Materials in Dusty Planetary Environments

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Introduction

Lander missions [robotic and crewed] to planetary bodies with dusty environments (i.e. Moon, Mars, asteroids) depend on long-term operation and performance in these environments. There is a critical need for improvements in the characterization of planetary dust effects on materials, flight systems and science instruments; plume-surface interactions (dust entrainment in engine plumes, transport, and landing site alteration); and development of materials and mitigation technologies for long-term operation.

Challenges

Dusty planetary environments pose significant challenges to the performance of flight systems and science instruments due to impacts from mechanical damage (i.e., abrasion)and materials properties degradation (i.e., thermo-optical property degradation, obscuration, optical scatter). Lofted planetary dust/ejecta entrained in engine plumes are accelerated to high velocities and can produce erosion on spacecraft surfaces (i.e. existing assets on the surface, as exemplified by the observed erosion of Surveyor surfaces from Apollo Moon landings) and also reach orbital velocities, leading to orbital debris (for the Moon at least), causing problems for orbiting spacecraft.

Ground-based testing challenges:

- Vacuum level required for high-fidelity adhesion/charging characteristics.
- Availability/existence of simulants that capture relevant effects (higher-fidelity chemistry, geotechnical properties, shape and size distribution of particles).
- Flight-like plume expansion when testing in high-vacuum chambers (require liquid helium shrouds to trap hydrogen)
- Technologies for internal and external particle deposition sensors and measurement of attachment/detachment forces

Critical Science and Technology Development Gaps

- Ground truth from dusty environments. Sensors are needed on landers (e.g. CLPS) that can return environmental data. Sample return would allow for laboratory analysis to better characterize the lunar dust at various locations and with higher fidelity. This data will allow us to update models and make better predictions.
- Environmental unknowns include true composition of regolith, dust lofting, and full picture of charging/plasma environment that interacts with dust.
- New materials are needed that are inherently resistant to dust adhesion (e.g. metamaterials, low surface energy).
- In-situ dust removal technologies are needed, both passive and active (with low-power consumption), with testing and validation in ground-based test facilities and through flight technology demonstrations on dusty planetary environments (Moon and Mars).
- There is a need for basic materials properties of highly insulating granular materials (e.g., regoliths), including electron yields and photoyields. These materials properties determine how dusty materials accumulate charge from interactions with the space environments (e.g., solar wind, magnetosheath, and magnetotail plasma, photoemission currents) and induced environments (e.g., engine plumes). Myriad applications and simulations require reasonable means to estimate dust charging due to these fluxes to accurately addresses charge induced dust accumulation and agglomeration

Science and Technology Development Opportunities

- Development of a sustainable presence for robotic and crewed missions, and potentially, a lunar economy.
- Enable long-duration/permanent presence on the Moon and Mars.
- Other environments: enable longer Mars missions.
- Application of derived technologies on Earth could be of great importance due to upcoming climate change challenges.
- Impactful way for early career engineers and scientists to obtain hands-on experience building flight hardware, science instruments and perform technology demonstrations.

Workforce Development

Technology development in materials for dusty planetary environments will benefit and enable hardware development for missions landing on planetary bodies and also have applications on Earth. Science and technology development needs should be clearly communicated to academia, government labs and industry, leading to solicitations for research and technology development funding opportunities for academia, governments labs and industry. It is recommended to engage Subject Matter Experts

(SMEs) and project customers in the development and tailoring of solicitations and in earlier stages of project development.

Outcomes

The key goal is to develop materials technologies in support of long-duration space missions, establishment of bases on the Moon and Mars, as well as lander and rover missions on dusty planetary bodies.

Science and Technology Impacts

The potential scientific and technological impact is tremendous. The ability to land/takeoff and conduct long-term operations in dusty planetary environments is critical to long duration space missions on planetary bodies. This is also critical for the establishment of long-term and permanent presence on the Moon and Mars, and in order to enable successful science and rover operations on the surface.