Lunar and Asteroid-Relevant Environments Across Suborbital Flight Platforms

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Abstract
One of the most pervasive challenges in performing planetary science experiments is the complication of gravity, and how it drives the physical results of many types of experiments. Suborbital platforms can be used to provide an environment for testing in low- to microgravity conditions similar to those found at the surface of the Moon, asteroids, and other small planetary bodies. We have developed a series of experiments that test the behavior of granular materials across a range of platforms, taking advantage of different lengths and quality of reduced gravity for technology development and to explore basic granular physics, test sensors, and observe more complex physical interactions.

Strata (and Hermes) - Orbital
The Strata series of experiments is designed to utilize microgravity environments to gain insight into geophysical properties of airless planetary bodies in space. Strata-1 (and more recently Hermes) took advantage of the microgravity and vibrational environment aboard the International Space Station (ISS) to explore the stratification, size segregation, and evolution of bulk density of particles in a column of regolith (Fries *et al*., 2018). Strata was entirely passive, except for an initial containment of the regolith prior to activation on the ISS. Hermes was designed using lessons learned from Strata and Strata-S1, and included some active components, including vacuum.

Strata-S1
The Strata-S1 experiment was developed and flown on a suborbital flight on Blue Origin's New Shephard vehicle in April 2019 to test and improve upon the hardware used in the Strata-1 ISS experiment, to test hardware that could be used on the ISS Hermes facility, and to assist with data analysis of those experiments. This type of testing can be used to enhance our understanding of the initial and final conditions of this family of experiments, which is essential for data analysis. Important data on granular mechanics behavior is also gathered during the microgravity portion of the flight.

All experiments are filled with granular materials and simulants that span a range of fidelity with respect to planetary regoliths. In this flight we studied the compressive pressures using load cells and other force sensors for measuring distributed forces throughout the column of regolith. Testing these components through an entire flight cycle provided an opportunity to characterize the effects on the experiment due to in-flight conditions, to study the granular material behavior in high-*g* and low-*g* conditions, and to provide context for the initial images from the Strata-1 data.

Strata-2P
With an eye towards additional gravitational testing and demonstrating the functionality of these experiments and sensors in a variety of gravitational environments, we developed the Strata-2P experiments for parabolic flight. These experiments are testing the influence of gravitational packing on different geotechnical tools, including overall compression, thermal and electrical conductivity sensors, and penetrometer forces. Additionally, this experiment has worked closely with K-12 teachers as part of a teacher-in-residence program.

We will discuss some of the scientific results of these experiments, which can inform interpretation of observations of planetary surfaces, theory, and numerical modeling. We will also review some lessons learned for hardware development and operation in flight as well as guidance for performance of some of the sensors and tools for future flights or planetary surface exploration applications.

References
M. Fries, *et al.* (2018), *Acta Astronautica*, 142, 87-94.

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