NASA SBIR 2020 Phase I Solicitation

H3.03  Lunar Dust Management Technology for Spacecraft Atmospheres and Spacesuits

Lead Center: GRC

Participating Center(s): JSC, MSFC

Technology Area: TA6 Human Health, Life Support and Habitation Systems

Scope Description

Upon their return to Earth one of the Apollo astronauts comment ed that “dust is probably one of our greatest inhibitors to a nominal operation on the Moon.” Advances in spacecraft atmospheric quality management are sought to address the intrusion and containment of lunar dust in pressurized volumes and compartments in spacecraft systems. This will require the development of particle filtration and separation techniques, barrier techniques and monitoring instruments. For space suits, the challenge is to prevent dust intrusion, while at the same time providing the capability to mate and de-mate connectors and suit components as well as enabling venting to the environment for certain components. This will require the development of specialized dust covers for a variety of connections.

Specifics Regarding Areas of Interest in Spacecraft Atmospheric Quality Management are the Following:

Particle Filtration and Separation Techniques

Techniques and methods are sought leading to compact, low power, autonomous, regenerable bulk particulate matter separation and collection techniques suitable for general spacecraft cabin air purification and removal of planetary lunar dust in main cabin quarters and airlock compartments. The particulate matter removal techniques and methods must accommodate high volumetric flow rates up to 11.3 m$^3$/minute and minimized pressure drop (typically <125 Pa). The filter and separation system needs to meet both the requirements for internally generated particulate matter, such as derived from materials, ECLSS and other processes, and biological matter and debris generated by the crew, and lunar dust intrusion. Permissible levels of suspended particulate matter total dust must be maintained to <3 mg/m$^3$, and the respirable fraction of the total dust to <2.5 ?m in aerodynamic diameter to <1 mg/m$^3$, as per the standards in the NASA-STD-3001 Vol 2, Rev. B. More specifically lunar dust needs to be maintained to a time-weighted average of 0.3 mg/m$^3$ for particles < 10 μm during intermittent daily exposure periods that may persist up to 30 days in duration for the Gateway or Habitat, and an average of 1.6 mg/m$^3$ for particles < 10 μm for a 7 day exposure period on the lander. Filtration performance should be at minimum 99.97 % collection efficiency for particles 0.3 micron in diameter and larger (or HEPA efficiency standard). The filter and separation system needs to also provide microbial and fungal control as outlined in the NASA-STD-3001 Vol 2, Rev. B requirements.

Barrier Techniques

Specialized particulate matter management systems specifically designed to collect and remove lunar dust from airlocks or suit preparation compartments or areas that provide a > 99.5% effective barrier to lunar dust transfer
between different volumes or compartments are also of interest. The barrier technique can include filtration, separation and mitigation techniques used within these smaller pressurized compartments and/or techniques that prevent the transport or transfer of lunar dust between compartments or to main cabin areas.

Monitoring Instruments

Instruments, or instrument technology, that measure particulate matter concentrations and particle sizes to verify compliance with particulate matter cleanliness levels (stated above) are desired. In addition, the instrument will need to monitor lunar dust intrusion in airlocks and into main cabin areas. Real-time measurement instruments must be compact and low power, requiring minimal maintenance and be able to maintain calibration for years. The instrument also needs to be compatible with the microgravity, reduced gravity and reduced pressure environments (26.2 kPa < pressure < 103 kPa) in the cabin and airlocks of the transit and lander vehicles. The different environmental parameters may necessitate different modes of operation within one instrument (preferred to minimize payload and operational resources) or it may require different sensor types. Particle sensors that are capable of distinguishing between different material types (lunar vs generic dust) when measuring particulate matter concentration and particle sizes will be highly desirable.

Specifics Regarding Areas of Interest in Spacesuit Components are the Following:

Garment Protection:

A lunar space suit requires a dedicated Environmental Protection Garment (EPG) to protect the pressure garment and crewmember from the extreme lunar surface conditions. The extreme conditions include but are not limited to:

1. Extreme cold scenarios
2. Extreme hot scenarios
3. Highly abrasive lunar regolith

Not only does the EPG have to protect against the conditions above, but it must also not inhibit the space suit mobility. It would be beneficial if space suit solutions provide protection for the crewmember in the highly abrasive lunar regolith environment along with accommodating the extreme cold and hot conditions.

Venting Portable Life Support System (PLSS) Covers:

There are several spacesuit components that require access to the environment for gas flow, both in nominal and off-nominal operations. These components require specialized covers that prevent dust intrusion while at the same time allowing for sufficient gas flow. These components are:

1. PLSS Shell Vent Ports

The PLSS shell has two ports to allow the evaporated water from the spacesuit water membrane evaporator (SWME) and its backup the Mini Membrane Evaporator (Mini-ME) to escape. The operation of these components is dependent on a low back pressure and each of the vent ports must have a flow through area of at least 7 in$^2$ to maintain the appropriate pressure for evaporation within the PLSS shell. The vents need to accommodate a water vapor mass flow of at least 2.6 lb/hr. The total area available for the vent ports is approximately 10 by 2.5 inches on either side.

1. PLSS Rapid Cycle Amine (RCA) System Vent Quick Disconnect

The RCA system for water vapor and CO$_2$ removal requires vacuum access for the desorption of these constituents. This is accomplished via a Quick Disconnect (QD) on the PLSS backplate. For efficient desorption, the pressure in the vacuum access line needs to decrease quickly and allow the flow of 0.65 L of ullage gas to the environment. The ullage gas can be assumed to be 100 % O$_2$ at 2.15 psi. Without a specialized cover, this gas dissipates within about 2 seconds. After the ullage gas has dissipated, the desorbed gas consists of CO$_2$ and H$_2$O with a mass flow of 325 to 360 g/min depending on the bed loading and metabolic rate of the crew member. Between 210 to 230 g/min of that flow is CO$_2$. The rapid decompression of the vacuum line is essential for efficient
operation of the RCA, as is the following diffusion of desorbed gas away from the absorber beds, both of which must not be impeded by the specialized dust cover.

1. Suit Purge Valve (SPV) and Low Flow Purge Valve (LFPV)

The SPV is located on top of the Display and Control Unit and is used during nitrogen purge operations in the airlock. The LFPV is used during off-nominal operations to ensure sufficient CO₂ washout in the helmet and to provide some gas flow through the pressure garment. While similar in design, both valves require different flow rates. The SPV requires 3.15-3.38 lb/hr and the LFPV requires 1.55-1.69 lb/hr of O₂ flow rate at 3.5 psi. Both valves are exposed on the outside of the spacesuit to enable crew member access and thus need specialized covers in order to tolerate large amounts of dust exposure.

1. Positive and Negative Pressure Relief Valves (PPRV and NPRV)

The PPRV and NPRV are located on the hard upper torso (HUT) and exposed to vacuum and dust. The full open flow rate requirement for the PPRV is 7.49 lb/hr of dry O₂ at 70°F with suit internal pressure of 10.1 psia and vacuum as the external reference. The requirement for the NPRV is 60.4 lb/hr of dry air at 70°F, with the airlock pressure at 4.15 psia and a suit pressure at 3.65 psia. Specialized covers are needed in order to tolerate dust exposure.

Non-Venting Portable Life Support (PLSS) Covers:

Two other connectors are on the exterior of the suit that do not need vacuum access and are nominally covered during an Extravehicular Activity (EVA). However, they need to be accessed at the conclusion of an EVA at which point they may be covered in dust. Specialized covers for these connectors are needed to both protect the connectors from dust intrusion during the EVA as well as during the removal of the covers. The connectors are as follows:

1. An 85-pin receptacle that serves as the battery charge connector and is located on the bottom corner of the PLSS.
2. The Spacesuit Common Connector (SCC) contains high pressure oxygen lines, water lines, an electrical connector as well as mechanical mounting features. The SCC is located on the front of the spacesuit and is integrated with the Display and Control Unit (DCU). The connector is flat and has a surface area of approximately 2.5 by 4 inches.

References

NASA-STD-3001 Vol 2, Rev. B.


Apollo 17 Technical Crew Debrief, Page 20-12, NASA Manned Spacecraft Center, January 4, 1973, MSC-07631

Expected TRL or TRL range at completion of the project: 3 to 4

Desired Deliverables of Phase II

Prototype, Analysis, Hardware

Desired Deliverables Description

Phase I Deliverables - Reports demonstrating proof of concept, test data from proof of concept studies, concepts
and designs for Phase II. Phase I tasks should answer critical questions focused on reducing development risk prior to entering Phase II.

Phase II Deliverables - Delivery of technologically mature hardware, including components, subsystems or treatments that demonstrate performance over the range of expected suit and spacecraft conditions. Hardware should be evaluated through parametric testing prior to shipment. Reports should include design drawings, safety evaluation, test data and analysis. Robustness must be demonstrated with long term operation and with periods of intermittent dormancy. System should incorporate safety margins and design features to provide safe operation upon delivery to a NASA facility.

State of the Art and Critical Gaps

The state of the art in spacecraft filtration are HEPA filters used on the ISS, known as Bacterial Filter Elements (BFE).

There are currently no viable airborne particle sensors for pressurized volumes on the ISS or slated for future missions. Commercial sensors are only compatible with standard conditions (1 atmosphere) and terrestrial gravity levels. Also there are no commercial particle sensors that can discriminate between material types or particle shapes that may be used to distinguish between lunar dust and generic cabin dust.

Relevance / Science Traceability

Lunar and Martian human surface missions (Artemis/lander/spacecraft) will be required to address and provide methods of controlling the intrusion of lunar dust into pressurized volumes.

The Life Support Systems (LSS) Project, under the Advanced Exploration Systems Program, Human Exploration and Operations Mission Directorate (HEOMD), is the expected customer for spacecraft cabin dust management technologies. The LSS Project would be in position to sponsor Phase III and technology infusion.

For Exploration EVA System Development, the xEMU Project is the expected customer.