STRATA-1: A PLANETARY SCIENCE EXPERIMENT ON THE BEHAVIOR OF ASTEROID REGOLITH IN MICROGRAVITY.

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Introduction: Strata-1 is an experiment studying asteroid regolith in the microgravity environment of the International Space Station (ISS). Strata-1 is answering questions about how regolith evolves under extended microgravity and ambient vibration, as well as what roles particle density, shape, and composition play in the evolution of regolith dynamics. The prolonged microgravity and vibrational conditions of ISS are analogous to those on small Solar System bodies.

Strata-1 Experiment Description: Strata-1 contains four clear tubes containing different regolith simulant materials, each being autonomously imaged. On the ground, each tube was filled with a different simulant and evacuated to mTorr pressure. Each tube includes an "entrapulator" that was used to compress the simulants during launch. Once on-orbit, the entrapulator was retracted to allow the simulants to move freely. Strata-1 is currently operating. At the conclusion of the experiment, the entrapulator will trap the materials in place and Strata-1 will be returned to Earth for further analysis. Strata-1 is located in an Express Rack locker with the long axes of the tubes aligned with the microgravity acceleration vector of ISS. A sensitive three-axis accelerometer, SAMS, is mounted to the face of Strata-1 for the entire one-year experiment to record the vibration environment (0.01 Hz to 400 Hz). Data is being analyzed now, including vibrational data from the SAMS sensor, as well as imagery from each of the four tubes. The latest results from the first set of images will be presented.

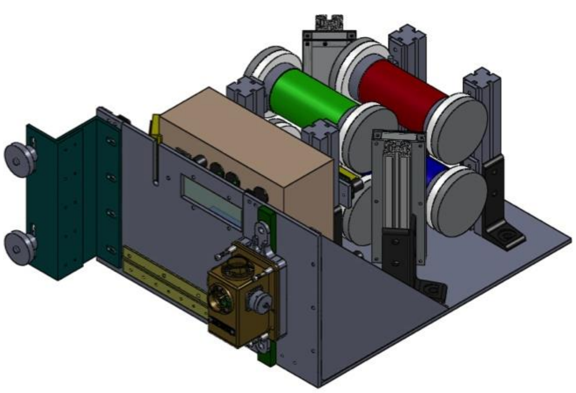

Figure 1: CAD model of Strata-1, including four regolith tubes, four cameras, an electronics box, and two sets of lights. The gold SAMS accelerometer is mounted to the front.

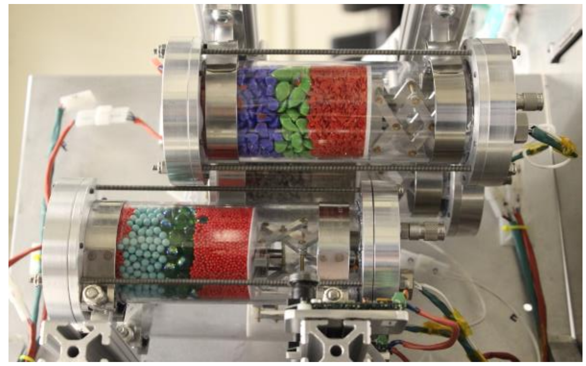

Figure 2: View of the Strata-1 interior, showing the regolith simulant tubes.

A new type of payload: Strata-1 launched to ISS in March 2016. Strata-1 is a Class-1E payload. The new Class-1E payloads are developed with an approach to streamline the payload development, review, approval, and integration processes. Strata-1 went from concept to flight-ready in just 10 months. The payload development team was led at NASA JSC, with hardware built primarily at UCF and JSC. The electronics were provided by T STAR, and the science team members are located at several institutions around the country.

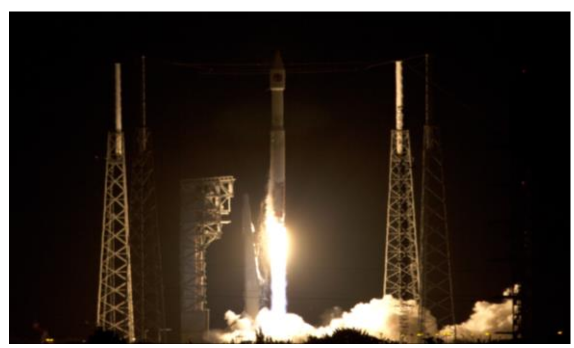

Figure 3: Strata-1 launched to ISS on March 22, 2016 at KSC onboard Orbital ATK's Cygnus spacecraft.

Regolith Simulant Materials & Experiments: The Strata-1 regolith simulants were chosen by the science team to include a range of complexity including a relatively simple system of glass spheres, a tube of glass fragments, a more complex system of crushed/sieved meteorite material, as well as a carbonaceous chondrite simulant. Each tube was sorted into three sizes and maintained in that configuration during launch using the entrapulator.

Experiment 1: The first tube is composed of spherical particles with three discrete grain sizes and colors. This allows for comparison of the size segregation observed on-orbit with Earth-based experiments, which have previously demonstrated that size segregation will occur with spherical glass beads, and computational simulations of the system, as spherical grains are most easily modeled by Discrete-Element-Method (DEM) codes. The grain sizes and quantity of each species were chosen due to numerical constraints and constraints involving interaction with the sample tube walls, porosity of the sample, and the Knudsen number (a measure of the mean free path of the grains). The Knudsen number was chosen to be 0.003 so that particle-particle collisions dominate [1]. The largest grain size was limited to 10 mm in order to keep the grains relatively small compared to the inner diameter of the tube (63 mm).

Experiment 2: The properties of the second tube are identical to Experiment 1, except with angular particles, created by manually fracturing hemispherical particles and then sieving to achieve the desired size distributions. A major limitation of current modeling efforts is the difficulty of including aspherical grains. Thus, by comparing Experiments 1 and 2, we will be able to identify the influence and significance of grain shape on the segregation process.

Experiment 3: The third tube contains a crushed and sieved ordinary chondrite to simulate the behavior of an ordinary chondrite-based regolith. It was sorted to three size distributions similar to Tubes 1 and 2, but contains particles of a wider range of density to include metal- and sulfide-bearing meteorite fragments.

Experiment 4: The fourth tube contains a carbonaceous chondrite simulant, sieved to three size fractions. The simulant was designed to mimic the mineralogy, particle size, and strength properties of CI carbonaceous chondrites. The behavior of materials in this tube will directly inform missions to carbonaceous bodies such as OSIRIS-REx, Hayabusa2, and the ARM mission concept.

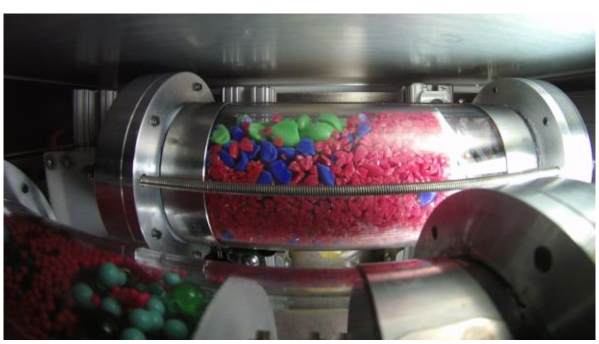

Figure 4: One of the first images downlinked from Strata-1. This images shows the angular, silica glass particles representing Experiment 2. Analysis is being performed now and results will be presented.

Simulation Methods: Two simulation methods are proposed for this research, Soft-sphere Discrete Element Method (SSDEM) [2,3] and Contact Dynamics Method (CD) [4,5]. In SSDEM, the particles interact through soft potentials (spring dashpot-type) that model the forces and deformation that occurs during collisions or enduring contacts. In CD, particles are not allowed to interpenetrate and forces are calculated unilaterally so that this premise is upheld.

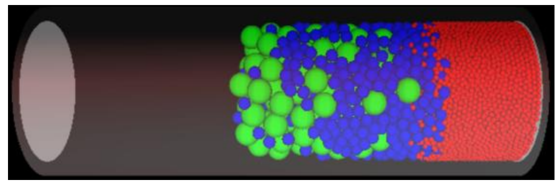

Figure 5: Prototype simulation (SSDEM) of one of the experimental tubes. The cylinder contains 2 mm, 5 mm and 10 mm glass-like spherical beads. Gravity is pushing to the right. All particles are frictional and are contained in a cylindrical container with the same material characteristics. This container can also be made to vibrate so that the experimental conditions in the ISS are matched.

A tool for studying regolith: Strata-1 will help us understand regolith dynamics and will inform design and procedures for landing and setting anchors, safely sampling and moving material on asteroidal surfaces, processing large volumes of material for in situ resource utilization (ISRU) purposes, and, in general, predicting the behavior of large and small particles on disturbed asteroid surfaces. This experiment will provide new insight into small body surface evolution.

Post-Flight Analysis & Strata-2: At the conclusion of the experiment (approximately one year on ISS), all tubes will be returned to Earth. Each tube will be cored and quantitatively analyzed for the particle size and density (where appropriate) distribution to form a data set that is complimentary to the time-lapse imagery. Imagery will be processed into time-lapse video showing the evolution of the simulants. These will be compared to simulation results and will allow for refinement of models.

Strata-1 is the first of several regolith investigations. Strata-2 is currently being developed. Future Strata investigations will involve active components such as probes to study regolith properties, impacts, inter-particle interactions, and anchoring techniques.

References: [1] Harth, K. *et al.* (2015) *Adv. Space Res., 55,* 1901-1912. [2] P. Sanchez, et al. (2011) *Astrophys. J.* **727**(2):120. [3] P. Cundall (1971) in *Proc.Int'l. Sym. on Rock Mechanics V.1* 129–136 -, Nancy. [4] C. M. Hartzell, et al. (2014) in *LPSC 45* 2849. [5] J. J. Moreau (1994) *Eur J Mech A* 13:93.