FINDING A DUST MITIGATION STRATEGY FOR LUNAR SURFACE OPERATIONS. P.E. Clark[1], S.A. Curtis[2], F.A. Minetto[2], J. Keller[3], [1]Catholic University of America (Physics Department) at NASA/GSFC, Code 695, Greenbelt, MD 20771 (email: pamela.clark@gsfc.nasa.gov), [2]Code 695, NASA/GSFC, Greenbelt, MD 20771, [3]Code 691, NASA/GSFC, Greenbelt, MD 20771.

Introduction: Design of an effective dust mitigation system to support NASA's new initiative to return to the surface of the Moon must be a high priority [1,2]. A number of strategies have been proposed based on brushing, magnetic susceptibility or magnetic attraction, variable EMF or other surfaces, and particle guns for charging or repelling dust [2].

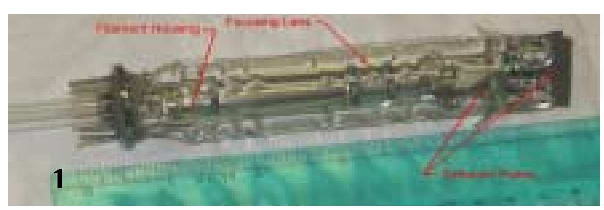
Brushing was demonstrated to be effective only on a short term basis during the Apollo missions [1]. Abrasivity of particles damaged surfaces, sometimes compromised seals. High surface area/volume of the particles meant sticking (electrostatic and mechanical) and little removal of finer particles leading ultimately to mechanical joint failure.

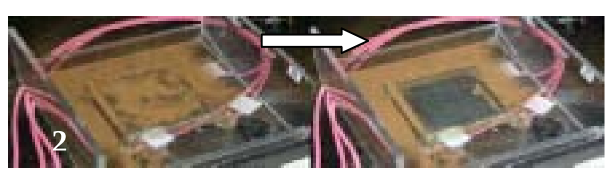
Magnetic Susceptibility/Magnetic Attraction strategies have been proposed to remove lunar fines based on the observations that metallic iron abundance and magnetic susceptibility increase with decreasing grain size in mare soils [3,4]. Tests of magnetic separation mechanisms have shown clumping and lower separation efficiency for the problematic finer grain sizes [5]. High gradient magnetic separation technique proposed for filtering fine dust from shelters [5] are not necessarily suitable for cleaning mechanical surfaces in the field. A question remains as to how much variation in magnetic susceptibility is present among all lunar fines, particularly those in uncontaminated highland soils.

Electrostatic Approach to Dust Control: Fields, charged particles, and dust particle interactions on the Moon are complex, their interactions dependent on environmental conditions and highly variable particle properties including size, shape, composition, magnetic and electrical properties. Lunar fines shows low electrical conductivity and dielectric loss [5], and thus tend to remain electrostatically charged [6]. Greater illumination and temperature increase surface potential. Less mafic particles tend to have lower loss tangents and greater conductivity and are thus more apt to become electrostatically charged more quickly [6]. Electrostatic charging of the Moon occurs via interaction of solar UV light with the surface causing photoemission of electrons and interaction of the local plasma environment [7]. Charged dust grains are repelled from like-charged surface or attracted to oppositely charged surface. Surface charging on the dayside is driven by photoelectron currents, resulting in electron depletion and positive charging of the surface; on the nightside, plasma electron currents result in electron accumulation and negative charging of the surface [8].

The properties and behaviors of individual particles in the presence of plasmas or photoemissive surfaces have been studied in the laboratory [e.g., 6,9-13] and theoretically modeled (e.g., 7,14,15]. Although foundational work on dust behavior in fields has been done, empirical analysis of collective dust behavior on surfaces within the context of surrounding non-conducting, dusty plasma/regolith environment is just beginning. Starting with theoretical models as well as dust behavior already observed on the lunar surface [16-19] as input for an empirical simulation, Calle and coworkers [20] recently demonstrated that dust particles can be transported by electrostatic fields whether charged or not by applying alternative waveforms of voltage to a surface with patterned grids of electrodes. Goddard investigators have proposed an instrument to monitor the dust and plasma environment on the Moon (LEED-Lunar Emissions and Electron Detector) to support longer-term efforts like the development of SPARCLE, Space Plasma Alleviation of Regolith Concentrations in the Lunar Environment [2,15,21].

Our original concept (SPARCLE) [3] involved using electron or ion guns (Figure 1 electron gun), acting as a plasma dust sweepers, an approach similar to one used to control spacecraft potential in a highly charged environment [22]. Because Calle and coworkers [20] have already achieved success in moving dust by systematic scanning of an electrostatic mesh surface with variable EMF (Figure 2), we now propose using particle beams to control the flow and remove/collect dust across such surfaces (Figure 3). How will the nature of the spacecraft surface covered with insulating dust affect electrostatic discharge? If the spacecraft surface is conducting the discharge would be relatively rapid. As long as the discharge rate occurs as the RC time

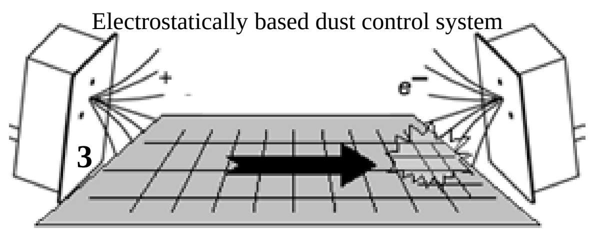




constant, as anticipated, an electron gun should be able to charge the surface up fast enough to overcome bleeding of charge. If the spacecraft surface is non-conducting, will the electron gun be able to provide sufficient potential to be attracted to oppositely charged plate? We anticipate that the gun will have a high enough current to offset charging due to the solar wind and the photoemissive effect which is 10-100 times higher than solar wind. What happens when the conductivity of the surface or the average particle size varies? Will variation in light and shadow generate a dual polarity surface which will cause dust movement [16] and differential charging? We are setting up experiments designed to answer these questions will lead to the conceptualization of such a device. **Building a Dust Device:** Immer and coworkers [23] performed a series of experiments which demonstrated that dust can be transported by electrostatic fields. Alternating waveforms of voltage were applied to patterned grids of electrodes on three-phase, copper-conductor screens fabricated using normal circuit board manufacturing techniques. Each phase was routed to a high voltage amplifier, allowing independent generation of phases. The set up wais designed to allow rapid removal of screen to measure the effectiveness of dust removal. Optically transparent materials such as Indium Tin Oxide coated polyester screens, which can be applied over solar panels, viewports, or visors, have also demonstrated minimal degradation in performance. Dust clearing increased with increasing voltage [23]. The dip in clearing effectiveness observed at 300 volts was thought to be caused by a resonance between switching phases causing dust to oscillate between mesh elements without being clear.

We are readying an environmental chamber designed to simulate the charging induced by solar illumination and solar wind domination during the lunar day (resulting in net positive charging of dust) and plasma interaction domination during lunar night (resulting in net negative charging of dust). We will be able to operate cryogenically, over a range of temperatures, observing the resulting electrostatic interactions, as important inputs for how to control the flow of dust through controlling the potentials of dust and contact surfaces via our recently constructed electron gun and an ion gun we will build as part of this effort. Potential of 'spacecraft' surface will be measured with an ion spectrometer, and, if available, roughened surfaces with dust-like properties will be tested as well.

Application to the Lunar Surface: Based on the minimal degradation in performance of laser ranging retro-reflectors on the lunar surface decades after Apollo [24], as well as on results from orbital geochemistry experiments which showed clearly definable terrane boundaries, environmentally-induced movement of dust should occur predictably and on a relatively modest scale [25]. Dust will be stirred up on the Moon primarily through mechanical contact at landing sites. Thus, structures which are mobile or stationary with moving parts would need dust control systems (Figure 3). Such structures could have outer skins which could act as electrostatic screens with varying phase EMF, plus ion or electron guns deployable using addressable, reconfigurable component manipulators [3]. Particle guns would be used to control the flow as illumination and temperature conditions changed. The goal is to provide a compact, low power device to be operational in <5 years with heritage from ionic sweepers for active spacecraft potential control.



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