Task 4. Spacesuit Lunar Regolith Dust Cleaning

2022

Proposed by NASA

Supported by the New Mexico Space Grant Consortium

Background

NASA needs your team to solve a problem that has been plaguing them since the Apollo missions– minimizing the harmful and insidious lunar dust from entering a vehicle or habitat when the crew returns from exploring the lunar surface.

When the first woman and the next man set foot on the surface of the Moon during the Artemis Program, they will be wearing the next generation of spacesuits that will allow them to perform extravehicular activities (EVAs) for conducting science and engineering studies on the Moon to better understand how humans can live beyond Earth.

A major hazard for equipment and crew is the fine lunar dust that adheres to spacesuits during EVAs and is brought into the cabin. For Artemis, the primary concern is the potential for large amounts of dust to enter the spacecraft and cause clogged mechanisms, instrument damage, torn spacesuits, and eye and lung irritation. To protect the vehicle and habitat environment during EVAs, NASA is seeking a method of efficiently cleaning lunar regolith dust off of the spacesuits before the crew enters the protected environments.

Lunar Regolith

Regolith, whether on Earth, the Moon, Mars, etc., is the layer of unconsolidated sediments that lie on top of solid bedrock. The 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, and roughly 10% to 20% of lunar soil is finer than 20 µm.

Characteristics of Lunar Dust

Though it is fine, lunar dust is very sharp, 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. (Heiken, 1991) An additional challenge is the constant solar radiation on the sunny side of the moon that creates a positive electrical charge on the dust, causing it to cling even more tightly to surfaces.

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 learned during Apollo. After three 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. The dust was inhaled, irritated the eyes of the crew, and damaged some mechanical systems aboard the spacecraft. [Anderson, 2018]

Particular points of concern for the Artemis Program include dust that is fine enough to pass through filters (usually 25 µm or smaller), but larger particles are also a concern because they can overwhelm filters, requiring frequent filter replacement. It is also necessary to protect the spacesuits themselves, to prevent fine particles from compacting or passing through the outer material.

Thermal Micrometeoroid Garment
Teams will explore designs for cleaning the outer layer of the Thermal Micrometeoroid Garment (TMG). Although they are currently exploring the next generation of spacesuit fabrics that will provide increased resistance to dust adhesion, penetration, and abrasion, NASA currently uses Ortho-Fabric on the ISS as the outer TMG layer. It is a 14-oz. ripstop woven fabric blend of Nomex®/Teflon™/Kevlar®. It is designed to withstand temperatures of −300° to +300°F (184.4° to 149°C) and is abrasion and tear resistant. It provides protection against micrometeoroids and maintains the optical properties needed for thermal control. Although it has a tight weave, it is susceptible to dust penetration that could damage the fabrics beneath it. Beneath the Ortho-fabric are multiple insulating layers, a pressure enclosure and a liquid cooling and ventilation system. (See Peters & Tang, 2018)

Artemis Project Infrastructure
NASA's infrastructure plans for a long-term sustainable presence on the Moon include a lunar terrain vehicle (LTV)) to transport crew near the landing zone, a habitable mobility platform to allow crews to traverse the Moon for up to 45 days, and a surface habitat that would house up to four crew members on shorter surface stays. Your team's cleaning device will likely be needed for all of these applications.

NASA Dust-Mitigation Testing
NASA is reaching out to industry and academia (including teams like yours) to find solutions to the dust problem. They plan to begin testing dust-mitigation technology on the lunar surface beginning in 2023, and they hope to extend the principles during future missions to Mars. It is possible that your team's solution will make the cut and end up on the moon or even Mars.

Problem Statement
Your challenge is to research, evaluate, design, and demonstrate a method for cleaning lunar regolith dust from spacesuits as the space crew enters a lunar vehicle or habitat. The design should be transferrable for use with any type of extraterrestrial habitat.

For full-scale deployment plans, you may assume that the cleaning will be conducted in an airlock similar to those in use at the International Space Station, with the added consideration of working in 1/6th gravity. At the contest, Teams will demonstrate gravity independence by operating their equipment in multiple orientations. Such ability would be useful on Gateway when the lander returns.

You may propose a second cleaning once the crew member is inside the vehicle/habitat (optional). This second cleaning may use a different process than the primary cleaning system. Note that your team's goal should be to maximize the amount of dust that is removed because it is impossible to remove 100% of the regolith from the suits.

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

- Review available literature on the mechanical properties of lunar dust, the fundamentals of cleaning methods borrowed from other applications, suit materials and designs, and Apollo lessons learned.
- Generate concepts for suit cleaning and narrow the focus to a small number of options to further explore, then fabricate one or more prototypes of suit cleaning hardware

- Test and iterate your suit-cleaning hardware and its ability to clean dust without significant wear or damage to the spacesuits.
- Develop, if applicable, a secondary cleaning system to be used inside the vehicle or habitat.
- Your technical report should include a complete process flow diagram showing all inputs, outputs, and processes.
- The cleaning process should operate independent of gravity and/or be operable in reduced gravity conditions (⅙ Earth's gravity).
- The cleaning process should not:
    - increase the risk of flammability in the vehicle or habitat.
    - Cause damage or excessive wear to the suit fabric either by the cleaning components themselves nor by dragging the dust particles against the surface of the suit.
- The design should minimize maintenance, weight, footprint, operational complexity, and cost.
- Scale-up: For a single full-spacesuit cleaning, discuss:
    - The time needed to complete the process
    - Expected energy requirements
    - Interaction needed by the crew member, if any
    - Expected effect on the crew member during the cleaning process
- Address containment and disposal of the collected dust; identify any waste products or by-products that will be produced and how they will be handled.
- Discuss the maintenance, power usage, footprint, weight, portability of the cleaning system, and its hourly or daily ability to clean the suits. (Is recharge time, disposal, cleaning, etc., an issue?)
- Conduct an engineering analysis on the ability to scale up the process and integrate it into the entry area of a lunar vehicle or habitat. Since the entrance/cleaning area design has not yet been defined (and may depend on your team's design), your team may assume an airlock similar to those in use at the International Space Station, and work in 1/6th of Earth's gravity.
- Present a Techno-Economic Analysis (TEA) to construct and operate a full-scale spacesuit-cleaning system for the entrance area of a lunar lander. The TEA will include your estimate of capital costs (CAPEX), operational costs (OPEX) for a full-scale solution, and appropriate graphical representation of your cost data.
    - Capital expenses typically include, but are not limited to, equipment, pipes, pumps, electronics, etc. Do not include costs of buildings and appurtenances in which the cleaning system will be manufactured.
    - Operating expenses should be calculated as the costs for launch, based on total equivalent system mass. Equivalent mass considerations include consumables, repair parts, power, crew time, volume, etc. (see Hanford, 2008).
    - Visualization tools: Sensitivity analyses, etc. (Recommended: NMSU TEA Short Course).
- Include a Public Involvement Plan, as applicable (See Team Manual).
- Address safety aspects of handling the dust or cleaning equipment. Safety issues for both the full-scale design and the bench-scale demonstration should be addressed in both the written report and the Experimental Safety Plan (ESP).
- To qualify for the P2E2 Award, document success in improving energy efficiency, pollution prevention, and/or waste minimization, as it applies to your project. Place this in a separate section of the report.

Bench Scale Demonstration

Bench-scale demonstrations will serve to illustrate the design considerations listed above and should demonstrate the team's cleaning process for the Thermal Micrometeoroid Garment (TMG) of the Extravehicular Mobility Unit (EMU)spacesuit.

During testing at the contest, all teams will be provided with the same fabrics, geometric spacesuit mock-up, and general testing protocols. WERC will adjust analytical testing according to each team's particular design, after reviewing the team's Preliminary Report and ESP.

Tentative bench-scale testing plan. (Updates will be posted to the WERC FAQs by early December, 2021):

- Fabrics: At the contest, teams will be given layers of spacesuit fabric (or surrogate fabrics), likely with Ortho-Fabric as the outer layer. The layers will simulate fabrics that are being considered for the TMG.

  To help teams test their designs at their home labs, teams will be provided (by December, 2021):
  a. a list of all layers that will be included in the testing material
  b. sourcing information for fabric vendor(s).
  c. If possible, WERC will provide fabric for teams' pre-contest testing. Watch the FAQs for updates.

- Geometry: WERC is considering simulating a portion of a spacesuit arm or leg by wrapping the fabric around a tubular structure (such as a dryer vent hose) to simulate the geometry and folds in an actual spacesuit. (We will refer to this as the "Spacesuit Mock-up.") Watch the FAQs for details.

- Dust: During the contest, WERC will use a surrogate for lunar regolith dust. WERC is working to source appropriate dust for testing. Watch FAQs for source and vendor information.

- Contest Testing: WERC plans to hand each team a spacesuit mock-up that is covered in in the surrogate lunar dust. Watch FAQs for dust-removal efficiency testing criteria.

- Gravity independence: WERC will provide a way for teams to demonstrate gravity independence by operating their equipment in multiple orientations. If possible, WERC will arrange partial gravity testing at a NASA research center. Watch FAQs for details.

Technical Report Requirements

The written report should demonstrate your team's insight into the full scope of the issue and include all aspects of the problem and your proposed solution. The report will be evaluated for quality of writing, logic, organization, clarity, reason, and coherence. Standards for publications in technical journals apply.

In addition to the listed requirements, your report must address in detail the items highlighted in the Problem Statement, Design Considerations, Evaluation Criteria, and the 2022 Team Manual.

Evaluation Criteria

Each team is advised to read the 2022 Team Manual as a group for a comprehensive understanding of the contest evaluation criteria. As described in the manual, your response to this task consists of four parts: a written report, a formal oral presentation, a demonstration of your technology using a bench-scale representation and a poster. General criteria used by the judges in evaluation of these four components are described in the Team Manual.

Your response to the problem statement will include consideration of the following points specific to this task.

- Potential for real-life implementation, including cost, weight, footprint, expected reliability, and maintainability. Judges will weigh these features of your solution against those for other teams.
- The quality/amount of dust removal. The bench-scale spacesuit fabric will be evaluated for cleaning efficiency.
- Thoroughness and quality of the process-flow diagram
- Thoroughness and quality of the economic analysis.
- Originality and innovation represented by the proposed technology.
- Other specific evaluation criteria that may be provided at a later date (watch the FAQs).

The Team Manual, Public Involvement Plan, and other important resources, are available on the WERC website: https://iee.nmsu.edu/outreach/events/international-environmental-design-contest/guidelines/.

References

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FAQs/Deadlines

- Mid-December, 2021 EH&S Short Course (watch website for dates and registration info).
- January: WERC will ship test dust and fabrics to teams, if possible. Contact us to request samples.
- Mid-January, 2022: EH&S Short Course; TEA Short Course
- 1 February, 2022: Experimental Safety Plan (ESP) due
- 7 February, 2022: Preliminary Report due
- 7 March, 2022: Send a draft of the technical report to your auditors (approx. date–see Team Manual)
- 28 March, 2022: Technical Report due
- Weekly: Teams are expected to check the FAQs online weekly for any updates in the task requirements. (wercdesigncontest.nmsu.edu)

Short Courses

WERC is offering two short courses. The optional courses are designed to prepare teams to more effectively complete their technical report and earn digital badges to add to their professional development portfolio. The courses are also available to the general public to gain professional development. Fees will be waived for contest-registered students, faculty, and judges. Watch the WERC website for schedules and registration.

Courses offered:

- Health and Environmental Safety (EH & S) (Mid-December and Mid-January)
- Techno-economic Assessment and Analysis (TEA) (Mid-January)

Awards

The WERC Environmental Design Contest and its sponsors award more than $25,000 in cash prizes, below.

1. Task awards (First, Second, Third Place; minimum amounts: $2500-$1000-$500, respectively).
2. Freeport-McMoRan Innovation in Sustainability Award ($2500)
3. WERC Resources Center Pollution Prevention/Energy Efficiency Award (P2E2 Award) ($500)
4. Judges' Choice Award ($500)
5. Peer Award ($250)
6. Terry McManus Outstanding Student Award. ($500-$1000, according to funding).

Additional awards may be announced at a later date.

Award amounts listed are minimum amounts and may increase with available funding. Detailed criteria for each award are listed in the 2021 Team Manual: https://iee.nmsu.edu/outreach/events/international-environmental-design-contest/guidelines/