ASCENT MODULE LUNAR DUST IMPACTS AND GATEWAY EXTERNAL CONTAMINATION.

D. C. Barker[1] and J. W. Alred[2], [1]Oceaneering International, Inc. (NASA Johnson Space Center, Houston, Texas, 77058, USA) donald.c.barker@nasa.gov, [2]NASA Johnson Space Center, 2101 E NASA Pkwy, Houston, TX 77058. john.w.alred@nasa.gov.

Introduction: Six Apollo surface sortie architectures were carried out completely with single use systems (Fig. 1). Dust contamination assessment internal to the vehicle has been partially quantified, but external and plasma-dust exospheric contamination is largely unknown. Landing plume material redistribution, anthropogenic splattering, photoelectric levitation, lofting and meteoroid displacement and settling, and general electrostatic adhesion to outer surfaces remains unquantified [1].

The Gateway station is concerned with lunar dust transported on the exterior of the crewed ascent vehicle which docks with Gateway. Such dust could be removed by docking loads and travel to Gateway affecting optical devices and coatings, radiators, etc. and, hence, cause performance or lifespan degradation. Repeated transfer of dust, across all grain sizes, to lunar orbit and to orbiting assets, such as Gateway, remain unknown. Analysis and modeling efforts are currently in work.

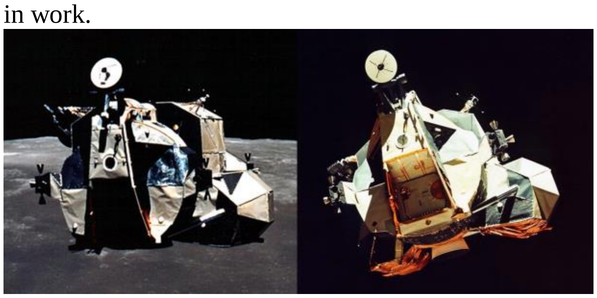

Fig. 1. Apollo 16 and 17 LM ascent vehicle prior to CM docking with unknown external dust loading.

Gateway Orbit: The Gateway station is expected to follow a highly eccentric, Near-Rectilinear Halo Orbit (NRHO), with an average perilune altitude above surface of roughly 1629 km (Fig. 2). Understanding the natural and induced environments is imperative to reduce risk, including dust characterization, transport and mitigation strategies for Gateway remain open work.

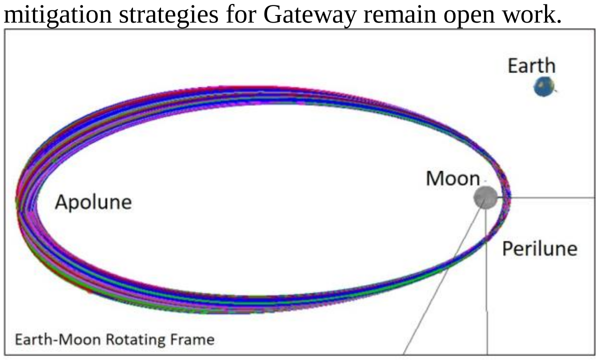

Fig. 2. Gateway NRHO orbit schematic.

Environments, Observations and Dust Loading: Natural and induced, surface and exospheric dust quantities and characteristics are expected to be compositionally and location dependent [2,3]. Near horizontal surfaces of landed spacecraft would be expected to attract and hold dust as length of surface stay increases assuming no disturbances. Adhesion of surface dust, especially glass spherules, onto painted and metallic surfaces was determined to be ~10^4 dynes/cm^2 and 2 to 3×10^3 dynes/cm^2 respectively, from Surveyor 3 [4,5].

Horizon-glow observations across programs, both by astronauts and instruments, attributed to an exosphere comprised of levitated material as observed by forward-scattering of sun light (~10 µm in size and ~50 grains/cm^2) [6]. Intense electrostatic fields (estimated at >500 V/cm) occur near the terminator boundaries, moving in a westward procession at ~15 km/hr, inducing dust levitation and lofting via photoelectric charge differentials. Levitated dust within the first few meters of the lunar surface, having insufficient velocity, ballistically returns to the surface over short distances. Lofted dust, <300 nm in size, attaining sufficient velocity to overcome lunar gravity (i.e. $qE > mg_l$) is observed in sunlight backscattering as a permanent yet variable exosphere, being either impact or dynamic fountain generated, and rising to over 100 km in altitude [7,8,9,10].

Natural dust deposition rates that contribute to hardware surface loading have been determined from meteoroid impacts assessments, Apollo surface detectors, and the Chang'E 3 mission with results ranging from 10 to 21.4 to 100 µg/cm^2/yr [11,12,13].

Contributions to the orbital dust environment include surface material ejected above lunar escape velocities during lunar lander thruster surface pluming [14]. This potentially induces an additional collision hazard (i.e. beyond micrometeoroids) in certain orbits and may potentially add material to the already transient lunar exosphere. Landing plume induced dust has also been shown to "sand-blast" nearby objects [15] through the landing process, and surface material may also settle back on vehicle surfaces once on the surface. Figure 3 provides an example of induced dust movement and settling on vehicle surfaces during the landing process with the Mars Science Laboratory (MSL) [16].

Fig. 3. Debris splattered MSL deck plate (MSL/JPL).

Hardware Hazards: Likely contamination affects in lunar orbit due to natural exospheric or transported dust include:

1) Ascent vehicle docking ring seals, surfaces and connectors. Experiments with JSC-1A simulant demonstrated seal leakage rates of 350 times experimental baseline in the presence of as little as $3.3x10^{-4}$ lb_m material, and baseline rates were not reacquired post cleaning [17,18]. Contributing factors include seal grease and materials properties.
2) Electrostatically sensitive/attractive surfaces of Gateway (e.g., solar panels, electrical wiring, surface structures).
3) Gateway EVA exposure to dust adhering to external surfaces.
4) Dust adhesion and/or effective micrometeoroid impingement from dust ejected from thruster landing plums.

Conclusions: Dust will only continue to be a growing issue for human activities to and from the Moon. The following list highlights ongoing and needed analysis addressing all the presumed risks discussed previously**:**

1) Ascent vehicle release of dust through the docking phase need to be modeled for worst case transport.
2) Quantify and understand all surface dust loading environments.
3) Quantify and understand induced orbital contributions due landing plume dust ejecta.
4) Implement operational countermeasures to monitor and protect seals (e.g. docking and hatch) and other components from dust impingement.
5) Assure Gateway surfaces are unaffected by potential dust impingement.
6) Operationally control risk to Gateway EVA entry and doffing operations to account for potentially very fine grained dust (<1 μm) accumulation on station exterior.
7) Will lengthy south pole surface operations near deeply contrasting light-shadow regions produce greater amounts of lofted/levitated dust?
8) Will South Pole highlands regolith have a higher incidence of induced dust excavation and loading?

References: [1] O'Brien B.J. (2011) *Planet. & Space Sci.*, 59, 1708-1726. [2] Colaprete, A. et al. (2016) *Science*, 351, 249-252. [3] Graf, J.C. (1993) NASA-RP-1265. [4] Carroll W.F. & Blair P.M. (1971) *Proc. 2nd Lunar Sci. Conf.* 3, 2735-2742. [5] Scott, R.F. & Zuckerman K.A. (1971) *Proc. 2nd Lunar Sci. Conf.* 3, 2743-2751. [6] Rennilson J.J. & Criswell D.R. (1974) *The Moon*, 121-142. [7] Stubbs T.J. et al. (2006) *Adv. Space Res.*, 37, 59-66. [8] Colwell et al (2009) J. Aero. Eng., 2, 1-7. [9] Wooden D. H. et al. (2016) *Nat. Geosci*., NGEO2779, 665-668. [10] Mishra, S.K. & Misra, S. (2019) *Phys. of Plasmas*, 26, 053703. [11] Katzan, C.M. & Edwards, J.L. (1991) NASA-CR-4404. [12] Li, D. et al. (2019) *J. Geo. Res. Planets*, 124, 1-10. [13] Hollick, M. & O'Brien, B.J. (2013) *Space Weather*, 11, 651-660. [14] Lane, J.E. & Metzger, P.T. (2015) *Acta Geophy*., 63, 568-599. [15] Carroll W.F. et al., ed. (1972) NASA-SP-284, 1-294. [16] Sengupta, A. et al (2009) *IEEE*, 2, 1-10. [17] Garafolo, J.G. & Daniels C.C. (2011) AIAA2011-3674. [18] Oravec, H.A. & Daniels, C.C. (2014) GRC-E-DAA-TN16579.