PRELIMINARY VALIDATION AND SIMULATION OF THE STRATA-1 MICROGRAVITY GRANULAR SEGREGATION EXPERIMENT.

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Introduction: Observations have shown that small asteroids have unexpectedly coarse surfaces. It has been hypothesized that the Brazil Nut Effect (which causes large grains to rise to the surface of a vibrated granular sample) may be responsible for the relative dearth of small grains on asteroid surfaces [1]. NASA recently flew the STRATA-1 experiment aboard the International Space Station (ISS) to investigate granular segregation in micro-gravity [2]. The experiment consisted of four tubes of varying granular mixtures that were exposed to the micro-accelerations associated with orbit reboost and docking events on the ISS for one year. One of the STRATA-1 samples contained spherical glass beads. This sample can be modeled using existing Discrete Element Method (DEM) software. A second STRATA sample consists of angular glass shards. By analyzing the observed grain motion in the two tubes as well as using DEM to simulate the grain motion, it will be possible to determine the influence of grain shape on granular segregation in micro-gravitiy. Including aspherical grain shapes significantly increases the complexity of DEM methods. Thus, the STRATA-1 experiment will provide a key test to determine whether this additional complexity is required to accurately simulate granular segregation in microgravity.

As a first step in the analysis of the STRATA-1 experiment, we have modeled the tube of spherical grains using LIGGGHTS, an open-source DEM software [3]. To validate the LIGGGHTS simulation before applying it to the STRATA-1 experiment, we compare the LIGGGHTS simulation to a simple, terrestrial shaking tube experiment. This work presents the DEM code validation experiment and the preliminary model of the STRATA-1 experiment.

Experimental Validation: The shaking tube experiment consisted of a clear tube filled with grains mounted to the dust cap of a subwoofer speaker. The goal of the experiment was to compare the peak grain heights observed experimentally and in the computational simulation. When connected to a frequency generator, the speaker provides linear displacement at any desired frequency, and adjusting the speaker's volume controls the amplitude of vibration. A camera was used to record the vibration and monitor the peak height of the grains throughout the experiment. The grains used in this experiment and simulation were .3 mm spherical Zirconium Oxide grains. Approximately 11,000 grains were used, and the experiment was run at 40 Hz with a z-axis displacement of .6 mm. Figures 1 and 2 show that the experimental and simulated grain heights are very similar to one another. Additionaly, the dynamics displayed in the simulation and experimental videos are qualitatively similar. Based on these results, we deterimed that the LIGGGHTS simulation correctly models grain collisions and can be used to model the STRATA-1 experiment.

Figure 1: Shaking tube experiment at 40 Hz. Peak grain height <1 cm.

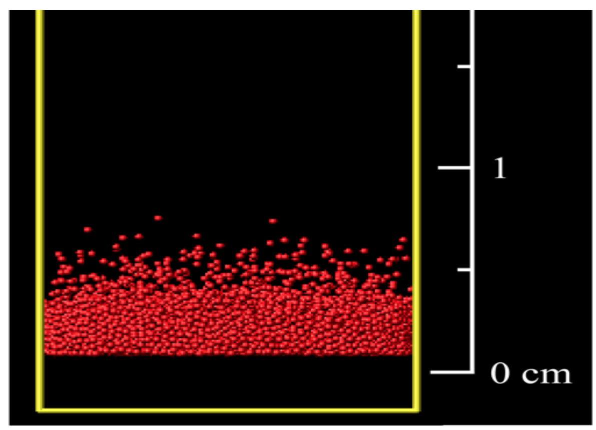

Figure 2. Shaking tube experiment recreated in LIGGGHTS.

STRATA-1 Model: This work focuses on the tube of spherical glass grains in the STRATA-1 experiment. The tubes were exposed to constant micro-accelerations on the ISS. All accelerations experienced by the STRATA-1 payload were recorded by the Space Accelerations Measurement System-II (SAMS) [4]. The SAMS data consists of acceleration magnitudes for the x, y, and z axes in 2 millisecond (msec) intervals. The SAMS data provides the opportunity to investigate specific acceleration events of interest (e.g.

spacecraft docking events). Docking events provide large accelerations that could significantly effect the mixing and segregation of the STRATA-1 grains. Figure 3 shows the SAMS data during the Commercial Resupply Service-9 (CRS-9) docking on 7/20/2016. There are clear spikes in the accelerations experienced by the tubes in all three axes.

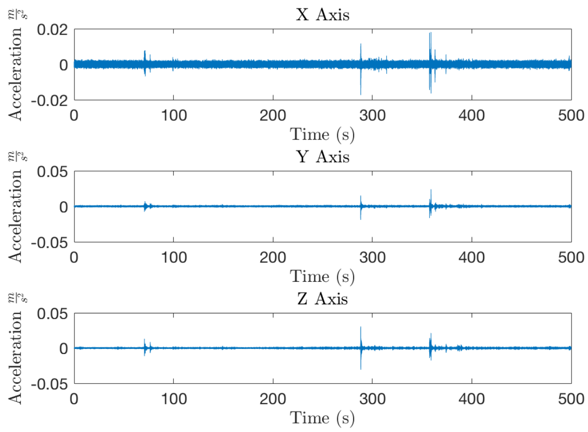

Figure 3: SAMS-II acceleration data during CRS-9 docking event.

To recreate the acceleration environment in the LIGGGHTS software, the tube displacement was defined as:

$$Z(t) = Z_o + A \sin \omega\delta \qquad (1)$$

where ω is 2 PI / period, and δ is the time elapsed from the start of the vibration. Using this displacement function and a vibration period of 2 msec, the amplitude of vibration was found such that the total acceleration experienced by the tube during the 2 msec time interval equaled the impulsive acceleration magnitude at the corresponding time step in the SAMS data. This was done for all three axes, and resulted in a list of shake amplitudes that can be applied to the simulation tube. It should be noted that the acceleration environment on the ISS in continuously changing, and the SAMS data only provides discrete data points. Our method of matching the total acceleration during the interval to the discrete data points is used to approximate the acceleration environment described by the SAMS data. However, the tubes actually experienced continuous accelerations throughtout the time interval that are larger than what is being applied in the simulation. Figures 4 and 5 shows the STRATA-1 tube simulation and experiment before shaking.

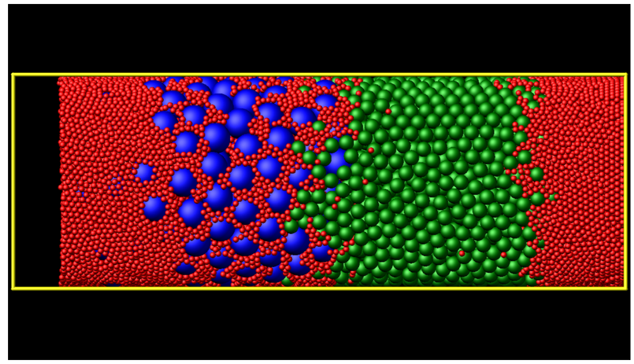

Figure 4. STATA-1 spherical grains tube in LIGGGHTS simulation. Terrestrial gravity is currently active and points to the right.

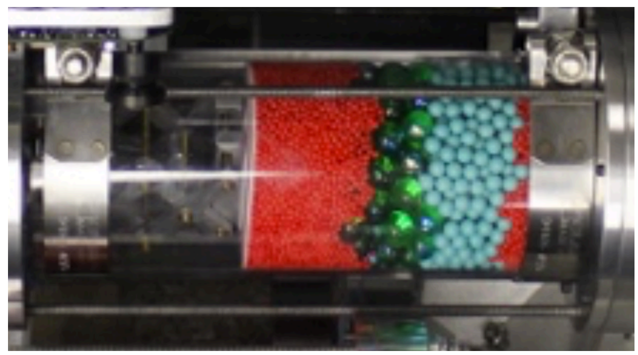

Figure 5. STATA-1 experiment spherical grains tube. Note that the entrapulator is deployed to keep grains from moving during launch and retracts once aboard the ISS.

Summary: STRATA-1 is an ISS payload to investigate granular segregation on small bodies. We are modeling the STRATA-1 experiment using LIGGGHTS, an open-source DEM simulation. To validate our code, a shaking tube experiment was conducted and modeled using LIGGGHTS. Very similar grain dynamics are observed in both the experiment and simulation, and the peak grain heights agree. Lastly, we have analyzed the SAMS data for CRS-9 and have applied the acceleration environment to the STRATA-1 tube simulated in LIGGGHTS.

References: [1] Maurel, Clara, et al. (2016) *Mon. Not. R. Astron. Soc.* 464 2866–2881 [2] Fries, Marc, et al. (2018) *Acta Astron.* 142 87-94. [3] Kloss, Christoph, et al. (2012) *Prog. CFD Int. J.* 12.2-3 140-152. [4] Sutliff, T. J. (1999) *IMTC/99. Proc. 16th IEEE.* Vol. 1. IEEE 254-259.