Five Stage Defense Against Lunar Regolith

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The properties of lunar dust (<50μm[1] particle size) present serious engineering challenges in the design of machines that will operate on the lunar surface. The traditional space design paradigm of avoiding moving parts is in direct conflict with current efforts to develop technologies for use on the moon such as rovers, manipulators, drills and ultimately In Situ Resource Utilization (ISRU) of lunar material. As previously mentioned by Harrison J. Schmitt[0], these challenges require a multi-layered approach if any of these technologies are expected to operate in such a harsh environment for any significant amount of time.

While building a manned moon base is currently on hold, a number of concurrent projects are intended specifically for the moon. Examples include CSA's Exploration Surface Mobility (ESM) projects, NASA's Regolith and Environment Science and Oxygen and Lunar Volatile Extraction (RESOLVE) project, Japan's robotic moon base (draft plan) and even the Google Lunar X Prize. However, these have in common a need for moving parts that will be exposed to the lunar environment. As broadly researched by Dr. L. A. Taylor, University of Tennessee-Knoxville, small particle size (median diameter 40μm), abrasiveness, and electrostatic and magnetic properties (due to the inclusion of nanophase-sized Fe^0 particles bound within the dust)[2] make lunar regolith extremely clingy and damaging to machines, as was seen in the various Apollo missions. During brief moon visits, EVA suits were degraded and in some cases leaked[13]; a few instances where camera lenses were covered with dust[13,14]; indium knife-edge sealed 'rock boxes' mostly failed to maintain vacuum[14]; and the Apollo 16 vacuum cleaner and Lunar Module (LM)[13,14] filter failures [13] are some of the examples of the difficulty encountered with lunar dust. While a brush was used to clear the camera lens, they were not effective in removing fine dust and tended to rub them deeper into the garment[15] which might conceivably increase damage. Even the efficiency of the retro reflector array installed on the lunar surface has apparently decreased by an order of magnitude[3] over the years.

In addition to temporarily suspended regolith dust as a result of electrostatic charge [micrometeorite impacts], there are indications that differential charging of the lunar surface at the terminator can result in strong local electric fields that can eject charged dust up to 100 km above the surface.[4, 5] Such floating particles would be attracted to artificially induced magnetic fields (as generated by any electric motor) and could eventually pass through seals typically used to protect rotating parts. In short, unless countered, lunar regolith will likely significantly damage moving parts and sensitive scientific instruments in addition to diminishing the effectiveness of solar panels and thermal radiators.

A possible way to counter this is to use a five-layered approach: Repel, remove, block, harden and replace.

1. Repelling the dust can potentially be done with a variable electrostatic field. Its polarization and frequency will need to be experimentally confirmed, but the premise is to 'shovel' the dust away

from critical parts. An example of this approach is NASA's electrostatic dust shield, which consists of an array of parallel electrodes powered by an alternating current. The onset of the current is slightly delayed at each electrode, effectively creating an electromagnetic wave that travels along the surface and pushes the dust away.[6] Alternatively, repellent materials may provide an equivalent alternative.

2. Dust removal can be accomplished though the use of an electromagnet to lift agglutinates from contaminated surfaces in order to avoid the deleterious effects associated with brushing. If installed at the end of a robotic manipulator, the electromagnet can be brought to the desired location to remove dust then moved to a safe location and de-energized, allowing the dust to fall to the ground as a mass rather than a mist. Alternatively, designs could be constructed such that an electrostatic curtain as described above 'pushes' the dust and an electromagnet 'pulls' it, or a magnetic field could guard sensitive equipment by pulling the dust towards the magnet and thus minimizing accumulation.

3. Physically blocking the dust is intuitively obvious but more difficult than commonly thought. The Apollo static indium-edge failures and the partial effectiveness of the internal filters used to minimize dust within the LM are indications of the challenge. Solutions can take the form of seals or filters, such as NASA's research into the use of spring-loaded Teflon seals[7] or CSA sponsored research into a dust filtration system, a magneto-electrostatic dust nanofilter, that apparently incorporates many of the above techniques [8,16]. A primary concern is ensuring that the blocking mechanism allows for rotating parts and is optically and thermally transparent when used on solar panels and thermal radiators. Added considerations are the extreme thermal cycling of the moon (ranging from 40-400°K), and the issue of outgassing.

4. If previous approaches cannot fully prevent regolith from penetrating mechanisms and parts cannot be otherwise protected, harder materials can be used. There are qualitative indicators of the abrasiveness of lunar dust, but quantifying this effect is more challenging. CSA has demonstrated that composite materials can be from 50 to 120 times more susceptible than aluminium when subjected to propelled lunar simulant.[9] While more research is required, it appears that the composites' microstructure renders them more susceptible to erosion, suggesting that hardness, resilience, and surface finish should be considered in material selection. When using composite parts exposed to a stream of lunar dust, the simple addition of a thin metal shell could significantly extend a component's life.

5. The final layer assumes some minimal infrastructure on the moon such that if the first four layers eventually fail the part can be replaced on site. This is perhaps the most challenging layer given that the prospect of a manned base has been placed on hold. Naturally, this implies that equipment can be designed to be modular and preferably maintainable robotically. While there is ongoing research to develop modular robots, actually performing the tasks of changing modules is not trivial under the best conditions. The International Space Station was designed to allow space robotics (Dextre[10]) to be used to replace failed Orbital Replaceable Units (ORU), but this requires dedicated grapple fixtures on the ORUs and availability of the specialized

component being replaced. While several projects, such as the Next Generation Canadarm[11] and the Planetary Medium Manipulator[12], are exploring these concepts further for equipment not specifically designed for robotic maintenance[11], it must be stated that incorporating modularity, accessibility and commonality of parts early in the design of future projects can substantially improve the process and odds of success.

Whether all five layers are needed will depend on the mission duration and critical nature of the machines being protected. For a short mission, only a few layers, such as materials selection, seals and part hardening, are likely to be needed. Longer-duration stand-alone missions might consider implementing the first four layers, while sustained missions would probably benefit from implementing all five. Irrespective of the mix of layers used, it is clear that ignoring the properties and effects of lunar dust has the potential to significantly impair mission outcomes, putting at risk our research, our equipment and our astronauts' lives.

References:

[0] " A common sense, layered, engineering design defense can solve any apparent problem with dust during ling term human activity and habitation in the lunar environment" Harrison H. Schmitt at the NASA Lunar dust Symposium at Ames Research Center, February 2, 2004

[1] AIAA 2005-2510 – The Lunar Dust Problem: From Liability to Asset; Lawrence A. Taylor, Harrison H. Schmitt, W. David Carrier III and Masami Nakagawa, 1st Space Exploration Conference: Continuing the Voyage of Discovery 30Jan – 1 Feb 2005, Orlando, Florida

[2] Lunar Sourcebook, a user's guide to the moon; Grant H. Heiken, David T. Vaniman and Bevan M. French, 1991; ISBN: 0-521-33444-6

[3] Long-term degradation of optical devices on the moon; T.W. Murphy et al, Icarus.208:31-35,2010 (http://arxiv.org/abs/1003.0713)

[4] Neutral Solar Wind Generated by Lunar Exospheric Dust at the Terminator, Michael R. Colloer and Timothy J. Stubbs; Aug 2008 (http://arxiv.org/PS_cache/arxiv/pdf/0809/0809.2952v1.pdf)

[5] http://science.nasa.gov/science-news/science-at-nasa/2005/07dec_moonstorms/

[6] http://science.nasa.gov/science-news/science-at-nasa/2006/19apr_dustbuster/

[7] http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20100021943_2010023804.pdf

[8] http://www.asc-csa.gc.ca/eng/media/backgrounders/2009/1112.asp

[9] Evaluation of the resistance of composite materials to lunar dust abrasion; Matheiu Lalumiere Boucher, Marie-Josee Potvin, IAC-10.C2.6.7, 2010

[10] http://www.asc-csa.gc.ca/eng/iss/dextre/

[11] http://www.asc-csa.gc.ca/eng/canadarm/ngc.asp

[12] ESM Planetary Medium Manipulator

[13] The Apollo Experience Lessons Learned for Constellation Lunar Dust Management, Sandra A. Wagner, Johnson Space Center, NASA/TP-2006-213726

[14] The Effects of Lunar Dust on EVA Systems During the Apollo Missions, James R. Gaier, Glenn Research Center, NASA/TM-2005-213610

[15]: Bean, A.L. et al (1970). Apollo 12 Preliminary Science Report, NASA SP-235

[16] MoonDust Lunar Dust Simulation and Mitigation, Roman V. Kruzelecky et al, AIAA 2010-6023

[17] Clark, Curtis, Marshall, Nuth, Minetto, Calle, “SPARCLED: Lunar Dust Capture, Containment, and Extraction Tool.” 3rd Annual NASA Lunar Science Forum, Ames Research Center, Moffet Field, CA , July 2010.