Z13.04 Lunar Dust Filtration and Monitoring

Lead Center: GRC

Participating Center(s): JSC, KSC

Scope Title
Lunar Dust Filtration and Monitoring

Scope Description

Advances in the removal, management, and monitoring of airborne particulates and external dust are sought to address the intrusion into and containment of lunar dust within the pressurized habitable volumes and compartments in crewed spacecraft systems. Specifically, advances in particle filtration and separation techniques, barrier techniques, and monitoring instruments are integral to maintaining conditions conducive to crew health and safety as well as protecting spacecraft systems from dust-related fouling during crewed surface exploration missions.

Currently on the International Space Station (ISS), astronauts must vacuum protective screens covering filters weekly to remove larger particles and lint fibers, which are generated by their daily activities, particularly exercising. In the early, shorter Artemis missions, the crew will have to contend with very small amounts of typical spacecraft cabin aerosols and with large amounts of the new contaminant, lunar dust. Lunar dust particles will carry some level of charge which is not well understood or quantified at this time, and other cabin aerosols may be charged as well. Particles are irregularly shaped and jagged, with abrasive properties that can damage mechanisms and equipment.

In the long-range goal of establishing a sustainable human presence on the Moon in habitats, air quality in the larger living areas will be challenged by all the aerosols that come from longer term human occupancy and aerosols generated by the equipment and processes that keep the habitat operational. In this scenario, the time spent on cleaning should be minimal for the crew. Therefore, filtration and separation systems should be as maintenance free as possible, and potentially regenerable, to avoid the cost of flying spares and consumables. Based on the level of lunar dust contamination, even short missions (on the order of 30 days) may require some form of regeneration or autonomous maintenance to minimize or eliminate crew intervention. Specific needs on this front are particle-flow barriers, filtration media, and inertial cleaning prefilter devices that are self-cleaning and/or regenerable.

Another risk of suspended particulate matter (PM) in spacecraft is false smoke alarms. On ISS, the smoke detectors are disabled during vacuuming and other housekeeping activities for this reason. Ideally, this would not be the practice during extensive dust cleaning in the lander after extravehicular activities (EVAs), and creative solutions in particle monitors should address this issue.

PM monitoring technologies are sought to measure a wide range of particle concentrations that will exist in different
stages of lunar missions. The lunar lander missions allow only minimal equipment within the small habitable volume but will have much higher concentrations of lunar dust. Therefore, miniaturized aerosol instruments should be capable of measurements in the range of tens of milligrams per cubic meter (mg/m$^3$) for particle sizes up to 20 µm and should be sensitive enough to verify small concentrations to prove that air cleaning systems are effective. Once cleaning has progressed, lunar dust mass concentrations may be very low, but large numbers of individual ultrafine particles may still be present. The Gateway outpost that will orbit the Moon will have some lunar dust contamination by way of the lander docking and exchanging air, as well as settled dust in the lander, which may be reentrained into Gateway air upon ascent, but overall, particle concentrations are expected to be much lower. The monitoring of this habitable space requires more sensitivity, with the ability to accurately measure down to 0.05 mg/m$^3$ for particles 10 µm and below.

Any monitoring technology is at risk of clogging from larger lunar dust particles or possibly even lint or other cabin aerosols. To avoid this, effective designs will have one or more precut features, such as size-selective inlets and screens, which should not require consumables or frequent maintenance and would potentially have self-cleaning features. Note that the ingestion of abrasive particles can cause damage to the internal components of a particulate monitor.

The performance of technologies should be evaluated through testing and/or analysis under relevant environmental conditions using aerosol reference instruments and relevant particle-size distributions of lunar dust simulants.

Measurement ranges for monitoring and permissible limits for filtration in lunar missions:

- Levels of suspended PM (cabin dust and lunar dust) must be maintained below 3 mg/m$^3$, and the respirable fraction of the total dust (smaller than 2.5 ?m in aerodynamic diameter) must be below 1 mg/m$^3$, per the standards in NASA-STD-3001 Vol. 2, Rev. B.
- More specifically:
  - During intermittent daily exposure periods that may persist up to 6 months in duration, lunar dust must be maintained below a time-weighted average of 0.3 mg/m$^3$ for particles less than 10 ?m.
  - For 7-day lander missions, lunar dust must be maintained below a time-weighted average of 1.6 mg/m$^3$ for particles less than 10 ?m.

Specific needs in each area of interest are given below.

**Bulk Particle Filtration and Separation Techniques:**

Techniques and methods are sought for compact, low-power, autonomous, regenerable bulk PM separation and collection. Techniques should be suitable for general spacecraft cabin air purification and removal of planetary or lunar (surface) dust in main cabin quarters and airlock compartments. The hardware developed needs to operate at reduced cabin pressures down to 56 kPA. The PM removal techniques and methods must accommodate high volumetric flow rates up to 3.4 m$^3$/min (for distributed ventilation architectures with multiple supply and return branches) and with pressure drop not to exceed 125 Pa. The system needs to meet requirements for both lunar dust and spacecraft cabin dust (derived from materials in the spacecraft, Environmental Control and Life Support System (ECLSS) processes, and biological matter and debris generated by the crew).

The proposed techniques and methods should provide the cleanliness levels stated above, either as a standalone unit or in conjunction with a high-efficiency filter stage. The overall filtration performance of the filtration system (which may include a high-efficiency stage) should be at minimum 99.97% collection efficiency for particles 0.3 µm in diameter (or HEPA efficiency standard). The filter and separation system also needs to provide microbial and fungal control as outlined in NASA-STD-3001 Vol. 2, Rev. B requirements. These standards must be maintained for a particulate generation rate of 0.31 mg/min per person and a surface dust intrusion rate of 50 g per EVA person (according to EVA-EXP-0070). The systems need to be capable of handling the total PM and planetary dust load over the broad size range of particles generated throughout the mission (up to hundreds of micrometers) and must operate in the surface environment for periods ranging from 2 weeks to 500 days or more. The filter and/or separation technology should provide sufficient capacity to collect and contain tens to hundreds of grams of lunar dust over its service life (which can include multiple regeneration cycles). If regenerable, the technology should provide an effective means of containing or preventing the release of the collected bulk PM during the regeneration process.
Barrier Techniques:

There is a need for PM management systems specifically designed to collect and remove lunar dust from airlocks, suit preparation compartments, or staging areas. These should provide a >99.5% effective barrier to surface dust transfer between different volumes or compartments. The barrier technique may include filtration, separation, and other mitigation techniques used within these smaller pressurized compartments, and/or techniques that prevent the transport or transfer of surface dust between compartments, to main cabin areas, or to orbiting habitats and crew transport vehicles.

Monitoring Instrumentation:

Instruments, or instrument technologies, that measure PM concentrations in particle size ranges specified in the cleanliness requirements (stated above) are desired. The instrument, or combination of instruments, will need to measure lunar dust and normal cabin dust in landers, airlocks, and habitable spaces at lunar gravity, as well as in the microgravity environment in the Gateway orbiter. Real-time measurement instruments must be compact and low power, require minimal maintenance, and be able to maintain calibration for 1 year. The instrument also needs to be compatible with 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 combined in one unit. PM sensors that measure size-segregated mass concentration (PM2.5 and PM10) over a wide range of mass concentrations and are capable of distinguishing between different material types (lunar dust, typical spacecraft cabin dust and smoke) are highly desirable.

In the long term, future integration of monitoring technologies with filtration or other cleaning technologies may drive the design and development of initially proposed technology solutions. Future autonomous vehicles are expected to use feedback loops for remediation of dirty air as well as monitoring filter and sensor health and performance.

Expected TRL or TRL Range at completion of the Project

2 to 4

Primary Technology Taxonomy

Level 1

TX 06 Human Health, Life Support, and Habitation Systems

Level 2

TX 06.1 Environmental Control & Life Support Systems (ECLSS) and Habitation Systems

Desired Deliverables of Phase I and Phase II

- Research
- Analysis
- Prototype

Desired Deliverables Description

For Phase I, research, numerical modeling, and preliminary breadboard results in a report are feasible.

For Phase II, firms should deliver a working prototype and accompanying test data to NASA, demonstrating performance to specifications using lunar simulants and other relevant test aerosols.

State of the Art and Critical Gaps

The state of the art (SOA) for filtration relies on consumables, and there are few incentives for making regenerable filtration or prefilter barriers. Self-cleaning prefilter devices are not requirements for most commercial and
residential filtration scenarios. The price for such systems is not justified when simple replacement filters are available. This solicitation specifies quantities of lunar dust loading in filters that far exceed the capacity of any commercially available filters.

The SOA for particulate monitoring includes miniaturized instruments, which may have very poor performance compared to reference-quality instruments. So-called "low-cost" sensors typically sacrifice accuracy for small-size and low-power needs and are only appropriate for environments that are relatively clean in comparison with the expected lunar dust contamination in the lander cabin after EVAs. In particular, it is difficult to accurately measure PM10 (particulate matter 10 µm and below) with commercially available miniaturized sensors. Instruments that are sensitive to single-digit mg/m³ mass concentrations are typically not capable of measuring high concentrations. Size-selective inlets to instruments typically require cleaning and maintenance, and self-cleaning options are nonexistent. There is no commercially available instrument that can distinguish between aerosol types (dust, smoke).

Relevance / Science Traceability

Human Exploration and Operations Mission Directorate (HEOMD) and Life Support Systems (LSS) can use this technology. It is necessary for Artemis or any other dusty planetary destination.

References