NASA SBIR 2021 Phase I Solicitation

Z13.03  Lunar Dust Mitigation Technology for Spacesuits

Lead Center: JSC

Scope Title:

Garment Protection

Scope Description:

The multilayered fabric system (layup) that protects the structure of the suit from the extremes of the space environment is called the Exploration Extravehicular Mobility Unit (xEMU) environmental protection garment (EPG). The EPG, especially the environment-facing EPG shell fabric, is the suit’s first line of defense against the extreme environment of the lunar surface. The EPG system must not only survive the environment but must perform per requirements and offer a level of protection to the underlying pressure garment system (PGS), portable life support system (PLSS), and informatics system.

The EPG is subjected to the following extreme environments:

1. Thermal
   - Extreme hot (260 °F, 127 °C).
   - Extreme cold (-280 °F, -173 °C).
   - Possible exposure to permanently shadowed regions (PSRs) (-373 °F, -225 °C).

2. Lunar regolith/dust
   - Highly abrasive.
     - Durability in the dust environment is a key requirement. The spacesuit must operate over prolonged exposure to and operation in the dusty regolith environment. This includes kneeling on the ground, thousands of walking cycles, and cleaning before ingressing the vehicle.
   - Electrostatically charged.
     - The suit is also required to severely limit the amount of dust brought into the vehicle. Therefore, materials that are easily cleaned and/or dissipative so that dust does not adhere to the suit are sought.

3. Radiation
   - The material must be able to be durable over hundreds of hours of ultraviolet (UV) radiation exposure. It is
primarily only the environment-facing layer (outmost layer) of the EPG that must be resistant to degradation from the UV environment.

- To prevent damage from discharges, NASA is considering materials that support an EPG that is dissipative.

4. Enriched oxygen atmosphere of the lunar lander in the Artemis program

- The lunar lander in the Artemis program will have an atmosphere of 34±2% oxygen at a pressure of 8.2 psi (56.5 kPa). During the period the astronauts reside in the lander, they will need nonflammable materials for the outer layer of their lunar spacesuits.

5. Suit penetration protection

- Lunar secondary ejecta.
- Microgravity impact.
- Low Earth orbit (LEO) micrometeoroids.

6. Plasma

- Charged environment in contact with the suit.

In addition to the extreme environments, other requirements include the following:

- Optical properties

  - The EPG shall have an average ratio of solar absorptivity to infrared emissivity (α/ε) of 0.21 (TBR).
  - The EPG shall have an average solar absorption of 0.18 (TBR).

- Mass

  - Using the current fabric layers, as a component the EPG weighs on the order of 16 lb. EMU layup mass (with seven layers aluminized Mylar) = 30.84 oz/yd² (1.92 lb/yd²). Orthofabric = 14.0 oz/yd² + 1.0 - 0.5. Aluminized Mylar = 1.12 oz/yd² maximum. Neoprene-coated nylon = 9.0 oz/yd² maximum.
  - NASA has a goal of a 25% weight reduction.

- Mobility impacts

  - While it is understood that the layered materials of the EPG will increase torque in the spacesuit joint by a small amount, the EPG cannot significantly affect mobility of the suit. This requires that the individual materials and the combination of the fabric layers of the EPG allow for joint mobility, such as bending of the elbow. The fabrics themselves must be flexible, and they must be flexible during exposure to the other environmental extremes, such as extreme low temperature and vacuum.
  - Within the environment listed above, the EPG must be flexible and low mass while meeting all other architectural, functional, interface, structural, and design and construction requirements imposed on the xEMU and EPG system.

Past program solutions do not meet the requirements of the Artemis program sustaining missions.

Beta fabric, the glass fiber fabric used in the Apollo spacesuit, addressed only the high flammability risk in the Apollo Lunar Module (LM) atmosphere of 100% oxygen at 4.8 psi (33 kPa). The three extravehicular activities (EVAs) in the last Apollo mission, with an average combined duration of 22 hr, resulted in damage to the outer
fabric of the Apollo spacesuits, and the suits could not have endured more EVAs. The glass fiber developed for NASA was the first-ever textile microfiber (3.8-Åm fiber diameter) that would not burn in a 100% oxygen atmosphere, but it did not have the mechanical properties to withstand abrasion from the lunar regolith.

In the EMU program for the Space Shuttle and International Space Station, the shell fabric was designed for LEO, a significantly different environment from the lunar South Pole. The most notable difference is the absence of abrasives in LEO—no lunar dust. Orthofabric, the three-fiber shell fabric developed for the Space Shuttle suit outer layer, was designed for the Shuttle airlock oxygen concentration of 30% at 10.2 psi (70.3 kPa) and for durability. While the Orthofabric does not support combustion in an exploration environment of 36% oxygen atmosphere at 8.2 psi, it is a woven fabric. The interstices of the weave (gaps between yarns) allow for some amount of lunar dust to penetrate, and therefore it is a poor barrier to dust. In addition, the GORE-TEX expanded polytetrafluoroethylene (ePTFE) film is easily abraded by the dust. Although GORE-TEX is a PTFE (Teflon) and inert, it can accumulate a charge.

In short, NASA is without adequate softgoods/textile solutions for the outermost layer of the EPG system that covers the xEMU suit system. NASA is looking for innovative materials solutions, likely requiring a layup of materials, to address all of the requirements listed above.

**Expected TRL or TRL Range at completion of the Project:** 3 to 4

**Primary Technology Taxonomy:**
Level 1: TX 06 Human Health, Life Support, and Habitation Systems
Level 2: TX 06.2 Extravehicular Activity Systems

**Desired Deliverables of Phase I and Phase II:**

- Analysis
- Prototype
- Hardware

**Desired Deliverables Description:**

Phase I Deliverables: Reports demonstrating proof of concept, test data from proof-of-concept studies, and 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 conditions. Hardware should be evaluated through parametric testing prior to shipment. Reports should include design drawings, safety evaluation, and 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:**

Good environment-mitigation technologies and strategies are nonexistent for the spacesuit.

**Relevance / Science Traceability:**

This scope is included under the Space Technology Mission Directorate (STMD) for Dust Mitigation. The project customer for this scope is the Exploration Extravehicular Mobility Unit Project (xEMU), which is under the Human Exploration and Operations Mission Directorate (HEOMD). Therefore, this scope has traceability to HEOMD as well.

**References:**

Note to Offeror:

No specific reference is available at this time. Under a Phase I contract, a Technical Monitor who is a subject matter expert will be assigned to the project and will be available for consultation upon award. Also, for the
purpose of this solicitation, offerors may consider lunar dust simulants such as OB-1A and NU-LHT 2M for planning purposes.

Scope Title:

Venting Portable Life Support System (PLSS) Covers

Scope Description:

For spacesuits, challenges presented by lunar dust include damage from abrasion, the effects of dust's electrostatic charge on the suit system, and dust intrusion to the suit system. Regarding the effects of dust intrusion, there is a need to provide the capability to mate and demate 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.

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 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 in. on either side.

2. PLSS Rapid Cycle Amine (RCA) System Vent Quick Disconnect (QD): The RCA system for water vapor and carbon dioxide (CO$_2$) removal requires vacuum access for the desorption of these constituents. This is accomplished via a 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% oxygen (O$_2$) at 2.15 psi. Without a specialized cover, this gas dissipates within about 2 sec. After the ullage gas has dissipated, the desorbed gas consists of CO$_2$ and water (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.

3. 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 CO$_2$ 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 to 3.38 lb/hr and the LFPV requires 1.55 to 1.69 lb/hr of O$_2$ 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.

4. 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 O$_2$ at 70 Â°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 Â°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.

Expected TRL or TRL Range at completion of the Project: 3 to 4
Primary Technology Taxonomy:
Level 1: TX 06 Human Health, Life Support, and Habitation Systems
Level 2: TX 06.2 Extravehicular Activity Systems
Desired Deliverables of Phase I and Phase II:

- Analysis
- Prototype
- Hardware
Desired Deliverables Description:

Phase I Deliverables: Reports demonstrating proof of concept, test data from proof-of-concept studies, and 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 conditions. Hardware should be evaluated through parametric testing prior to shipment. Reports should include design drawings, safety evaluation, and 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:

Good dust-mitigation technologies and strategies are nonexistent for the spacesuit.

Relevance / Science Traceability:

This scope is included under the Space Technology Mission Directorate (STMD) for Dust Mitigation. The project customer for this scope is the Exploration Extravehicular Mobility Unit (xEMU) project, which is under the Human Exploration and Operations Mission Directorate (HEOMD). Therefore, this scope has traceability to HEOMD as well.

References:

Note to offeror:

- PLSS schematics and hardware drawings shall be provided if offeror is selected for award.
- Dust simulant characteristics shall be provided if offeror is selected for award.


Scope Title:

Nonventing Portable Life Support System (PLSS) Covers

Scope Description:

For spacesuits, challenges presented by lunar dust include damage from abrasion, the effects of dust's electrostatic charge on the suit system, and dust intrusion to the suit system. Regarding the effects of dust intrusion, there is a need to provide the capability to mate and demate 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.

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 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, and 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
Expected TRL or TRL Range at completion of the Project: 3 to 4

Primary Technology Taxonomy:
Level 1: TX 06 Human Health, Life Support, and Habitation Systems
Level 2: TX 06.2 Extravehicular Activity Systems

Desired Deliverables of Phase I and Phase II:

- Analysis
- Prototype
- Hardware

Desired Deliverables Description:

Phase I Deliverables: Reports demonstrating proof of concept, test data from proof of concept studies, and 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 conditions. Hardware should be evaluated through parametric testing prior to shipment. Reports should include design drawings, safety evaluation, and 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:

Good dust-mitigation technologies and strategies are nonexistent for the spacesuit.

Relevance / Science Traceability:

This scope is included under Space Technology Mission Directorate (STMD) for Dust Mitigation. The project customer for this scope is the Exploration Extravehicular Mobility Unit (xEMU) project, which is under the Human Exploration and Operations Mission Directorate (HEOMD). Therefore, this scope has traceability to HEOMD as well.

References:

Note to offeror:

- PLSS schematics and hardware drawings shall be provided if offeror is selected for award.
- Dust simulant characteristics shall be provided if offeror is selected for award.