# SPARCLE: CREATING AN ELECTROSTATICALLY BASED TOOL FOR LUNAR DUST CONTROL

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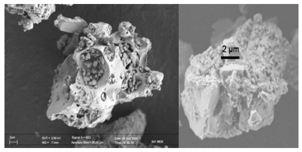


Figure 1: SEM photo of grains comparing surface morphology of Lunar Dust (left) and simulant (right) illustrating size distribution, clumping, and complexity of smaller particles

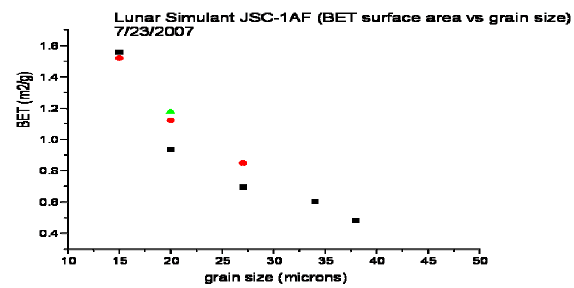
**The Dust Problem**: The characteristic persistent adhesion and abrasion of lunar soil particles when interacting with surfaces introduced into the lunar environment [1,2,3] results from the combined electrical and physical properties of the grains. Particles reentrant surface structure causes them to physically 'hook on' like velcro and, apparently, to be easily electrostatically attracted. Here we present the results of our ongoing efforts to design and develop tools to remove dust based on our characterization of the nature of dust particles and forces affecting them. These behaviors result from their combined electrical and physical properties, which cause the particles to be easily charged, electrostatically attracted, and then almost impossible to dislodge by physical means alone. To insure the success of the longer duration missions planned for the return to the Moon, these issues with dust must be resolved. Understanding and being able to control changes in potentials of surfaces and charged particles on planetary regoliths is now an issue of considerable interest. Our study of soil surface properties will provide the basis for design of tools to remove or capture lunar dust [4].

**Surface, Shape, and Size Frequency Distribution:** The relationship between specific surface area and volume in lunar dust grains as a function of grain size (**Figures 1 and 2**) is recognized as a characteristic that controls the interaction between lunar dust and its environment. Carrier and coworkers [1] established the high Surface to Volume Ratio (SVR) of lunar grains relative to smooth spheres of equivalent size. The exact nature of this relationship is poorly known, particularly for lunar fines (<20 microns) which are thought to pose the greatest hazard for machinery and human health. If a sizable portion of dust grains have diameters in the range of 3 microns or below, they pause the serious risk of silicosis. The lunar regolith is an impact-generated soil-like layer above bedrock dominated by particles ranging in size from centimeter to submicron scales [1,2,5]. Lunar dust has high specific surface area (8 times as much surface area as a population of spheres with equivalent particle size distribution). Particles have reentrant hook-like projections,

| Sample | Surface area ($m^2$/g) | $I_s$/FeO* <250 μm | Mean particle* size μm (<1 mm fraction) |
|---|---|---|---|
| 10084 | 0.59 | 78 | 52 |
| 12033 | ~0.02 | 4.6 | 97† |
| 12070 | 0.57 | 47 | |
| 14003 | 0.51 | 66 | 99 |
| 14163 | 0.21 | 57 | 56 |
| 14259 | 0.61 | 81–89 | 63 |
| 15301 | 0.68 | 48 | |
| 15401 | 0.48 | 5.6 | 61 |
| 15401 | 0.40 | 5.6 | 61 |
| 61221 | 0.78 | 9.2 | 68 |
| 61241 | 0.72 | 47 | 72 |
| 63321 | 0.43 | 47 | 87 |
| 63341 | 0.42 | 54 | 80 |
| 74220 | 0.42 | 1.0 | 41 |
| 74220 | 0.46 | 1.0 | 41 |
| 75081 | 0.50 | 40 | 67 |

*From Morris (1976).
†Quaide *et al.* (1971).

Figure 2 Cadenhead et al [12] shows range of specific surface area measurements and associated 'typical' particle size. Typically, these soils have Specific Surface Areas which are equal to or greater than those of our simulant.




| | | |
|---|---|---|
| For Close Packed Spheres | | Simulant SSA 0.5 $m^2$/g |
| Diameter(u) | SSA ($m^2$/g) | for Diameter >35μ |
| 1000 | 0.0019 | Simulant Equiv Diameter 4μ |
| 100 | 0.019 | Soil Average SSA 0.57 $m^2$/g |
| 10 | 0.19 | for Median Diameter 75μ |
| 1 | 1.9 | Soil Equivalent Diameter 3μ |

Figure 3 Simulant BET SSA measured as a function of size fraction. Icons represent three sets of measurements to generate errorbars. For comparison, see close packed sphere and bulk lunar soil data [1] indicating that simulant like lunar soil is rougher than spheres of the same size and specific gravity, and has an SSA smaller or equivalent to lunar soil even when compared to a lunar larger particle size fraction.

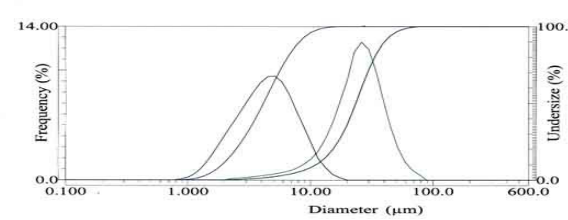



Figure 4 Normalized frequency and cumulative frequency distributions for lunar simulant at t=0 (right) and at t=60 seconds (left) when only the finest fraction remains in solution. Note the presence of an ultra fine component at or below 3 microns.

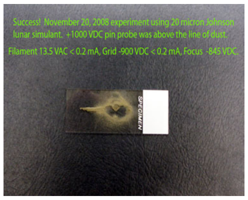


Figure 5. Successful induced dust migration with a focused electron beam in the presence of an electric field.

are highly anisotropic, porous, and compressible, aligning along long axes. 10-20% of collected soil particles, the lunar fines, or dust, are below 10 microns in size.

We systematically measured surface to volume ratio (SVR) throughout the grain size distribution but particularly for the smaller fractions (<50μ) of both lunar soil and simulant to establish a basis for understanding the behavior and potential health risk associated with lunar dust (**Figure 3, 4**) [4]. Our Gemini surface area analyzer operates using the BET method, an extension of Langmuir Theory dealing with the adsorption of gases on solid surfaces. A sample is kept at constant temperature under nitrogen. Pressure is increased. A nitrogen monolayer forms and the extent to which it remains adsorbed when the pressure is decreased (in hysteresis) depends on the effective volume and size of surface irregularities, via capillary action. The lag, or hysteresis, in nitrogen adsorption, relative to smooth spheres yields estimates of the surface area, pore volume and pore size distribution. Prevalence of micron-scale grains is indicated by our most recent results.

**Electrostatics**: Fields, charged particles, and dust particle interactions on the Moon are complex, dependent on highly variable environmental conditions and particle properties including size, shape, and composition, magnetic and electrical parameters. Lunar fines exhibit low electrical conductivity and dielectric loss [1], thus tend to remain electrostatically charged; less mafic particles tend to have lower loss tangents and greater conductivity and are thus more apt to become electrostatically charged more quickly [6]. Charged dust grains are repelled from like-charged surface or attracted to oppositely charged surface.

Starting with theoretical models as well as dust behavior already observed on the lunar surface [7,8] as input for an empirical simulation, Calle and coworkers [11] 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.

**SPARCLE**: The SPARCLE (Space Plasma Alleviation of Regolith Concentrations in the Lunar Environment) [10] concept is a NASA patent protected electrostatically-based tool for dust mitigation. SPARCLE leverages decades of spacecraft operations which successfully controlled spacecraft potential with charged particle beam technology [11]. The concept involves using a charged particle gun combined with an oppositely charged plate electron, to control the electrostatic potential of the surface and the flow of dust using simulated lunar environment facilities at KSC.

Considerable efforts went into designing a functional experimental configuration and identifying an electron gun with optimal functional range, robust filament, and proper shape of the focused beam as a probe or point source as well as controllable an electron production rate acceptable in that setting. We ran the successful experiment that successfully focused the electron beam to control the electrostatic potential of the surface, so that, in the presence of an electric field, a plate of the opposite potential induced dust migration away from the probe (**Figure 5**). The next step will involved pulsed rather than continuous burst of electrons and experimenting with multiple-point probes. A sample collection device will also be included the measure the effectiveness with which particles are removed as a function of size.

**Ongoing Developments**: The SPARCLE development team is already partnered with the lunar habitat airlock design team at JSC who see tremendous potential for SPARCLE to provide lunar dust removal from any object in the airlock with minimal expenditure of resources. We can test its ability to attract dust with from a variety of introduced surfaces with a range of positive and negative potentials in a simulated airlock environment under a variety of temperatures and pressures, thereby establishing a proof of concept. The final design for SPARCLE will be based on the results of the airlock simulation tests. Our present concept involves using a cleaning wand with internal electron or ion guns to control its surface potential and generate a setting that will predictably attract dust under the ambient conditions. We are experimenting with special coatings to determine which ones facilitate removal from soft (e.g., spacesuit) and hard (e.g., walls) surfaces. The dusty wand will be cleaned by being thrust into a receptacle with an opposite charge to electrostatically remove dust from the wand.

**References:** [1] Carrier et al (1991) Lunar Sourcebook, 475-568; [2] McKay et al (1991) Lunar Sourcebook, 285-356;; [3] Gaier and Creel (2005) NASA TM-2005-213610; [4] Clark et al (2009) Proc. SPESIF-09; [5] Carrier (2003) JGG Engineering, 129, 10, 956-959; [6] Sickafoose et al (2001) JGR Space Physics, 105, 85, 8343-8356; [7] Criswell (1973) Photon and Particle Interactions with Particles in Space, 545-556; [8] Berg et al (1976) Dust and Zodiacal Light, 233-237; [9] Calle et al (2004) Space Congress, 2acalle.pdf; [10] Curtis et al (2006) EOS Trans AGU 87, 36, P41A-01; [11] Comfort et al (1998) J. Spacecraft Rockets, 35, 6; 845-859; [12] Cadenhead et al (1977) Proc LunSciCon 8th, 1291-1303.