Regolith Simulant Preparation and Geotechnical Characterization for Plume Surface Interaction Testing

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Introduction: The landing videos obtained from Apollo lunar excursion modules demonstrate that descent engine plumes interact with regolith and accelerate it to significant velocities [1]. These plume surface interactions (PSI) therefore pose a risk to the sustained human exploration of the lunar surface. High velocity particles may damage landers and surrounding surface assets such as habitats, power systems, communication systems, and rovers. Radiator and solar panel efficiency could also be reduced. Furthermore, PSI ejecta could contaminate the Apollo landing sites and permanently shadowed areas.

Attempts to determine PSI ejecta velocities have included analyses of the Apollo landing videos [2], unified flow solvers [3], and lagrangian simulations [4,5], but these studies have produced a range velocities that include particles that can exceed 2 km/s. Consequently, further efforts are needed to establish narrower constraints on PSI ejecta velocities and risks.

Regolith simulants, simulated lunar lander engine plumes, and appropriate vacuum chamber testing can be used to generate lunar relevant PSI events. By measuring initial particle velocities at an impingement point during a ground-test, trajectory calculations can then be used to find when and where PSI ejecta would impact the lunar surface [6]. These tests can also study varying the height of the engine above the surface, the thrust of the engine, and the nozzle design. However, each test must begin with regolith simulants prepared to consistent geotechnical initial conditions. Therefore, ground tests require regolith tests bins and techniques that can consistently reproduce geotechnical charateristics. In addition, similar techniques will be needed for future large-scale tests using more powerful engines, and for applications such as excavation, drilling, and other lunar surface activities at larger scales.

Here we report on regolith simulant preparation and geotechnical characterization for PSI testing under vacuum conditions developed at NASA Kennedy Space Center. These procedures were designed to support the PSI physics focused ground-tests that took place at NASA Marshall Space Flight Center in 2021. The objectives of these first PSI ground-tests were to provide imaging data of crater and ejecta dynamics as a result of a Mach 5.3 500 K GN2 jet impinging into a bin of lunar regolith simulant, and for that data to provide comparisons to computational models [7].

Figure 1: Geotechnical properties can be testing location dependent.

The regolith test bin included a transparent side plate that split the jet in half. This enabled a view of the crater evolution in profile. Various mass flow rates, chamber pressures, nozzle heights and regolith simulants all influenced cratering behavior [8]. However, it was found that geotechnical properties can vary with testing locations (Figure 1), with the most consistent properties resulting from a ‘snowing’ test-bin loading technique (Figure 2). These preliminary findings highlight the importance of controlling, and accurately measuring, the geotechnical properties of regolith simulants, and emphasize the need for further large-scale ground testing. Without this understanding, and further testing, the importance of environmental and plume parameters to PSI risks will remain unknown.

Figure 2: The ‘snowing’ technique produces the most consistent geotechnical properties.

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