

**DUST MITIGATION - IMPACTS & OPPORTUNITIES FOR SCIENCE ON THE LUNAR SOUTH POLE.**

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**Introduction:** Lunar dust will be a feature of all lunar surface science investigations, whether welcome or not. While lunar dust may pose problems for some investigations, it is also the subject of many critical scientific discoveries made since the Apollo days. Dust mitigation, or learning how to work with and around the inevitable dust we will encounter on the surface, is not a new concept. However, new initiatives throughout NASA are underway in an effort to tackle dust mitigation strategically for the Artemis program. Dust mitigation efforts and technologies will enable successful lunar surface science investigations.

**Dust Mitigation:** The effects of lunar dust will impact several systems during lunar landing, operations, ascent, and docking to other vehicles. This includes human health toxicology, vision obscuration, failures of seals, clogging of joints and mechanisms, false instrument readings, abrasion of surfaces, thermal control, and more. Any lunar surface system or scientific investigation on the surface will have to find ways to mitigate dust in order to ensure success.

**Dust Mitigation Strategy:** An integrated dust mitigation strategy includes operational and architectural approaches, in addition to passive and active technologies. Dust mitigation influences surface operations, habitats, descent/ascent, and orbital assets, and impacts most surface systems, subsystems, and equipment. Dust management includes tolerating dust exposure, detecting/monitoring dust, controlling entry of dust into vehicles/systems, and removal of dust.



Figure 1: Gene Cernan, Apollo 17 Commander. Credit: NASA

**History:** Dust mitigation efforts going forward will leverage lessons learned from Apollo. Looking back, almost all who walked on the Moon had something to say about lunar dust. Apollo 17 Commander Gene Cernan (Figure 1) stated “I think dust is probably one of our greatest inhibitors to a nominal operation on the Moon” and also stated “probably the most difficult job of all the closeouts was trying to dust the suits...The real-time transcripts will show just how much time and effort was spent in dusting.” Pete Conrad, Apollo 12 Commander, recalls, “The dust went as far as I could see in any direction and completely obliterated craters and anything else...I couldn't tell what was underneath me. I knew I was in a generally good area and I was just going to have to bite the bullet and land, because I couldn't tell whether there was a crater down there or not.”

**Artemis Dust Mitigation:** A team at NASA has formed to tackle the challenge of dust mitigation in the Artemis program. The team, spread across the Agency, has representatives from the Human Lander System (HLS), Space Technology Mission Directorate (STMD), Orion, Gateway, Lunar Surface Systems, Human Health and Performance (HHP), Extravehicular Activities (EVA) Office, Astromaterials Science division, Crew Office, Flight Operations Directorate (FOD), EVA Tools, Environmental Control and Life Support Systems (ECLSS), and more. The team is leveraging lessons learned from Apollo [1-2], work performed during Constellation [3-4], and beyond [5-6]. The team is working across the various programs to address dust mitigation efforts including requirements, testing (standards and facilities), technology development and integration, system and subsystem-level analyses, environment definition, surface operations, and on-orbit docking and ingress to the Gateway and Orion.

**Dust Mitigation Technologies:** Operational and architecture technology solutions can include providing ways to keep dust out of habitable volumes (e.g., suitports, severable airlocks, mud-rooms, porches), landing site selection, prepared landing pads, and optimized EVA and traverse planning. Passive technology solutions can include HEPA filters, cyclone separators, softwalls, low-energy surface coatings, coveralls/aprons, dust tarps, brushes, tape, and wipes. Active technology solutions can include electrostatics, compressed air, high-energy surface coatings, and vacuums.

NASA STMD is funding several dust mitigation technologies including the Electrodynamic Dust Shield, Patch Plate Materials Compatibility, and Dust Tolerant Mechanisms. Additionally, three different dust mitigation subtopics were released in the January 2020 Small Business Innovation Research (SBIR) solicitation including Active and Passive Dust Mitigation Surfaces, Dust Tolerant Mechanisms, and Lunar Dust Management Technology for Spacecraft Atmospheres and Spacesuits. Dust mitigation technology development and integration into investigations will enable science exploration in the lunar South Pole region.

**The Role of Dust Mitigation in Lunar Science:** It is critical for the success of scientific investigations on the lunar surface to understand the role dust will play. Dust mitigation technologies will enable several instruments to succeed on the surface. Additionally, ground testing of future payloads and instruments against the effects of lunar dust will be necessary. For instance, rovers that may carry scientific payloads (such as the Volatiles Investigating Polar Exploration Rover, or VIPER) need to provide mobility as the wheels traverse through the regolith. Incorporating something like dust sleeves over mechanisms may be necessary. Investigations that involve mechanisms (such as drills or arms transporting samples to instruments) need to understand how to mitigate dust to improve reliability and extend operations. Science investigations that rely on imagery, optics, or solar panels will need to protect their surfaces from the abrasiveness of lunar dust. Incorporating certain technologies into the design of future investigations (e.g. surface coatings) will be necessary.

**The Scientific Value of Lunar Dust:** Lunar dust is not just an obstacle to performing science on the Moon. It is the dust itself, collected during Apollo, which unveiled some of the mysteries of the Solar System. Even to this day, scientists are performing new investigations as part of the Apollo Next Generation Sample Analysis Program (ANGSA). During and since Apollo, countless discoveries and publications have been released regarding the early history of our Solar System, the formation of the Earth and Moon, and the geologic history of the Moon. Beyond just sample collection, several Apollo surface investigations involving the regolith revealed discoveries. For instance, the images of bootprints on the surface (Figure 2) show that the top layer of regolith is easily compressed, giving insight into the porosity of the regolith [7]. Porosity is an important parameter for interpreting remote sensing data. Porosity could not be investigated with returned samples because the regolith was compacted. Another

surface investigation during Apollo was the Apollo 17 Lunar Ejecta And Meteorites (LEAM) Experiment. This was part of the Apollo Lunar Surface Experiments Package (ALSEP) and aimed to measure the speed, direction, and total kinetic energy of particles impacting the surface [8].



Figure 2: Apollo 11 Bootprint in the Lunar Soil, photographed with the 70 mm lunar surface camera. Credit: NASA

**Dust in the Artemis Era:** Specific investigations aimed at studying lunar dust could be proposed for future lunar surface missions, ranging from no additional mass or power needed (i.e. use of imagery to determine porosity, size distributions, etc.) to varying levels of mass and power requirements. It is likely that future surface investigations will unveil insight into lunar regolith, even if that is not the primary goal. Returned regolith samples from the lunar South Pole region will answer questions about the differences in composition and characteristics at different locations on the Moon. It will be imperative that future lunar surface science investigations consider dust during their testing, development, and operations. Dust mitigation technologies, or at least understanding the impacts of dust on a given investigation, will thus enable the success of science during Artemis. As we return to the Moon for longer durations, dust mitigation will become more relevant than ever before.

**References:** [1] Gaier J. (2005) NASA/TM—2005-213610 [2] Taylor L. et al. (2005) AIAA 2005-2510 [3] Wagner, S. (2006) NASA/TP-2006-213726. [4] Hyatt M. and Straka S. (2011) NASA/TM-2011-217037 [5] Gaier J. (2016) Dust Mitigation Gap Assessment Report, IAWG [6] Wagner S. (2014) NASA/TP-2014-217399 [7] Hapke B. and Sato H. (2016) *Icarus*, 273, 75–83. [8] Berg O. (1973) Apollo 17 Prelim. Sci. Rept. NASA SP-330, 16-1 to 16-9.