Scope Title
Dust-Tolerant Mechanisms

Scope Description
A return to the Moon to extend human presence, pursue scientific activities, use the Moon to prepare for future human missions to Mars, and expand Earth’s economic sphere will require investment in developing new technologies and capabilities to achieve affordable and sustainable human exploration. From the operational experience gained and lessons learned during the Apollo missions, conducting long-term operations in the lunar environment will be a particular challenge given the difficulties presented by the unique physical properties and other characteristics of lunar regolith, including dust. The Apollo missions and other lunar exploration have identified significant lunar-dust-related problems that will challenge future mission success. Lunar dust is composed of regolith particles ranging in size from tens of nanometers to microns, and lunar dust concerns are a manifestation of the complex interaction of the lunar soil with multiple mechanical, electrical, and gravitational effects.

Mechanical systems will need to operate on the dusty surface of the Moon for months to years. These systems will be exposed to the harsh regolith dust and will have little to no maintenance. This scope seeks technologies that can function with or tolerate dust intrusion in the following areas:

- Actuators and power transfer components (motors, pistons, shape memory alloy, gear, belt, chain, steering, suspension, hinges, bearings, etc.).
- Fastening, joining, and securing components and hardware (structural connections, threaded fasteners, quick pins, latches, restraint systems).
- Sealing materials and techniques that can keep out regolith and operate in the harsh Moon/Mars environments.
- Dust-tolerant fluid and electrical connectors (quick disconnects, umbilicals, modular commodity interfaces).
- Moving components for dust protection (iris, hatch, covers, airlocks, closures, fabric/flexible protection).
- Tools and devices for exploration and in situ resource utilization (ISRU) (sample tools, dust cleaning, landing gear, pointing actuator).
- Material handling and transportation components (hoist, lift, pallet, pick and place, common transport interface, etc.).

Successful solutions will have the following performance characteristics:
Operational for extended service of 10 to 100 months with limited or no maintenance.
Linear and static joints will function and perform the designed actuation/motion/mate-demate cycles of 1,000 or higher.
Linear and static joints will function with minimal solid film or without lubrication.
Rotational joints will have operational lifetimes on the order of hundreds of thousands of cycles.
All mechanisms will function throughout lunar temperature cycles between 127 °C (260 °F) and -173 °C (-280 °F).
All mechanisms will function in the extreme cold of permanently shadowed regions (≤238 °C).
All mechanisms will function reliably with lunar regolith (simulant) coating the exposed mechanism surfaces.
All mechanisms will function in the high vacuum lunar environment of 10⁻⁹ Torr.
All mechanisms and materials will function in the lunar electrostatic and radiation environment.

Expected TRL or TRL Range at completion of the Project

2 to 6

Primary Technology Taxonomy

Level 1
TX 07 Exploration Destination Systems

Level 2
TX 07.2 Mission Infrastructure, Sustainability, and Supportability

Desired Deliverables of Phase I and Phase II

- Research
- Analysis
- Prototype
- Hardware
- Software

Desired Deliverables Description

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II demonstration, with delivery of a demonstration package for NASA testing in operational test environments at the completion of the Phase II contract.

Phase I Deliverables: Research, identify, and evaluate candidate technologies or concepts for dust-tolerant mechanisms. Simulations or laboratory-level demonstrations are desirable. Deliverables must include a report to document findings.

Phase II Deliverables: Emphasis should be placed on developing, prototyping, and demonstrating the technology under simulated operational conditions (regolith, thermal, vacuum). Deliverables shall include a report outlining the path showing how the technology could be matured and applied to mission-worthy systems, functional and performance test results, and other associated documentation. Deliverable of a functional prototype is expected at the completion of the Phase II contract. The technology concept at the end of Phase II should be at a Technology Readiness Level (TRL) of 6 or higher.

State of the Art and Critical Gaps

Previous solutions used in the Apollo program did not address the current need of long-term usage. Terrestrial solutions often employ materials or methods that are incompatible with the lunar environment.

Critical Gaps:
Seals at rotary and linear joints are very common for actuation in dusty environments. Most of these seals, however, use elastomers that would off-gas and become brittle in a lunar radiation environment and at lunar temperatures. Solutions are needed that employ advanced materials, metallic seals, or nontraditional techniques that can operate in the lunar environment for an extended period of time (months to years).

Bearings that are tolerant of dust infiltration. Regolith getting past the protective seals and into bearings is a common failure point. Solutions are needed for bearings that are highly dust tolerant to reduce the risk of failures due to dust intrusion.

Operations on the lunar surface will include assembly, construction, and extravehicular activity (EVA) tasks. These tasks will involve the mating/demating of various structural, electrical, and fluid connections. Dust on the surface of these joints will impede their proper function and lead to failures. Solutions are needed to protect these joints from dust contamination.

Dust-protective enclosures, hatches, and moving covers are needed to protect delicate components. Materials and coatings are needed that eliminate or minimize the adherence of lunar dust to these surfaces. Solutions are needed for self-cleaning shapes, materials, and mechanisms that can clean/remove/reject regolith from vital moving parts of mechanisms as they operate.

Relevance / Science Traceability

Dust will be one of the biggest challenges for operation on the lunar surface for the Artemis program.

“I think dust is probably one of our greatest inhibitors to a nominal operation on the Moon. I think we can overcome other physiological or physical or mechanical problems except dust.” Gene Cernan, Apollo 17 Technical Debrief.

References

1. Dust Mitigation Gap Assessment Report, International Space Exploration Coordination Group (ISECG):