Frontier Technologies for Lunar Dust Control in Environmental Control Systems Aboard the Deep Space Gateway. M. E. Johnson[1] and B. E. Troutman[2], [1]JSC Engineering, Technology and Science Contract (NASA Johnson Space Center, Houston, Texas, 77058, USA, matthew.e.johnson@nasa.gov), [2]JSC Engineering, Technology and Science Contract (NASA Johnson Space Center, Houston, Texas, 77058, USA, brian.e.troutman@nasa.gov).

Introduction: According to Apollo 17 astronaut Harrison "Jack" Schmitt, "Dust is going to be the environmental problem for future missions, both inside and outside habitats." The NASA missions that delivered astronauts to the moon, Apollo 11 through 17, did so without the enhanced understanding of the characterization of abrasive nature of lunar dust that we have today, including the transport mechanisms which introduced contamination. The Artemis program represents the first attempts to design human spacecraft systems with an understanding of lunar dust in mind from conception to deployment for use. Approaches for the design of dust-tolerant spacecraft systems are presented for Environmental Control and Life Support Systems (ECLSS) and Active Thermal Control Systems (ATCS) on the Deep Space Gateway. Design guidelines and technological solutions in the mitigation of lunar dust for these subsystems is provided herein. These approaches are subject to future design trade studies. Testing strategies that address the robustness of spacecraft subsystems exposed to the unique characteristics of lunar dust are also explored.

The problems posed by abrasive nature of lunar dust within environmental control systems are myriad and often overlap, as shown in Fig. 1. Microscopic lunar dust poses a risk to mechanical components threatening to bind and seize mechanical parts and prevent normal operation, however, they also potentially threaten virtually all spacecraft systems through scratching, cutting, interference with chemical processes, unwanted thermal insulation, clogging, erosion and other processes. This engineering problem warrants substantial attention, and is perhaps the most pervasive problem affecting human exploration missions to and from the moon today.

ECLSS Dust Mitigation

The habitation volumes in spacecraft, hereafter referred to as Intravehicular (IV) zones, were severely challenged during previous Apollo flights to the moon. Once the crews landed and traversed the lunar surface, significant amounts of lunar dust were introduced into the Lunar Excursion Module (LEM) and subsequently the Command Module once docked in orbit. The threat to IV volumes is real and the dust affects nearly every component, especially filtration systems, hatch seals, and mechanisms. If not controlled, it can impair or clog heat exchangers, short electrical connectors, degrade glass and optics, and damage portable electronics.

The Deep Space Gateway ECLSS will play a vital role in mitigating lunar dust contamination in the future. Two main levels implemented include prevention and control. Procedures are being developed to minimize transport of dust into vehicles. Using a Concept of Operations approach, the system will be heavily dependent on crew to reduce dust intrusion, once the lunar ascent vehicle docks with Gateway. Lunar dust microscopic particles are transported, on surfaces (crew and equipment) or airborne in a microgravity environment. Contamination controls should be both active and passive.

ECLSS active controls provide the first line of defense and involve filtration of fine particles via main cabin fans and inter-module ducts using optimized filters. The design of these filter systems is still in the development stage. By using positive air pressure over large crew hatches and soft seals/curtains, introduction of dust into adjacent cabins can be minimized. Other active methods for maintaining surface cleanliness may include vacuuming, wiping with tack cloth or Cyberclean™ compound, and dislodging particles with air wands. Passive controls use the latest design practices and lessons learned to minimize harmful effects of dust size materials. These include using a tortuous path for seals/bearings, dust boots, covers, and sealing of sensitive equipment where feasible. Exposed surfaces should have smooth finishes and rounded internal corners to preclude dust collection. Selection of dust repellant coatings and/or energizing surfaces are also useful in minimizing dust collection. A description of both active and passive control techniques to achieve success, and the testing approaches to substantiate performance, are further described below.

TCS Dust Mitigation

The Deep Space Gateway ATCS will need to contend with lunar dust in both IV and Extravehicular (EV) zones of the vehicle. For ATCS internal systems, mechanical damage can occur with pumps and valves. Outside of the pressure shell, lunar dust adhesion potentially threatens the operational lifetime of optical surfaces such as thermal coatings and radiators (e.g. scratching and marring of surfaces) and affects emissivity, absorptivity and reflectivity. External mechanical components such as actuators are susceptible to wear and jamming. EV TCS systems benefit from the protocols established from ECLSS IV since these and further external protocols may serve to minimize dust transported on the EV surfaces of lunar ascent vehicles returning to the Gateway. Previous work done on the protection of painted external surfaces has already demonstrated superior characterization of the space environment, and it yielded conclusions that brushing alone would not be sufficient to remove the dust[1,2] Consideration is also given to work at the Jet Propulsion Laboratory (JPL) which presents an enhanced understanding of dust monolayer characterization on surfaces, which will be explored in testing. This drives dust mitigation standards and classification levels which are part of the effort to develop a systematic design methodology.

For risk reduction and safety purposes, there is a need to implement technologies that robustly address the issues of lunar dust contamination and are sufficiently developed to facilitate their incorporation into spacecraft systems in a timely manner. Recently developed technologies, coupled with directed and specific testing, can yield potentially effective strategies that will address the most pervasive threats of lunar dust: mechanical component infiltration, surface contamination, and human health. Methods could include employing electrostatic manipulation of dust particles, considered within NASA to be the most effective method to transport large quantities of lunar dust, and could potentially be used as integrated tools for spacecraft hardware or hand-held variants for dust control on spacesuits, tools and external surfaces.

In this discussion the authors will further examine surface topological modification through optical and chemical means for intrinsically dust-resistant materials. There are new efforts underway to develop testing gloveboxes and utilize specialized NASA test equipment to characterize and test the effects of dust and its adhesion on these hardware systems. This treatise will describe the methods to demonstrate technology effectiveness and identify best practices and design standards that are needed for controlling lunar dust in environmental control systems on the Deep Space Gateway.

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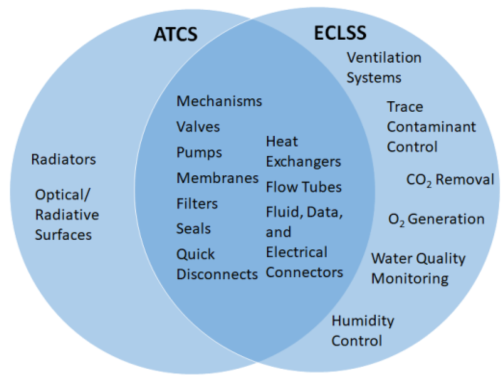

Figure 1 – Common Hardware Affected by Lunar Dust