EXPERIMENTAL APPROACH AND APPARATUS FOR LABORATORY INVESTIGATION OF ASTEROID REGOLITH PROPERTIES.

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Introduction: Over the last decade, the NASA *NEAR-Shoemaker* and JAXA *Hayabusa* missions to asteroids 433 Eros and 25143 Itokawa, and spacecraft-reconnaissance-quality radar observations of near-Earth and small main-belt asteroids (NEAs and MBAs), have caused a profound shift in our understanding of these bodies. Despite the clear evidence that small asteroids undergo drastic physical evolution, the geophysics and mechanics of the processes driving that evolution remain a mystery due to a lack of scientific data on the geophysics of these small bodies and on the mechanical properties of regoliths in the unique micro-gravity regime they inhabit. Although we might be tempted to extrapolate our knowledge of the properties of lunar regolith to the comminuted surfaces of small asteroids, the orders-of-magnitude lower surface gravitational accelerations on NEAs can lead to some at times counter-intuitive geological phenomena. Figure 1 illustrates just a sampling of interesting (and in some cases, wholly unexpected) regolith features on Eros and Itokawa that suggest interactions dominated by granular structures.

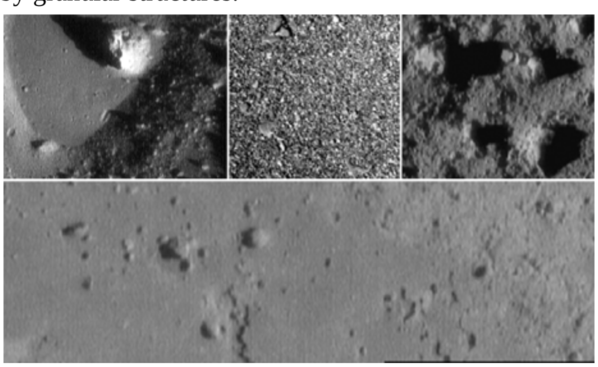

Figure 1: Evidence of processes at work on granular aggregates in the regoliths of Eros and Itokawa – ‘ponds’ (interpreted as accumulations of ~10-micron-scale grains that have migrated to topographic lows), centimeter-scale grains, evidence of clumping or cohesion of granules, and ‘rivulets’ in the finer material (suggesting cohesion of the granular material).

Scheeres et al. [1] performed a survey of the known relevant forces that act on grains and particles on asteroid surfaces (including gravitational and rotational accelerations, Coulomb friction, self gravitation, electrostatics, solar radiation pressure forces, and surface contact cohesive forces), developed their analytical form and relevant constants for the space environment, and considered how these forces scale relative to each other. Among key findings of that study is the result that van der Waals cohesive forces should be a significant effect for the mechanics and evolution of asteroid surfaces and interiors and that asteroid regolith may be better described by cohesive powders (for a familiar analogy, consider the mechanical properties of bread flour) than by traditional analyses assuming cohesionless grains.

This observation implies that regoliths composed of impact debris of the sizes observed on small asteroids should behave on their microgravity surfaces like flour or other cohesive powders do in the 1-g environment here on Earth.

This is a paradigm-shifting perspective that would fundamentally alter our interpretation of the properties of and processes at work on NEA surfaces, and offers a novel experimental approach for regolith analog studies: rather than working with regolith simulants composed of mm- to cm-scale granules directly in reduced gravity conditions, we propose instead to work with cohesive powders in a 1-g, terrestrial laboratory environment.

Experimental Approach and Apparatus: We are beginning a series of laboratory experiments to investigate the role of cohesion in governing regolith processes and geomorphological expression on small solar system bodies. Our goals are to develop an improved understanding of the geomorphological expression of granular media in the microgravity environments of regoliths on small asteroids and to quantify the range of expected mechanical properties of such regoliths.

Many previous experimental results with cohesive powders [e.g., 2–5] have been obtained under ambient atmospheric conditions and we will reproduce some of those measurements for the sake of comparison. We will focus the bulk of our investigation, though, on powders that have been thermo-vac’ed to bake off adsorbed water, with experiments conducted in vacuum conditions to achieve the necessary ‘cleanliness factor’ and to properly recreate the environment on an airless body. An important result from [6], detailing a theoretical and experimental analysis characterizing the cohesive properties of lunar regolith, is the concept of surface cleanliness and its relation to cohesion. In the space environment the minimum distance between particles can be much closer than is possible on Earth, where atmospheric gases, water vapor, and relatively low temperatures allow for significant contamination of surfaces. In the extreme environment of space, surfaces are much ‘cleaner’ due to the lack of adsorbed molecules on the surfaces of materials, allowing for closer effective distances between surfaces so that the dipole-dipole interactions between molecules in the particle surfaces can come into play.

The environmental chamber for our experimental work resides at Ball Aerospace & Technologies Corporation (BATC) in Boulder, CO and is shown in Fig. 2. This facility consists of a small, cylindrical, ultra-high-vacuum chamber that resides within a larger, industrial-grade, rough-vacuum chamber. Pressures within each chamber are monitored and controlled independently, and when thermal control of the inner chamber is required, the outer chamber can be evacuated to provide enhanced thermal isolation. Descriptions of each major component are as follows:

Large, outer chamber. The large outer chamber is used to house and provide enhanced thermal isolation to the thermally-controlled inner chamber. This cylindrical chamber was custom built by LACO Technologies and consists of an industrial-grade stainless steel body with dual clear acrylic hinged doors. The chamber is 40 in. long × 24 in. diameter (internal dimensions) and provides vacuum performance down to 0.05 Torr. There are eight 2.75-in. KF ports for custom electrical, fluid, and fiber feed-throughs.

Small, Thermally-Controlled Inner Chamber. The small cylindrical ultra-high-vacuum inner chamber also was custom built by LACO Technologies and consists of a stainless steel body with bolt-on stainless steel doors and ports that are sealed by metal gaskets. The chamber is 24 in. long × 12 in. diameter (internal dimensions) and is expected to achieve a vacuum level on the order of 10^{-5} to 10^{-6} Torr under experimental conditions with the regolith and supporting hardware in place. The chamber is thermally controlled by circulating a heat-transfer fluid through the coiled length of 0.25-in. copper tubing, which is silver-soldered to the chamber body. The temperature is controlled using a Neslab Model LT-50 recirculating chiller. It has an operating temperature range between -40°C and +40°C using a heat transfer fluid in a five-gallon reservoir. Higher temperatures are achieved using a simple hot plate with a reservoir of heat transfer fluid and a mechanical pump. There are eight 2.75-in. KF ports for custom electrical, fluid, and fiber feed-throughs.

Motorized Linear Slide. A motorized linear slide is installed in the inner chamber for mechanical manipulation of the experimental apparatus. The system was purchased from Zaber (Part Number KT-LLS280-S) and provides 26 cm of travel. Communication is provided through an RS-232 interface.

Roughing Pump. A Sogevac SV100 3-kW, oil-sealed rotary-vein pump is used to rough pump both chambers. The pump can be isolated from the chambers using a high-vacuum manual valve.

Turbo Pump. For applications requiring high-vacuum, a turbo molecular pump is used in conjunction with the rotary-vein roughing pump, which will allow for a maximum vacuum on the order of 10^{-5} to 10^{-6} Torr.

Pressure Sensors. Pressure in the chambers is monitored using MKS Baratron pressure gauges with a range of 1 to 1000 Torr for the outer chamber and 0 to 100 Torr for the inner chamber.

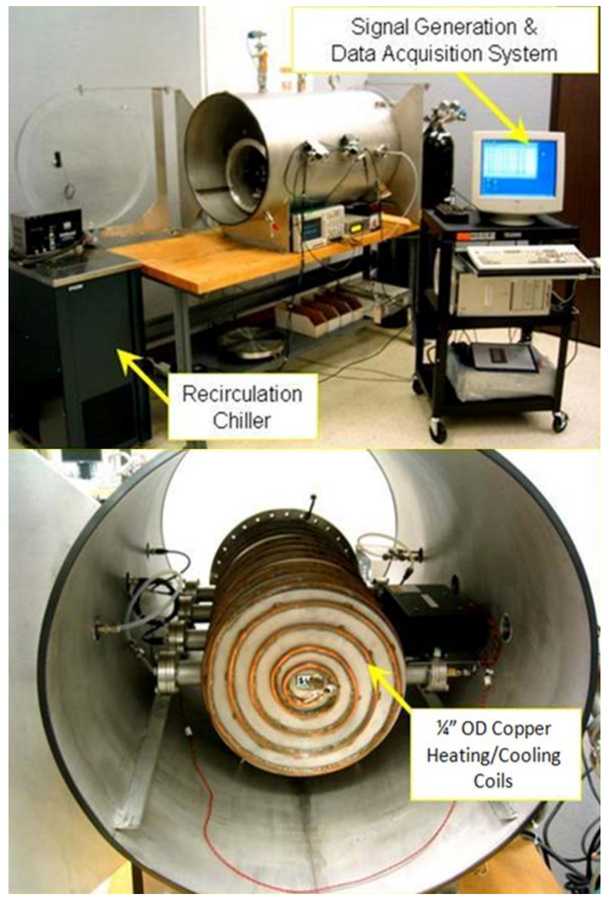

Figure 3. The environmental chamber consists of a small temperature-controlled high-vacuum cylinder that is housed in a larger low-vacuum cylinder. The system contains numerous electrical, fluid, and fiber feed-throughs and a motorized linear slide to accommodate a range of experimental configurations.

References: [1] Scheeres D.J. et al. (2010) *Icarus* **210**, 968–984. [2] Alexander A.W. et al. (2006) *Powder Technol.* **164**, 13–21. [3] Rognon P.G. et al. (2008) *J. Fluid Mech.* **596**, 21–47. [4] Mériaux C. and Triantafillou T. (2008) *Phys. Fluids* **20**, 033301-1–033301-13. [5] Vandewalle N. et al. (2007) *Eur. Phys. J.* **E 22**, 241–248. [6] Perko H.A. et al. (2001) *J. Geotech. Geoenviron. Eng.* **127**, 371–383.