GENERATING SLOPE FAILURES IN REGOLITH SIMULANTS IN VARIABLE GRAVITY. A. Dove,[1] W. Chambers[1], C. Cox[1], A. Rothermich[1], A. Nicola[1], [1]Physics Department, University of Central Florida (adove@ucf.edu).

Introduction: Surfaces of airless solar system bodies consist primarily of layers of regolith, or dusty granular material, that is produced by a history of bombardment by everything on scales from cosmic rays to micrometeoroids and larger impactors. Recent flybys of asteroids have revealed the presence of a variety of regolith distributions and patterns on their surfaces [1, 2, 3]. Regolith spills along slopes seem to be the result of avalanches and landslides (as also observed on the Moon [4]) while eroded craters and so-called ponds (smooth level dusty deposits at the bottom of some craters) reveal the action of various regolith flow mechanisms [5]. Better understanding of the processes leading to these surface morphologies is essential to the future exploration of such regolith-covered Solar System bodies. Additionally, knowledge of material cohesion and flow behavior of regolith on various terrains would assist in the interpretation of the nature (shape and size) and depth of the surface regolith layer solely based on remote sensing observations. The proposed experiment addresses open questions on the statics and dynamics of granular matter on the surfaces of small Solar System bodies, including:

a) the flow behavior of granular material along slopes (landslides and avalanches) under reduced-gravity conditions;
b) the displacement of granular matter in response to impact-induced seismic vibrations; and
c) the responses of regolith to subsurface "jets" or gaseous outflow features, such as those seen on comets and due to rocket exhaust from rendezvous spacecraft.

Classical theory of granular matter avalanches predicts that the angle of repose is independent of the strength of gravity; however, the first experiments performed under reduced gravity conditions clearly demonstrated a dependency of the avalanche behavior and the flowability of glass beads on the *g*-level applied [7] (Figure 1). In addition, experiments performed by Brucks et al. [8] indicate that the flow behavior is strongly dependent on the properties of the granular material. The discrepancies between theory and experimental results and the dependence on material properties require further investigation, in particular the collection of additional data on the static and dynamic angle of repose and the material flowability under reduced gravity conditions.

Furthermore, observations of asteroid surface features suggest that seismic vibrations lead to regolith flow and redistribution. Based on observations of the asteroid Eros, Cheng et al. [5] suggest that seismic vibrations play an important role in the formation of ponds and the covering of surface craters with fine regolith powder. The observation of the surface of Itokawa also reveals features that could be attributed to regolith flow through seismic vibrations [9]. Experimental data of the effect of vibration on granular matter flows is limited and is necessary to assess the validity of such models and better characterize the flow properties induced by vibrations.

The SLOPEs experiment was designed by an interdisciplinary undergraduate student group to address these questions on the statics and dynamics of granular matter on the surfaces of small Solar System bodies. This has been accomplished by exploiting the variable gravity environment enabled by parabolic airplane flights. Here we describe the experiment flight campaigns, and we will present the results of analysis of the static angles of repose, their response to the dynamic g-level environment, as well as responses to vibrational and jetting perturbations.

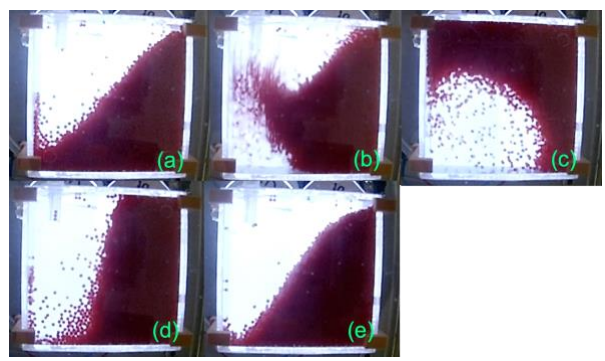

Figure 1. Example images from a jetting experiment during a low-g parabola. Particles are 2mm diameter red acrylic beads, and the jet is induced from a small outlet in the top left corner. In (a) the regolith is position to create a slope, and the jet is active only in (b). Figures (c) shows how the flow disperses the particles, and Figures (d) and (e) show the subsequent flow dispersion and settling.

Parabolic Flight Experiment: The experiment consists of multiple (10-12) experiment chambers that are housed in an experiment storage rack during the flight. Each chamber is evacuated and has an inner box (~4" square) that contains a regolith simulant including such materials as acrylic beads, sand, and a CI regolith simulant with different size distributions. The inner boxes rotate to create mass movement in the low-gravity portions of the flights. Some boxes have a vibration motor mounted on one face, and 2 boxes allow a short burst of air into the chamber to simulate jetting effects

(Figure 1). Two cameras are mounted on each side of the rack and can be adjusted to provide face-on and side-on view of the experiments.

These experiments were flown in different configurations on three different test flights, two in March, 2018 and one in November, 2019. Each flight had approximately two martian (1/3-*g*) and three lunar (1/6-*g*) parabolas, followed by about 20-25 "zero-*g*" parabolas (see examples in Figure 2). Ideally, one experiment was operated per parabola, repeating the same experiments across the martian, lunar, and zero-*g* parabolas for comparison. Martian and lunar parabolas typically provide slightly longer operational times for experiments, and zero-*g* parabolas have been shown to vary by up to ±0.01*g*, occasionally with a slight negative-*g* effect that usually arises due to turbulence.

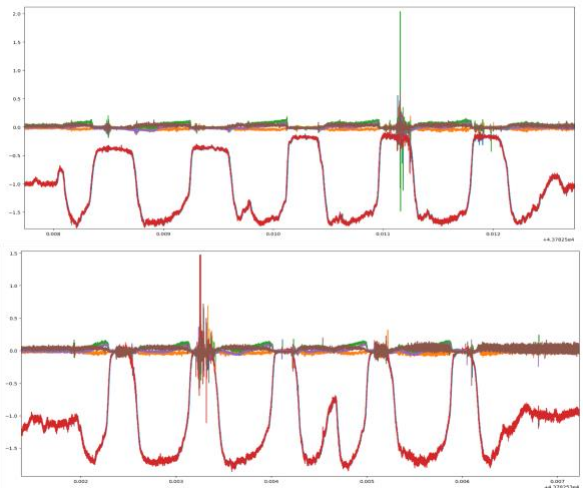

Figure 2. Acceleration profiles for different sets of parabolas, as recorded by accelerometers mounted on the SLOPE experiment during the Nov. 2019 flight. Red lines are the "z-component of the acceleration, where a value of -1 represents a typical 1-g acceleration. (Top) Martian (x2) and lunar (x3) parabolas. (Bottom) low-g parabolas.

Experiment sequences began with box rotation to a starting position during the high-*g* phase in between parabolas or during the previous parabola. During the low-*g* phase of the parabola, the experiment would be activated to rotate the box through a pre-determined angle. This angle varied between flights, as it was found after the first flight that greater rotation was needed to induce initial slope failure events. The inner box could then be additionally rotated by 5-10º at a time to create steeper slopes or induce additional failures in the materials. In the experiments with a vibration motor one face, it was operational as long as the experiment was powered, so during the setup phase and throughout the parabola. On the final flight, two of the boxes had an optional "jetting" mechanism that allowed the introduction of a short burst of air into the inner simulant chamber (Figure 1), and this was activated after the initial rotation phase, such that the particles could be observed to settle depending on the gravity level.

Figure 3. Examples of a fine material simulant experiencing a "negative-g" effect, causing the material to cohesively peel upwards (a-b); and the high angle of repose that could be achieved in the ~1mm particle regolith box during a zero-g parabola.

Expected Results: We will track angle of repose and bulk density as a function of factors such as material type, particle sizes, and gravity levels. In addition to this, we use data from the transition from coming out of the low-*g* portion and into the ~1.8-*g* portion of the parabola. This was particularly observed after the experiments experience a slight negative-g force that acts to fluff up the material (i.e. Figure 3), and thus we can observe effects due to gravitational settling and evaluate compaction of the various regolith materials. These results will be compared with granular dynamics models in order to inform behavior in larger granular systems, including those on the surfaces of planetary bodies.

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