CHARACTERIZING THE LUNAR PARTICULATE ATMOSPHERE WITH THE AUTONOMOUS LUNAR DUST OBSERVER (ALDO).

C. G. Grund[1] and J. A. Colwell[2], [1]Ball Aerospace & Technologies Corp. (BATC) 1600 Commerce St., Boulder, CO 80301,cgrund@ball.com. [2]University of Central Florida 4000 Central Florida Blvd,, Orlando, FL 32816, jcolwell@physics.ucf.edu.

Introduction: Billions of years of meteoroid bombardment have shaped the lunar surface, created and stirred the lunar regolith, and covered the moon with dust. Since the Apollo era, the particulate atmosphere and mobility of dust, have been recognized as both a hazard to human health and a challenge to equipment function and longevity. The NASA Constellation Program promises sustained human and robotic presence on the moon, affording a unique opportunity in the next decades for better study of the natural dust formation, lofting and redistribution processes on airless bodies such as the moon, as well as the development a working understanding of the effects of human activities on the lunar dust environment.

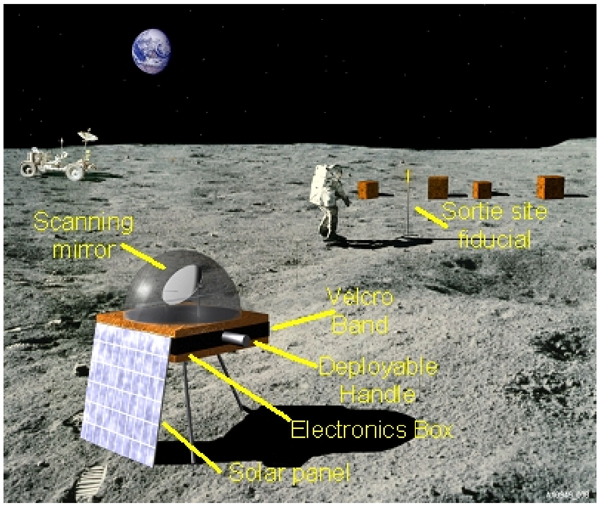

Figure 1 Concept for the Autonomous Lunar Dust Observer deployed at a Lunar Sortie site. Once deployed, the system self –calibrates scans to the local gravity vector and a site specific fiducial, and automatically begins acquiring data.

To provide a means for the systematic study of dust phenomena in and around landing and experiment sites, Ball Aerospace & Technologies Corp. (BATC) and the University of Central Florida (UCF) have undertaken an operational concept and design study for the Autonomous Lunar Dust Observer (ALDO). Shown in Fig. 1, ALDO is a low power, low mass, highly sensitive, scanning laser radar (lidar) system capable of characterizing the local 3D dust distribution at extended ranges.

Lunar Particulate Atmosphere and Formation Phenomenology: Unlike terrestrial dust that is oxidized, shaped, and chemically transformed by contact with water and atmospheric gases, lunar dust contains a large fraction of sub-micron size particles that levitate against lunar gravity in the airless environment.

On the dayside, photoemission of electrons from the lunar surface produces a photoelectron layer with a scale height of a few tens of cm. The positive surface potential of ~10V produces a vertical electric field that can cause dust particles in the regolith to lift off the surface, forming a particulate “atmosphere”. Observations by the Surveyor 5, 6, and 7 spacecraft showed a glow of forward-scattered light near the lunar surface[1] believed to be light scattered by dust particles launched off the lunar surface at low speeds (~1 m/s) by electrostatic forces. The Lunar Ejecta and Meteorites Experiment (LEAM) deployed on the surface of the Moon by the Apollo 17 astronauts also apparently detected relatively slow-moving dust particles moving under the influence of near-surface electric fields[2,3]. At terminator crossings large potential differences can exist over small spatial scales as some facets of the local topography are directly exposed to the solar UV flux while neighboring facets are in shadow, and large local electric fields may develop that can mobilize dust [4,5].

Because the charge to mass ratio on dust particles increases with decreasing particle size, at some size (~1 micron) the upward electric force can balance gravity leading to stable levitation. Smaller particles may be accelerated to large velocities and altitudes of many km or even to escape velocity[6]. Electrostatic transport of dust may also be responsible for redistribution of dust on the surface of other solar system objects, such as small moons and asteroids[7,8,9].

During sorties, ALDO can provide a measure of the influence of human activities on the dust environment. Once the astronauts depart, the systematic mapping of lofted dust from micrometeoroid impacts and charge effects will produce a wealth of data from which to develop a more complete understanding of natural dust levitation and redistribution.

Why lidar?: In order to understand the relationship between larger scale natural events and dust levitation and transport, or between astronaut activities and the evolved dust environment, it is necessary to observe the larger context. In order to understand the relationship between environmental factors, such as illumination and surface properties, and lofted dust it is necessary to be able to map the vertical and horizontal distribution of dust over large spatial scales. Lidar systems remotely collect time-resolved (range-resolved) backscattered light intensity from a short laser pulse. For similar particles, lidar backscatter is proportional to particle number density and cross section. Thus a single lidar, particularly when scanned, can remotely observe the dust distribution at many locations essentially simultaneously, to altitudes inaccessible to in situ sensors, and without the logistical issues of deploying multiple in situ sensors. Because optical wavelengths are of the order of the size of the particles of interest, lidar is also a sensitive detection tool. From a sampling standpoint, lidar is an ideal tool for observing the dust environment in and around sortie sites

Instrument Concepts and Architecture: The ALDO architecture under study is shown in Fig. 2.

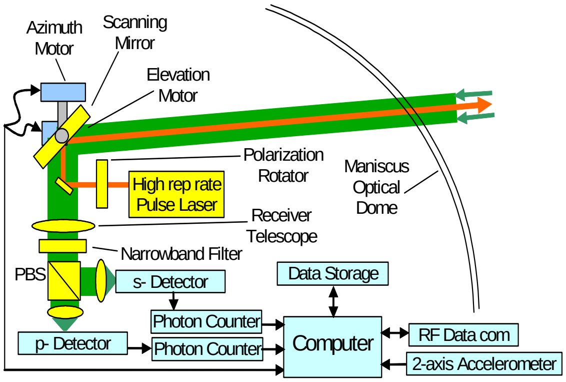

Figure 2 Top level ALDO Architecture.

Its design facilitates sortie operations because the system is self-contained, self-powered, autonomous, RF-linked, and can be deployed at a significant distance (typically 100's of m) from the sortie site. Current thinking suggests a pulse laser of relatively low peak power but high repetition rate coupled with photon counting detection will produce the most sensitive and practical system in a compact and robust package. Such lidars have served well in terrestrial applications[10,11]. The polarized laser beam is directed via the alt-azimuth scanning mirror to illuminate the environment around the sortie site. Laser light scattered from suspended dust (and the ground, the fiducial, and other sortie components) is directed by the scanning mirror to the receiver telescope. Orthogonal polarization components of the received power are split by a polarization beam splitter (PBS) into separate paths with independent photon counting detectors, and counts resolved as a function of time (range) are recorded for each laser pulse return. The returns from many laser pulses are averaged to form a backscatter profile. The ratio of the s- and p- polarization intensity profiles provides insight into the departure from sphericity of the particles, and enables the gravitational or charge-driven orientation of particles can be studied[12].

The elevation angle relative to local vertical is calibrated from the platform vertical attitude computed from the balance of the 2-axis accelerometer signals and mirror position encoders. The azimuth angle relative to the sortie site is calibrated as the lidar beam scans across the fiducial marker.

Preliminary radiometric modeling suggests particle volume backscatter cross sections of $1*10^{-12}\ m^{-1}sr^{-1}$ are measurable, equivalent to ~$5/m^3$ 1 µm diameter spherical silicate particles. With this low particle loading, it is expected that 2% backscatter intensity measurements can be made at 1 km range, and scan volumes of 30° elevation X 360° azimuth sector with 100 m volume element resolution at 1 km range could be completed every few minutes. Higher density dust phenomena can be studied with much higher resolution, if needed. For example for typical micrometeoroid ejecta where the mass yield may be 10^{-4}g – 10 g(3), $10^4 – 10^9$ average sized particles might be generated. The ensuing cloud might easily approach $10^3 – 10^8$ particles/m^3 in near-surface volume elements (at 1 km range) of 10 m^3 that could easily be resolved by ALDO with perhaps 0.01 s temporal resolution, enabling detailed process studies of such events.

References:

[1] Rennilson and Criswell, (1974), *The Moon, 10,* 121-142.

[2] Berg et al., (1976), *Interplanetary Dust and Zodiacal Light*, Springer-Verlag, Heidelberg, 233-237.

[3] Colwell et al., (2007), *Rev. Geophys.45,* RG2006, doi:10.1029/2005RG000184..

[4] De and Criswell, (1977), *J. Geophys. Res., 82(7)*, 999-1004.

[5] Criswell and De, (1977), *J. Geophys. Res., 82(7)*, 1005-1007.

[6] Stubbs et al., (2006), *Adv. Space Res.*, *37*, 59-66.

[7] Lee (1996), *Icarus* **124**, 181-194.

[8] Colwell et al. (2005), *Icarus* **175**, 159-169

[9] Hughes, et al (2008), accepted *Icarus*.

[10] Grund and Eloranta (1991), *Opical Eng., 30*, 6-12.

[11] Grund and Sandberg (1997), *Adv. in Atmospheric Remote Sensing with Lidar*, Springer-Verlag, 3-6.

[12] Richard and Davis (2008), accepted *Astron. and Astrophy*.

Acknowledgements: Support for this work is provided by NASA contract NNH08CC16C .