EXPERIMENTAL SETUP TO STUDY CRATER SCALING RELATIONSHIPS FOR GAS-BASED EXCAVATION ON SMALL BODIES.

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Introduction: The surfaces of rocky and icy small solar system bodies are covered by a layer of pebbles, cobbles, and boulders, termed regolith. The geotechnical properties of regolith are a critical aspect for the design of *in-situ* planetary exploration [1] and planetary defense missions [2]. However, little is known about regolith geotechnical properties *a-priori* and extrapolations from prior surface exploration missions is typically used to justify design choices and operation strategies. This has often led to surprising outcomes, even for targets previously thought to be well characterized.

While some regolith properties may be determined remotely, such as boulder size, shape, and regolith porosity, others are more poorly constrained, such as strength. For small bodies, variations in regolith strength can lead to a diversity of outcomes: such as meter-high bouncing (Hayabusa at asteroid Itokawa [3]), spacecraft displacements of hundreds of meters (Philae at comet 67P/CG [4]), and penetration into the surface (OSIRIS-REx at asteroid Bennu [5]).

In the case of the NASA New Frontiers sample-return OSIRIS-REx mission to the near-Earth asteroid (NEA) Bennu, the regolith was mobilized by both spacecraft intrusion [5] and gas and thruster fire [6], as predicted by [7]. This allowed two independent measurements of the bulk density and cohesion of the Bennu near-surface, demonstrating the utility of gas- and thruster-based excavation to probe regolith geotechnical properties of asteroidal regolith at relatively safe distances for the spacecraft. As thrusters are a necessary component to any spacecraft exploring small bodies, we foresee that thruster-based science activities will be an essential part of small body exploration moving forward, as it enables a deeper understanding of asteroid surface physical properties.

Here, we present a series of experiments that were undertaken with the goal of constructing reliable models and scaling relationships for gas-based excavation in low-gravity bodies. These experiments enable an essential understanding of how thrusters can be used to explore low gravity planetary surfaces. Models exist for how regolith reacts to thruster fire on larger bodies [8], but little is known about how to extend such relationships to low-gravity airless bodies. The outcome of this study could be used to understand thruster-based excavation at (99942) Apophis [9], and future asteroid rendezvous targets.

Gas Cratering Experiments: For these gas-based cratering experiments, we have re-configured the Johns Hopkins University Applied Physics Laboratory's (JHUAPL) Planetary Impact Laboratory (PIL) gas gun [10]. The PIL gun consists of a single-stage, compressed inert gas gun and a large impact chamber. The impact chamber is ~1.3 meters in diameter and ~2 meters tall. The impact chamber can be pumped down to 75 Pa. The gun fills a reservoir up to 6k psi with N_2. In comparison, OSIRIS-REx expelled N_2 gas at 3k psi [5]. For the gas-cratering experiments, we have lowered the barrel of the gun into the impact chamber until it is ~ 20 cm from our target, a bucket of coarse regolith [11]. The height of the target is then adjusted as it sits on a transmission jack. The chamber is pumped down to ~1 Torr. We investigate the influence of varying gas pressure and the height from the tip of the barrel to the surface of the target on the resulting crater diameter, crater depth, and ejecta physical and kinematic properties. Fig. 1 shows a demonstration of our gas firing experiment.

Figure 1. Snapshots of a gas cratering experiment using the APL PIL configured to perform gas-only experiments on a coarse particle target that has a small fraction of dust. Note the early onset of dust ejected at shallow angles. The dust ejection angle steadily steepens with time. The coarse particles are mobilized more slowly than dust and have a fixed ejection angle.

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