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Evaluating regolith stratification in an asteroid-like environment via ISS and suborbital experiments

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Abstract

Through the Strata family of experiments, we are taking initial steps to explore regolith size distributions in microgravity environments. These results are especially relevant in light of the images returned from Bennu and Ryugu, which show surfaces dominated by cm- and larger-sized particles. Here we discuss the particle motion and redistribution observed in experiments performed on the ISS and a suborbital flight, and how those motions are governed by gravitational acceleration and the ambient vibrational environments. This data can be used for interpretation of small body surfaces, and for models to extrapolate surface features to depth.

1. Introduction

Knowledge of the particle size distributions and layer depths of regolith on the surface of small, airless bodies such as asteroids and moons is crucial to the success of science and exploration missions, as it will clarify choices for appropriate landing and exploration sites, as well as the design requirements for exploration and ISRU hardware. Understanding the evolution of particle size distributions in regolith layers aides in interpretation of ground-based and remote-sensing observations of the regolith-covered surfaces of airless bodies, and in predictions of how those surface layers represent the particles at depth.

The Strata family of experiments was designed to study the mixing and segregation dynamics of regolith on small bodies by utilizing the low-gravity vibrational environment on the International Space Station (ISS) and with suborbital flight experiments. Here we present the results of an analysis of a subset of data from the Strata-1 experiment, which operated aboard the ISS from April 2016 – May 2017 [1], the Strata-S1 experiment, which flew aboard the Blue Origin New Shepard vehicle in May, 2019, and initial results from the Hermes Cassette 1 experiments, which arrived at the ISS in May, 2019 and are currently operating on orbit.

1.1 Experiment descriptions

Strata-1 was designed as a passive experiment that could operate autonomously aboard the ISS, which provides a microgravity and vibrational environment similar to that at the surface of asteroids (nominal gravity levels on the order of 10^{-6} g and vibration over a wide spectrum that can simulate everything from seismic vibrations to the effects of landed vehicles). We utilized imaging capabilities to observe the behaviour of different layers of regolith simulant over the entire duration of the experiment stay on the ISS. The experiment consists of 4 polycarbonate tubes, each filled with a regolith simulant and evacuated prior to flight. Still images were taken periodically throughout the duration of the experiment, at pre-defined intervals that cycled through so as not to line up with specific times of day. Local acceleration data was provided via an ISS SAMS-II (Space Acceleration Measurement System II) unit mounted on the experiment. SAMS measures vibratory/transient accelerations over a frequency range of 0.01-300 Hz.

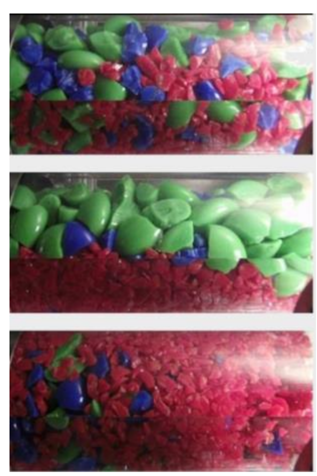

Figure 1. Cropped images from one of the tubes containing glass shards in the Strata-1 experiment. Similar simulants are used in Strata-S1 and Hermes. Images show different areas of coverage and distributions, demonstrating dynamic motion of the particles.

The Strata-S1 experiment was designed to fly on the Blue Origin New Shepard rocket with several science and technology testing objectives. A flight aboard the New Shepard vehicle provides a very clean microgravity environment for about 3 minutes, in which we could evaluate the regolith behavior and test sensors for future flight projects. Additionally, because we have video and sensor data throughout the flight, we used this test flight to evaluate both hardware and regolith behavior during launch and landing conditions (higher g-loads, higher vibration). The experiment tubes used in this flight were the same overall design as the Strata-1 tubes, and similar regolith simulants were used, with updated particle sizes. Accelerometer data is provided by the New Shephard vehicle, and we compare with data from force sensors measuring compressive forces on the simulant column throughout the flight.

Hermes is a new facility (managed by NASA Johnson Space Center) aboard the ISS that was designed to be used for microgravity regolith experiments. Its unique design facilitates experiment changeout while maintain vacuum, electrical, and hardware interface architectures aboard the ISS. Importantly, Hermes allows experiments to be connected to the ISS vacuum system, providing consistent vacuum in the experiment tubes throughout the duration of the flight. The first Cassette (a set of experiments) to be flown with Hermes was based on the Strata-1 experiment and the hardware and sensors tested with Strata-S1.

2. Data analysis

We will primarily present results from the Strata-1 experiment and initial results from the Strata-S1 and Hermes experiments. This data consists of still images and SAMS accelerometer data. Upcoming results will include force sensors inside the experiment tubes, measuring the forces of compression on the regolith. We have primarily focused on analysis of the glass shard tube (Fig. 1), and have developed an automated method of analyzing the image data to reveal bulk sorting and motion patterns of the different particle sizes (represented by red (~2mm), blue (~5mm) and green (~10mm) glass shards). Fig. 2 represents the bulk motion of the particles over the lifetime of the experiment.

In conjunction with the image analysis, we are compiling acceleration data centered around both quiescent periods and times when we see particular upset "events" in the image data. The accelerometer data is very information-rich, providing information both about the magnitude of acceleration events with fine resolution to evaluate at which frequencies they are occurring. We will conduct analysis filtering frequencies relevant for different types of accelerations expected for small body surfaces, to determine what effect those vibrations have on the regolith size sorting.

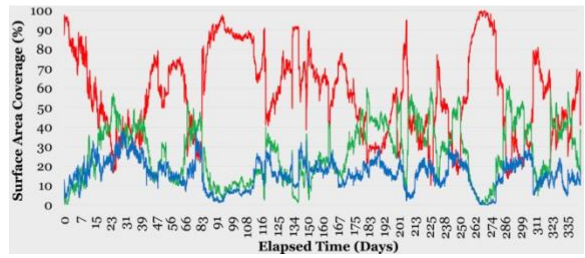

Figure 2. Percentage of visible surface area of particles in the experiment tube as a function of particle size (represented by color) for the glass shard tube over the lifetime of the Strata-1 experiment.

3. Summary and Conclusions

Despite the "passive" environment of the Strata-1 experiment on the ISS, we observe a large variation in the particle distribution over time, and can identify significant events that perturb the system. In particular, we are identifying when major changes occur in the structure of the regolith, and attempt to correlate these with identifiable events in the SAMS acceleration data. By comparing these datasets, we can assess the effect of both the magnitude and vibration frequency of the accelerations on the regolith particle size distributions. This data can be used as input to models of small body surfaces to better understand observed structures and interpret effects at depth.

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References

[1] M. Fries and the Strata-1 team (2018) The Strata-1 Experiment on Small Body Regolith Dynamics, *Acta Astronautica*, 142, 87-94.