WERC 35th ENVIRONMENTAL DESIGN CONTEST

NEW MEXICO SPACE GRANT

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Task 4. Overview

Life Support Systems: Dust Mitigation in Lunar Habitats

This is not the full task problem statement. The complete document will be published when all parameters are approved by our NASA MSFC. Items in question are noted in italics in the document.

Sponsored by the New Mexico Space Grant Consortium

Task

Dust mitigation in space is a challenging issue that affects crew health and equipment longevity. Teams are invited to design a system to remove their choice of: dust from a cargo container or space suit fabric as it is moved from the lunar surface into the space crew's habitat. You are allowed the freedom to select your own dust-resistant surface materials and dust-removal techniques. Successful designs may help the space industry identify new approaches that will help humanity return to the Moon and possibly prepare for eventual missions to Mars.

Background

When the next crew sets foot on the surface of the Moon during the Artemis Program, they will be performing extravehicular activities (EVAs) to conduct science and engineering studies. These studies will develop technologies to support future exploration to help us better understand how humans can live beyond Earth. NASA's plans for a long-term sustainable presence on the Moon includes a progressive increase in habitation capability that eventually will support crews of four for 30 days or longer [1, 2]

A primary challenge in lunar exploration is the potential for large amounts of lunar dust to cling to equipment and spacesuits during EVAs, then enter a vehicle or a habitat when the crew returns from exploring the lunar surface. Dust has been a matter of concern since the Apollo missions, as it compromises crew health and damages equipment. Because future lunar explorers will need solutions to this problem, NASA plans to test dust-mitigation technology for lunar habitats and extend these technologies to support dust mitigation during future missions to Mars.

Lunar Regolith

Regolith, whether on Earth, Moon, Mars, etc., is the layer of unconsolidated sediments that lie on top of solid bedrock. Lunar regolith varies in thickness from 5-10 m on the lunar surface; it is categorized by particle size, with soil and dust being the smallest particles. Lunar dust includes particles 0.5-50 µm in diameter. Roughly 10% to 20% of lunar soil is on the lower end of this range, being finer than 20 µm [3, 4].

Characteristics of Lunar Dust

Lunar dust consists of fine or ultrafine particulates and has a very sharp morphology since no weathering processes are active on the Moon to smooth the edges. The dust is highly variable in shape but tends to be elongated, causing the particles to pack together along the long axes. As particle size decreases, adhesive, cohesive, and excitatory forces become very strong, causing them to stick together and tightly adhere to spacesuits, tools, equipment, and lenses. An additional challenge is solar radiation creating a positive electrical charge on the dust, causing it to cling even more tightly to surfaces [4, 5].

Damage Caused by Lunar Regolith Dust

Due to its sharp edges and small particle size, lunar dust can be dangerous to a mission. This was discovered during the Apollo missions. After three Apollo EVAs, the suit bearings became so highly contaminated with dust that the astronauts had difficulty moving and a fourth EVA would not have been possible. During their return to Earth in the Lunar Module, microgravity was reestablished, causing the dust on the suits to become airborne and float through the cabin. It damaged instruments and caused respiration hazards and cytotoxicity in the crew [3, 6, 7].

For humanity's return to the Moon, measures must be taken to ensure that lunar dust does not compromise crew health and performance, contaminate products used by the crew, or damage equipment. Fans, bearings, and other rotating equipment are particularly susceptible to dust damage [5, 7, 8]. Refer to Chapter 4 of Ewert, et al. [8] for an overview of the effects of dust exposure on NASA life-support systems.

Dust-Mitigation for Lunar Habitats

Dust mitigation for lunar habitats entails two lines of defense. First, preventing dust from entering the habitat, and second, removing any dust that gets past the habitat entry. In this task, teams will address the first line of defense by designing a system that will successfully remove dust from a lunar notional logistics cargo container (i.e., an industry term for a theoretical container that represents an actual lunar cargo container). Teams interested in removing dust from spacesuits may tailor the task to their parameters.

Note that a number of dust-mitigation strategies are being pioneered. These include electrostatic treatments that use electrical energy to disperse dust and physical removal systems that include a variety of agitation or cyclone technologies.

Teams are urged to search for gaps in existing technology to identify novel ways to remove dust from the container before it is moved into the lunar habitat. You may consider an innovative tiered approach in which multiple new or existing technologies would be implemented in tandem or in series to yield optimal results. If in series, consider the sequence of technologies that would be most effective from both a dust-removal perspective and a systems perspective.

Although the moon's gravity is ⅙ of Earth's, teams are not required to simulate reduced gravity for their bench-scale demonstrations because such simulations would be difficult to achieve under WERC's contest conditions. In the technical report, teams should address the predicted outcome of their solution at ⅙ of Earth's gravity, and offer supporting analyses.

Systems and Process Planning

Crew time is a scarce and costly resource. Ideal solutions must minimize operational and design complexity to ensure that minimal crew time is spent on training, use, maintenance, or repair during a mission. This will possibly drive teams to automation or ground-commanded control. Designs should ensure crew safety (See NASA Technical Standards 6001 [9]) while minimizing energy requirements, material volume, and mass. To address these issues, teams are encouraged to engage industrial engineers and human-factors engineers as a part of their team.

Note that these are multiple objectives. An important challenge of the design, and one that the space industry is facing, is to determine how to optimize these many variables.

Problem Statement

Your challenge is to research, evaluate, design, and demonstrate a method for preventing dust from entering a lunar habitat by effectively cleaning objects as they enter the habitat. Build a bench-scale apparatus that fits inside a simulated airlock that will clean a dusty scale-model notional logistics cargo container or a notional logistics space suit. Success will be judged by the amount of dust reduction, ease of use, minimization of crew time, expected reliability, and conservation of power, volume, and mass of the dust-mitigation system. See *Bench-scale Demonstration*, below, for bench-scale container and airlock parameters.

Design Considerations

Your proposed design should provide specific details and outcomes as follows:

- Review available literature on the mechanical properties of lunar dust, Apollo lessons learned, and the fundamentals of dust mitigation borrowed from lunar and other applications.
- Design a dust-mitigation system that strikes an appropriate balance between minimizing crew time (simplicity in setup, training, operation, and maintenance), energy to operate, mass, volume, footprint, and cost.
- Design a bench-scale system that is operable in Earth's gravity, but in the technical report address the design's applicability in ⅙ Earth's gravity at the lunar surface.
- Plan a method of transferring the item from the lunar surface to the airlock for cleaning, then into the habitat. Although teams will not be expected to build this as a part of their bench-scale demonstration, you shall describe, in the technical report, your proposed technologies for moving the container/space suit from the lunar surface, into the airlock, and into the habitat. Provide all necessary supporting evidence and documentation.
- Utilizing a provided block of wood (external dimensions 9" x 11" x 12"*), design, select any material or combination of materials and encase the block with these materials. These materials may include spacesuit fabric or dust-resistant materials. (**Preliminary size – see Final Task statement)*
    - If focusing on space-suit fabric cleaning, teams may either cover the block with space suit fabric or they may substitute the provided block with their own fabric-covered prototype, upon approval. Submit your request to WERC.
    - If focusing on the cargo container, the surface materials must be abrasion- and impact-resistant, as appropriate for a full-scale cargo container that will be used during an EVA. In lieu of the wood block, upon approval, teams may substitute their own prototype of similar dimensions to those listed above. Submit your request to WERC.
- Follow the bench-scale design criteria (below) for building the bench-scale demonstration system.
- Generate concepts for your solution, narrow the focus to a small number of options to further explore, then fabricate one or more prototypes of dust mitigation processes; test and iterate.
- Include a complete process flow diagram in your technical report showing all inputs, outputs, and processes.
- Ensure that the dust-removal process(es) do not damage the surface or fabric either due to the mechanism(s) that remove the dust nor by dragging dust particles against the prototype.

- Conduct an engineering analysis on the ability to scale up the process so that it can be integrated into a lunar habitat and be able to clean multiple full-size cargo containers (or spacesuits) in a reasonable amount of time. Include in the technical report:
    - Time needed for the system to complete the cleaning of one item and for cleaning a set of 5 similar items. Cleaning of multiple items may be conducted in any way chosen by the team (in bulk or one at a time, etc.). Consider, as applicable to your design, the expected frequency and time requirements for recharging or resetting equipment in between cleaning jobs, disposing of dust, cleaning the system itself, etc.)
    - Containment and disposal of the dust collected during cleaning.
    - Expected power usage, volume, and mass requirements;
    - Operational controls for item transfer from the lunar surface to the airlock, and finally to the habitat: automation vs interaction by crew members or ground control;
    - Expected effect on crew members' workload (direct interaction, time, convenience, etc.);
    - Expected routine maintenance of the system;
    - Modularity of parts in the event of repairs, etc.
- Address safety concerns for the crew, dust exposure, flammability, etc. [9].
- Evaluate the possibility of your system producing waste products or by-products (in addition to collecting dust). If there is a potential for these, address how they will be handled.
- Present a Techno-Economic Analysis (TEA) to construct and operate a full-scale dust-mitigation system for the entrance of a lunar habitat; The TEA will include your estimate of capital costs (CAPEX), operational costs (OPEX) for a full-scale solution, expected revenue (if applicable) and appropriate graphical representation of your cost data.
    - Capital expenses typically include, but are not limited to equipment, pipes, pumps, electronics, etc. needed to build the dust-mitigation system as well as any surface materials needed for the cargo container/space suit. Do not include costs of buildings and appurtenances in which the dust-removal system will be manufactured. Do not include the cost of the airlock, unless its design is a specific and integral part of the dust-mitigation design.
    - Operating expenses should be calculated as the cost for launch, based on total equivalent system mass. Equivalent mass considerations include crew time, consumables, repair parts, power, cooling, mass, volume, etc. (see [10]).
    - Visualization tools: Sensitivity analyses, cash flow diagrams, etc.
- Address safety aspects of handling the dust or cleaning equipment. Safety issues for the full-scale design should be included in the technical report. Safety issues and PPE needed for the bench-scale demonstration should be addressed in both the written report and the Experimental Safety Plan (ESP).

Bench Scale Demonstration *(Watch for the full task problem statement for more details.)*
Teams will demonstrate a bench-scale design that will clean lunar dust simulant from a notional logistics cargo container or space suit, according to the design considerations listed above.

Although plans may change (*see full task problem statement*), WERC plans to provide three sealed chambers representing the lunar surface, the airlock, and the clean lunar habitat. The chambers will be designed to prevent dust from escaping into the contest bench-scale demonstration area. See Figure 1 for a schematic of the proposed chamber configuration. These chambers are provided as a courtesy to reduce the amount of bulky equipment your team needs to bring to the contest. If your team prefers to provide your own sealed airlock, include plans for this in the ESP.

The team's bench-scale apparatus need only operate within the simulated airlock provided by WERC. Teams are not expected to build a means of transferring the container or spacesuit item from lunar surface to the habitat, although theoretical plans for this are expected in the technical report.

Lunar Regolith Simulant

The lunar regolith dust to be used in the bench-scale demonstrations is simulant LHS-1 (from Space Resources Technologies/Exolith Labs) [11]. As of this writing, the simulant costs $45/Kg. To test your bench-scale apparatus at your home institution, purchase fresh batches of the simulant directly from the manufacturer. Do not use "old" batches that you obtained previously. LHS-1 has gone through at least 3 feedstock changes that could produce variable results during testing. Adhering to these standards will ensure consistency among teams.

Teams will provide at the contest:

Their own notional logistics cargo container or spacesuit prototype and a functional bench-scale dust-mitigation system that can remove dust from the surface of the team's selected item. These items should be compatible with the WERC-provided test chambers, unless other arrangements are made.

The WERC-provided notional logistics cargo container blocks will be ready to ship to your team in the Fall. Email werc@nmsu.edu to request your prototype blocks, or you may construct your own from a block of pine wood 9" x 11" x 12", with all corners at 90^{o}.

WERC will provide at the contest:

- The LH-1 simulant needed to run all bench-scale demonstrations and three testing chambers, as illustrated in Figure 1, including stages with accompanying high-resolution digital cameras for testing the team's system.
- In addition to the items described above, WERC may be able to provide additional bulky items that may be difficult for teams to bring to the contest. Although teams will provide the majority of items needed for the bench-scale demonstration, you may submit requests to WERC by February 26, 2025 for items needed to run the bench-scale demonstration at the contest. (*See Team Manual*).

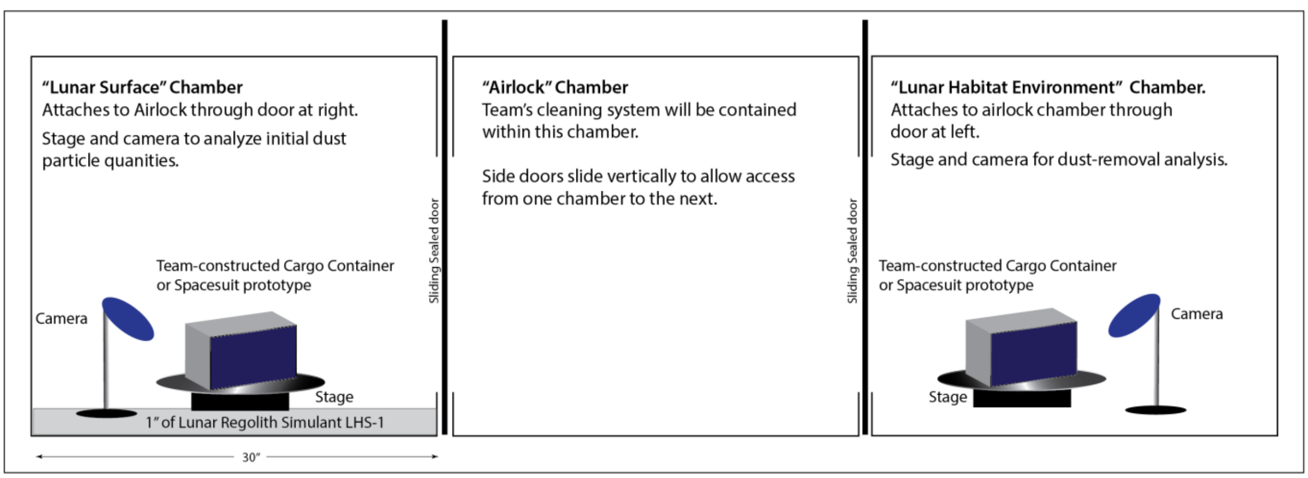

Figure 1. Schematic of Bench-scale demonstration chambers provided by WERC.
(*Subject to minor changes – see final task statement.)*

WERC-Provided Testing Chamber Details (See Figure 1) (plans subject to change – see final task statement):
Chamber dimensions and features

- Interior dimensions: *currently planned to be 30"W x 30"D x 30"H*
- Cutouts for cargo transfer between chambers: *currently planned to be 26"W and 26"H*
- Sealed sliding access doors between chambers
- Hinged access door on the back of each chamber to allow for equipment load-in.

Chamber 1: "Lunar Surface." The chamber will contain a layer of approximately 1" of LHS-1 lunar regolith dust simulant on its floor, a stage on which the cargo box will be placed, and a high-resolution digital camera that will record initial dust amounts while the cargo box/spacesuit prototype rests on the stage.

Chamber 2: "Airlock." The chamber will be empty to allow room for teams to set up their dust-cleaning system within the chamber.

Chamber 3: "Clean Lunar Habitat Environment." The environment will be cleaned between each demonstration. It will contain a stage The high-resolution digital camera will record the final dust amounts while the cargo box/spacesuit prototype rests on the stage.

Chamber Transitions: Watch for details in the final task problem statement and in the Task 4 FAQs. If necessary, cutouts between chambers will provide access between Chamber 1 and Chamber 2 and between Chamber 2 and Chamber 3. The access doors will slide up/down to allow access between chambers. They will be fitted with gaskets to prevent dust from escaping during the demonstration.

Contest Analytical Testing:

Equipment Prototype Requirements

The notional logistics container or spacesuit prototype used in your bench-scale demonstration should be technically and logistically feasible for its application (if a container: scratch- and impact-resistant; if spacesuit fabric: meet spacesuit specifications.)

Analytical Testing

To test your system's success at removing dust from your prototype, WERC will use high-resolution cameras to conduct dust-particle point counts prior to and after cleaning. Point-counting details will be provided at a later date – Watch the Task 4 FAQs. If your system would benefit from a different dust-measurement method, submit your team's proposal for measuring dust removal in your ESP.

Evaluation Criteria

Each team is advised to read "Evaluation Criteria" and "Contest Scoring" in the 2025 Team Manual for a comprehensive understanding of the contest evaluation criteria. For a copy of the Team Manual, Public Involvement Plan, and other important resources, visit the WERC website: Guidelines | werc.nmsu.edu

In addition to evaluation criteria that applies to every task, judges will evaluate your team's response to the problem statement, with consideration of the Design Considerations listed above.

Experimental Safety Plan (ESP) and Required Short Course.

Submit your plans for the bench-scale demonstration in your team's ESP. See team manual for details.

Dates, Deadlines, FAQs (*dates subject to change—watch website FAQs*)

- Today: Email us to let us know you are interested in this task. We will contact you with breaking news.
- October 15, 2024 - December 31, 2024 – Early Bird Registration (discount applies).
- December 1, 2024 - February 20, 2025: Mandatory On-demand Course: Preparing the Experimental Safety Plan. See website and Team Manual for information.
- February 17 - 26, 2025: Experimental Safety Plan (ESP) due. Include requests for volume of brine concentrate and ancillary equipment needed at the contest.
- March 7, 2025: Final date to register a team.
- March 31, 2025: Technical Report due
- Weekly: Check FAQs weekly for updates:
    - Task-specific FAQs: 2025 Tasks/Task FAQs
    - General FAQs: 2025 General FAQs
- All dates or task requirements are subject to change. Check FAQs for updates online.

References

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[11] University of Central Florida CLASS Exolith Lab. https://sciences.ucf.edu/class/exolithlab/ (Accessed 7/10/24).