DUST ANALYSIS AT THE MOON. Y.J. Pendleton[1], S.P. Worden[1], M. Bicay[1], and J.L. Heldmann[1], [1]NASA Ames Research Center, Moffett Field, CA 94035

Introduction: Early measurements from the Surveyor, Lunokhod, Clementine, and Apollo missions to the Moon each returned evidence suggestive of the levitation of dust particles above the lunar surface. Subsequent theoretical modeling suggests that such levitation is possible due to the differential charging of the lunar surface. Theory predicts that dust levitation events should be correlated with the day-night transition on the Moon and indeed most data indicates that dust activity increases near the terminator. The phenomenon of dust levitation is therefore of high scientific interest and additional data is required to more fully understand the cause and effect of this dust transport mechanism.

In addition to the scientific interest in studying lunar dust transportation processes, dust is an insidious problem for human exploration. Therefore, information gleaned from these studies will also be useful for mitigating adverse dust effects in relation to human exploration. The lunar dust is potentially detrimental for several reasons including: 1) the small, angular particulates are especially harmful to humans, 2) fine particles are harmful to hardware components, joints, etc. (even on the relatively short stay Apollo missions hardware components were severely compromised by lunar dust contamination), and 3) incoming high velocity particles (e.g. 30 km/s), though thought to be infrequent, could prove fatal if impacting a critical component (such as an astronaut face shield).

This paper therefore discusses several mission scenarios (including robotic orbiter, robotic lander, and astronaut deployed concepts) to measure: 1) the dust transport due to human activities on the lunar surface, 2) the time dependence of dust lofting rates and the impact direction correlated with the lunar day / night cycles, 3) the vertical distribution of lofted dust properties, 4) the infall rates of cometary and asteroidal interplanetary dust particles, and 5) in situ dust properties.

Many small airless bodies in the Solar System are covered with a dusty regolith and therefore the processes causing lunar dust transport (electrostatic charging) may also operate on bodies such as asteroids, other planetary satellites, Mars, etc. Thus the information acquired through these lunar studies could also be applied elsewhere in the Solar System.

Dust Levitation Mechanism: It is believed that the levitated dust on the Moon observed by Surveyor, Clementine, Lunokhod, and Apollo is mainly caused by differential charging of the lunar surface near the terminator. The dust particles become electrostatically charged due to the Moon's interaction with the surrounding plasma environment as solar ultraviolet and x-ray radiation cause the photoemission of electrons from lunar surface materials [1]. Most of these emitted electrons escape from the lunar surface and thus the surface becomes positively charged [2]. A layer of positively charged dust can then form in the lunar vacuum above the negative space field charge of the electron cloud [2]. On the lunar night side the plasma electron currents dominate (electron driven) and so the surface charges negative [1, 3]. Such a model can account for dust levitated on the order of decimeters to meters above the lunar surface [2].

To account for the observations of grains at ~100 km altitude, Stubbs et al. [3] present a dynamic "fountain" model that explains how sub-micron dust is lofted up to 100 km above the lunar surface. In this model the charged dust grains follow ballistic trajectories, subsequent to being accelerated upward through a narrow sheath region by the surface electric field [3]. This dynamic dust grain fountain model predicts that sub-micron sized dust grains would be lofted to altitudes of 0.1-100 km at the terminator.

Laboratory studies also support the notion of dust levitation on the Moon. Sickafoose et al. [4] performed levitation experiments on dust grains in a low density plasma. Their results show that: 1) grains can levitate in a plasma sheath above a conducting surface, 2) levitating grains can reach a height corresponding to that predicted by theory, and 3) a mechanism to inject grains into a sheath is not required if the electric field is sufficiently strong [4].

Science Measurements: For the proposed mission concepts we intend to measure: 1) the dust transport due to human activities on the lunar surface, 2) the time dependence of dust lofting rates and the impact direction correlated with the lunar day / night cycles, 3) the vertical distribution of lofted dust properties, 4) the infall rates of cometary and asteroidal interplanetary dust particles, and 5) in situ dust properties.

We also intend to define measurements to quantify the differences between dust lofted through natural electrostatic effects and dust lofted due to astronaut activity on the lunar surface. Understanding the different effects of both of these dust transport mechanisms is of high scientific importance and is also critical to enable human exploration on airless, dusty planetary bodies.

Robotic Orbiter: One mature concept for a low-cost orbiter under study is being adapted from a mission that was a semi-finalist in the NASA competition for the LRO secondary payload (won by LCROSS). The Lunar Explorer for Elements and Hazards (LEEAH) mission is designed to systematically explore the lunar surface composition using a unique ion mass spectrometer technique capable of detecting the presence of water in all areas, including permanently shadowed regions. It will characterize dynamic processes that cause lifting and transport of lunar dust, and the dependence of this activity on solar illumination and the local space environment. LEEAH will characterize radiation through total integrated dose and solar energetic particle measurements. It will also carry a novel biology experiment that will examine the impact of both radiation and microgravity on living systems.

LEEAH is based on high heritage subsystems and sensors, including an existing, qualified spacecraft bus based on NASA's *The History of Events and Macroscale Interactions During Substorms* (THEMIS) program. The science sensors are contributed from existing flight spares and the remaining ones are built out of high Technology Readiness Level (TRL) components. Rigorous reviews of the proposal concluded that the rapid development schedule (24 months) and modest cost ($53 million) were credible.

Robotic Lander: There are multiple instruments that could be utilized on the lunar surface to characterize the lunar dust. A static lander could provide measurements at one location whereas a lander platform with mobility capability can characterize the lunar dust at multiple locations. In situ measurements of dust composition, particle size distribution, surface reactivity, adhesion properties, thermal properties, magnetic properties, and conductivity could be obtained by a robotic lander.

Astronaut Deployable Experiments:

"*No pest strip*". The "no pest strip" concept is to deploy vertical strips of various materials to which lunar dust might adhere in order to obtain vertical profiles of dust lofting (similar to "no pest strips" that cause insects to stick to the hanging strip). The no pest strip will also assess the relative "stickiness" of the lunar dust. Due in part to the changing mass to surface area ratios of different sized particles, we anticipate that a size dependence may exist regarding the adhesion efficiency of lunar particles. We also anticipate that different components of lunar fines may preferentially adhere to different types of materials (for example, one of the best dust collectors during Apollo was the spacesuit material).

Aerogel Canister. Aerogel canisters will be used to record high velocity particles (e.g. 30 km/s) that impact the lunar surface. These measurements will record the infrequent but potentially deadly high velocity particles and, at least for the lower velocity particles, provide material for compositional analysis [5]. One container will be placed on the lunar surface near the human base and the second container will be placed at a site further away from the base which is not affected by human surface operations. Ideally at least one of the aerogel canisters (namely the canister closest to the human base) would be returned to Earth for detailed study in the laboratory and the second canister (located away from the human base) could remain on the lunar surface to continue gathering data and be returned to Earth on a subsequent mission. In a manner similar to the return of the "no pest strip", care must be taken to ensure the aerogel collectors are not expose to contamination.

Rollout carpet. The rollout carpet concept consists of a material (similar to solar panel material used on rooftops, although the precise nature of this material will be assessed during this proposed study) that will be rolled out across the lunar surface to cover a large surface area and return to Earth a record of the particles striking the lunar surface. The carpet will record two types of dust arrival: 1) incoming hypervelocity cometary and asteroidal particles and 2) local lofted dust. The hypervelocity particles will likely vaporize upon impact and so will be evidenced by small craters on the detector. The lofted dust will be evidenced by grains collected on the carpet. Through this study we will assess the most beneficial collection materials to use with regards to ease of deployment, efficiency of dust capture, and mass considerations.

Dust sensors (impact rate and direction). These dust sensors would be similar to the LEAM experiment in that impact rates and directionality will be measured. A timing device will be included to measure impacts as a function of time and several sensors can be mounted in different orientations to measure the azimuth of incoming dust particles. We will evaluate the LEAM mechanism and evaluate the engineering design, making note of LEAM components that failed (e.g. thermal control malfunctioned, dust cover deployment occurred late, etc). These sensors are also the only proposed instruments with power, thermal, and communications requirements (the remaining instruments are passive sensors) and we will evaluate each of these requirements.

References: [1] Manka, R.H. (1973) *Photon and Particle Interactions with Surfaces in Space*. 347-361. [2] Foldi, T., Berczi, S. *Acta Mineral. Petro.* 43. [3] Stubbs, T.J., et al. (2005) *Adv. Space Res*. 37, p. 59-66. [4] Sickafoose, A.A. et al. (2001) *JGR*, 107. [5] Tsou, P. et al (2003) *JGR*. **108**, #E10, 8113.