**LUNAR DUST AND ITS IMPACT ON HUMAN EXPLORATION: IDENTIFYING THE PROBLEMS.** J. S. Levine, Department of Applied Science, The College of William and Mary, Williamsburg, VA 23187 and NASA Engineering and Safety Center (NESC), Robotic Spacecraft TDT, NASA Langley Research Center, Hampton, VA 23669, jslevine@wm.edu

**Introduction: Lunar Dust and the Apollo Experience:** On July 20, 1969, as he was about to become the first human to set foot on another world, Apollo Astronaut Neil Armstrong climbing down the ladder of the Lunar Module (LM) onto the lunar surface communicated with Mission Control at NASA Johnson Space Center in Houston and reported [1]:

*I'm at the foot of the ladder. The LM footpads are only depressed in the surface about 1 or 2 inches, although the surface appears to be very, very fine-grained, as you get close to it, it's almost like a powder; down there, its very fine … I'm going to step off the LM now. That's one small step for (a) man: one giant leap for mankind. As the-The surface is fine and powdery. I can-I can pick it up loosely with my toe. It does adhere in fine layers like powdered charcoal to the sole and sides of my boots. I only go in a small fraction of an inch. Maybe an eighth of an inch, but I can see the footprints of my boots and the treads in the fine sandy particles.*

Armstrong's first encounter with lunar dust came somewhat earlier in the mission during the landing of the Lunar Module (LM) on the lunar surface when the exhaust gas from the LM blew large amounts of surface dust into the very thin lunar atmosphere that significantly obscured the visibility of the lunar surface. Fortunately, Armstrong successfully landed the Lunar Module on the lunar surface even though visibility was reduced due to the large amount of lunar dust added to the very thin lunar atmosphere.

Armstrong's observation that the surface of the Moon "appears to be very, very fine grained…. almost like a powder" was a very important discovery. The presence of very fine lunar dust over the surface of the Moon had a very significant negative impact on human lunar exploration, affecting human health, lunar surface equipment and systems, including astronaut spacesuits and helmets and lunar surface operations.

During their extensive post-flight NASA technical debriefings, all of the Apollo astronauts commented on their experiences with lunar dust while on the Moon. During his post-flight mission debriefing, Apollo 17 Astronaut Eugene Cernan, one of the last two humans to walk on the Moon (the other was Harrison Schmidt) told NASA officials [2]:

*I think dust is probably one of the greatest inhibitors to a nominal operation on the Moon. I think we can overcome other physiological or physical or mechanical problems except dust...One of the most aggravating, restricting facets of lunar surface exploration is the dust and its adherence to everything no matter what kind of material, whether it be skin, suit material, metal, no matter what it be and its restrictive friction-like action to everything it gets on.*

An extensive investigation of lunar dust was performed by Gaier [3] who based his study on the Apollo mission reports, technical debriefings and the transcripts of the voice traffic between the astronauts on the lunar surface and Mission Control. These documents are available on line at http://www.hq.nasa.gov/aldsj/. Gaier [3] writes that one of the surprises of the Apollo experience was how troublesome the lunar dust turned out to be. It obscured their vision on landing, clogged mechanisms, abraded the Extravehicular Mobility Suits (EMS), scratched the instrument covers, degraded the performance of radiators, compromised seals, irritated their eyes and lungs, and generally coated everything with surprising tenacity. Some of the EMS components were deteriorating at the end of the missions, which ranged from 21 to 75 hours on the lunar surface. Gaier [3] has divided the observed effects of lunar dust as described in the astronaut's extensive post-mission NASA debriefings into 9 categories: (1) vision obscuration, (2) false instrument readings, (3) dust coating and contamination, (4) loss of traction, (5) clogging of mechanisms, (6) abrasion, (7) thermal control problems, (8) seal failures and (9) inhalation and irritation.

**The Nature and Structure of Lunar Dust:** The lunar regolith is the unconsolidated covering of material on top of the primordial lunar bedrock and contains a mixture of dust, gravel, dirt and pebbles [1]. Over billions of years, the regolith has been constantly bombarded by micrometeoroids. When the micrometeoroids hit the regolith, they create a miniature shockwave in the soil, which causes some of the soil to melt and some to vaporize to a gas [1]. The molten soil immediately freezes again forming tiny pieces of glass—glass shards. These tiny glass shards are jagged and very sharp. Due to the absence of wind or rain on the Moon, the glass shards remain jagged and very sharp over time. Due to the constant hammering by micrometeoroids over billions of years, the lunar surface dust is extraordinary fine, similar to flour, which makes it very sticky and causes it to cling to everything, e.g., spacesuits, helmets, surface equipment, scientific instrumentation, etc.

Lunar surface dust enters the lunar atmosphere as the astronauts walk around and kick it up. In addition, the motion of wheels on the mobility system is another mechanism of transferring surface dust to the atmosphere. The lunar atmosphere is much too thin to hold up the surface dust for any appreciable time and the surface dust quickly settles back to the surface of the Moon. If somehow, the atmosphere of the Moon were to increase in mass, the lifetime for surface dust to remain in the atmosphere would also increase, making lunar dust even more dangerous to humans on the Moon.

**Human Activities and the Mass of the Lunar Atmosphere:** The total mass of the very thin atmosphere of the Moon is about $10^7$ g (about 100 tons) and the natural rate of supply of gases to the atmosphere is on the order of 10 g $s^{-1}$ [4]. Due to its very low mass, the atmosphere of the Moon is susceptible to impact by activities associated with human presence and exploration. Each Apollo landing mission deposited rocket exhaust and spacecraft effluents totaling about

0.2 lunar atmosphere masses [5,6]. During the Artemis Program return to the Moon currently being planned and to begin in 2024, human presence and exploration of the Moon will continue and at a greater pace than during the Apollo missions of 50 years ago. A denser lunar atmosphere resulting from human presence and exploration will result in a longer atmospheric lifetime of surface dust in the atmosphere.

**Dust in the Atmosphere of Mars: An Earlier NASA Workshop:** The Moon is not the only Solar System body that is a target for human exploration where dust is a problem. Dust in the atmosphere of Mars may also be a problem for human exploration. In 2017, the NASA Engineering and Safety Center (NESC) organized a workshop entitled, "Dust in the Atmosphere of Mars and Its Impact on Human Exploration." The results of this workshop were summarized in a published conference summary [9], a NASA Technical Memorandum [10], and a conference proceedings volume [11].

**Conclusions:** The Apollo Missions to the Moon led to the unexpected discovery that lunar dust has a very negative impact on the astronauts, their surface systems, including space suits and helmets, other surface equipment and on lunar surface operations. The next phase of the human exploration of the Moon, the Artemis Project, will send humans back to the Moon for longer periods that the astronauts will be on the lunar surface and exposed to lunar dust. It is critical to the success of future human lunar missions that we develop techniques and technologies to reduce and mitigate the negative impact of lunar dust on the astronauts, their surface systems and surface operations [12].

**References**

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