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Investigation of the flow characteristics of lunar regolith simulants under reduced gravity and vacuum on a partial-g parabolic flight

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In the field of planetary and asteroid exploration missions, one of the main interests is to gain knowledge about the components of the local Regolith to understand the properties and formation of these objects and to possibly use bound elements for in-situ resource utilization (ISRU). The handling and transport of Regolith, especially within smaller scientific sampling devices and analysis instruments, is a central issue that is often underestimated. Due to its physical properties, lunar Regolith for instance has an increased risk of clogging conveying and processing devices and hence complicates the design of such systems. In most current concepts for lunar and Martian exploration missions, the excavated Regolith is fed to a storage or analysis instrument through a series of hoppers, pipes, and similar devices. This transport process is mainly affected by the flow characteristics of the Regolith, and reduced flowability or clogging could impact the success of any mission trying to handle, sample or process Regolith.

As part of the Lunar In-situ Resource Experiment (LUISE), transport processes for lunar Regolith were examined. A series of experiments with representative funnel geometries were conducted on a partial-g parabolic flight under $0.38g$ Martian and $0.16g$ lunar gravity. The experiments aimed to examine key parameters for hopper designs used in sampling processes for science experiments or ISRU processes on Mars and Moon. Two different representative lunar Regolith simulants, JSC-1A and NU-LHT-2M, were used in the investigation (sample mass $< 50g$, grain size $< 2mm$). To avoid gas inclusions in the porous simulant material, the experiments were conducted under a low vacuum between 10^{-3} and $10^{0}kPa$. 21 different funnel geometries with variable inclination angle and opening width were tested. They were designed similar to an hourglass, with two different funnels on each side. The material flow was initiated by turning the assembly upside-down. The inclination angles of the funnels varied from $55deg$ to $75deg$ in $5deg$ steps, both in symmetrical and asymmetrical configuration. Three opening widths were investigated, namely $8mm$, $13mm$, and $18mm$.

Although both simulant materials showed highly variable flow characteristics, a clear direct proportional dependence between flow rate and g-level was observed. With the transition to lower g-levels, the consolidation of the simulant was significantly reduced, so that in some cases the filling level of the respective hoppers raised and prevented further material flow. The cohesive character of both simulants mainly appeared at lunar gravity. Here the material flow of NU-LHT-2M occasionally came to a sudden stop or did not start at all. Steeper and wider hoppers in most cases lead to increased flow rates, whereas geometries with wider openings tended to reduce the flow continuity. Based on these results, guidelines can be established for designing conveying devices to be used for instruments on Mars or Moon.