Electrostatic or magnetic dust removal

Lunar Orbital

- Architecture and operational considerations
    - Proximity to blast ejecta in orbit
- Passive technologies and tools
    - Capped connectors and docking mechanisms
    - Two stage cabin filtration
    - Dust wipes
- Active technologies
    - Dust vacuum
    - Electrostatic or magnetic dust removal

Dust Mitigation Projects : The Space Technology Mission Directorate is funding a variety of dust mitigation projects to enable the integrated dust mitigation strategy. The projects listed below will ensure that existing active and passive technologies are mature and can potentially be infused into the various architecture elements.

Patch Plate Materials Compatibility Assessment. A number of heritage and new spaceflight materials should be extensively tested in the lunar environment to understand both how the materials change with time and how regolith adheres to the surfaces. A microscope and dust sensor addition to this passive experiment willl greatly improve the science retrieved from this passive payload.

Lunar Demonstration of Electrodynamic Dust Shield. A mature active dust removal technology that uses electric fields to remove dust from surfaces. This technology can be integrated into optical systems and thermal systems. This technology is currently undergoing technology demonstration on the International Space Station.

Dust Tolerant Mechanisms Testing. Rovers and other architecture elements will have rotary joints for steering, suspension, and drive actuators. These joints will be subjected to a dusty lunar environment. This work will enable better rotary joint design for small and large architecture elements.

Lunar Dust Mitigation Best Practices Guide. Many architecture elements are in need of a guide to design dust mitigation for mechanisms, optics and many other applications. This ‘Best Practices’ guide will call on experience in previous NASA projects, experiences in military operations, and industry knowledge.

Other dust mitigation investments and activities are being coordinated through Small Business Innovative Research, NASA’s Human Exploration and Operations Mission Directorate, and NASA’s Science Mission Directorate.

Dusty Environments Classifications: One last piece of NASA’s Lunar Dust Mitigation Strategy is the development of dusty environments classifications to enable requirements generation and systems engineering and integration functions. The dusty environment classifications will be organized by various dust loading parameters such as surface dust loading, volumetric dust loading, and dust velocity. The classifications will define testing protocols and metrics. Testing to a predefined protocol described in the classification will also raise awareness where additional dust mitigation strategies are needed for a given system.

Conclusion: An integrated dust mitigation strategy requires coordination from architecture to technology development. Many of the concerns associated with lunar dust can be lessened with early consideration. Through architecture and operational considerations and technology maturation, NASA aims to resolve The Dust Problem.

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