

MAGNETIC GRAPPLES FOR LOW-G ANCHORING AND MULTI-POINT ASTEROID SAMPLE RETURN. A. H. Parker¹, K. J. Walsh¹, D. D. Durda¹, K. Nowicki¹, and the Project ESPRESSO Team. ¹Southwest Research Institute, Boulder, CO (aparker@boulder.swri.edu).

Introduction: Surface science operations and sample return from small asteroids present a substantial technical challenge. Current and past missions have encountered difficulties with predictable surface anchoring (e.g., Philae's multi-kilometer bounce) and sample collection. Current mission architectures require that the primary spacecraft conduct the sample collection maneuver, placing the entire mission in jeopardy during surface proximity operation. Because of the high risk of these maneuvers, typically only one sample site is planned for. The surfaces of current sample return mission targets Bennu and Ryugu are both extremely heterogeneous, and it is unclear how well a sample collected at a single site will reflect the diverse surface components.

We have developed and tested a novel anchoring and sampling architecture for the surfaces of small asteroids that will enable low-risk surface operations and sampling from multiple sites on any given target body. Here we outline the basic system architecture, tests conducted to date, and plans for future development.

Magnetic Manipulation of Asteroid Regolith: Nearly all asteroid regoliths are expected to have a substantial ferromagnetic component [1]. Terrestrial meteorite samples generally show attraction to magnets. A suitable arrangement of "switchable" permanent magnets can provide a safe, low-power means of anchoring to asteroid surfaces or collecting regolith samples. For the following reduced gravity tests, we use the high fidelity CI chondrite regolith simulant produced by the UCF Exolith Lab¹, and have conducted supporting 1g tests with a Phobos regolith simulant designed for the MMX mission [3] with very similar results.

Reduced Gravity Experiments: We developed a mid-scale vacuum regolith chamber for reduced gravity flights on the NRC-CNRC Falcon 20 research aircraft. In October 2018, we conducted four experimental flights with this chamber and the CI chondrite regolith simulant, with each flight executing between 10 and 12 parabola maneuvers. The chamber was equipped with a 3-axis accelerometer providing measurements at 400 Hz to record the simulated gravity environment that the chamber and its contents experienced during the flights.

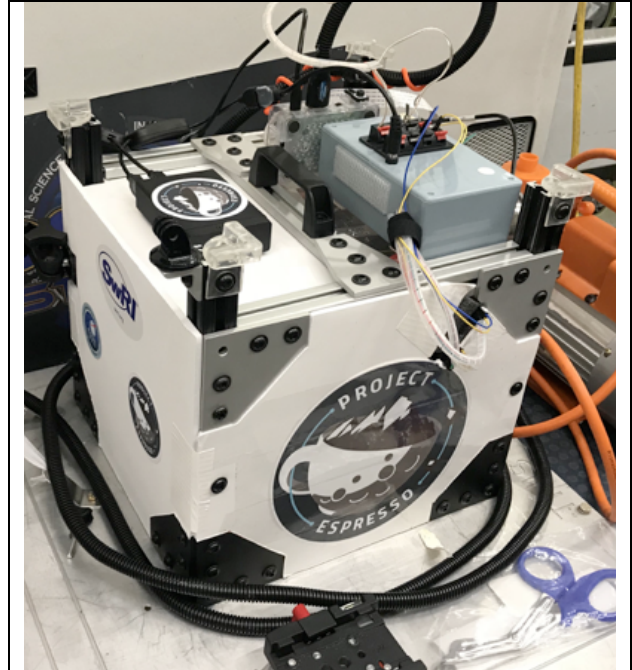


Figure 1: Flight chamber and C&DH electronics. Eight liter aluminum chamber housed inside was pumped down to ~0.5 torr for duration of flights. Chamber status monitored by seated operator with remote video screen.

Once the aircraft entered the reduced gravity portion of a parabola, a single 1 cm diameter N42 grade neodymium sampling magnet was lowered into the regolith bed by means of a servo-actuated slide rail, then retracted by the same servo before the end of the reduced gravity phase. The magnet was suspended by a Kapton ring spring hung from a 500 gram strain gauge, providing a means of measuring required extraction force and an extremely low-*k* coupling to the servo rail and any vibration or impulses transmitted from the chamber exterior. The Kapton ring also carried an embedded copper film conductor, enabling 5v power to be provided to an offset-weight vibration micromotor attached to the top side of the sampling magnet. This vibration motor was switched on and off at different portions of the sampling procedure to either "burrow" the sampling head into the regolith during the reduced gravity phase, test the adhesion of a collected sample once the magnet was retracted from the regolith bed, or to clear the magnet of any regolith during the hyper-g phase of the parabolas.

¹ https://sciences.ucf.edu/class/simulant_ci/



Figure 2: Time series of a CI chondrite sample extraction. Left: Sampling head lowered onto regolith bed. Center: Sampling head being extracted from regolith bed. Right: Suspected sampling head and 15 gram collected sample, bound in a 30mm sphere by magnetic field. Experiment under vacuum and under 0.03g reduced gravity conditions.

Typically, a ~15 gram, ~3 cm sphere of material was extracted from the surface during a sampling experiment. The noise in the strain gauge record from g-jitter was substantially higher than the extraction forces, resulting in no direct measurement of anchoring forces. However, the contact patch area of the extracted lower hemisphere of regolith is 18 times that of the bare magnet, providing an order-of-magnitude increase in effective surface area over which shear and tensile stresses are distributed from the anchor into the surface materials.

“Switchable” Permanent Magnets: Two axially-magnetized cylindrical magnets housed inside a magnetic yoke can be arranged such that by rotating one magnet by 180° within the yoke results in the magnet switching from a state with substantial magnetic flux exiting the yoke to one in which the magnetic flux is entirely short circuited within the yoke, resulting in a negligible field outside the yoke. Similar geometries will allow a sampling head to be magnetically active during a sampling maneuver while not unduly influencing other instruments aboard the main spacecraft during transit; alternatively, an anchoring system based on this geometry can be switched on and off, allowing both anchored and mobile operations. The advantages of a switchable permanent magnet system over an electromagnetic system are primarily in size, reliability, and power requirements. These switchable permanent magnets only require power to switch between states and thus produce no heat during sustained use, and they can be made extremely small ($< 1 \text{ cm}^3$) and lightweight.

Mission Concept and Future Development: A parent spacecraft carries a fleet of small sampling microsatellites. These samplers consist of a small electronics and propulsion package contained within a shell with an everting shape – that is, where the entire outside shell

can be folded to become its interior, and vice versa. This biomimicry architecture is inspired by the stomach eversion used by starfish to ingest food. In the pre-eversion state, the exterior surface can be magnetized with switchable permanent magnets. These samplers are ballistically deposited on the surface of a target body at many sites, where material passively collects on their outside surfaces. The surfaces of the samplers then evert, trapping collected regolith on the new interiors, and the magnets are switched to the off state. Small thrusters loft the samplers back off the surface at low speed, where they are intercepted by the parent spacecraft and stowed for return to Earth.

SwRI and Project ESPRESSO are developing a much larger reduced gravity vacuum environment chamber (the Airborne Space Environment Chamber). In this chamber we will conduct free-flying experiments to further mature the microsat lander and magnetic sampler architecture with a variety of regolith simulants.

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References: [1] Lodders, K. & Fegley, B. (1998) “The Planetary Scientist’s Companion.” *Oxford University Press*. [2] Miyamoto H. et al. (2018) *LPSC 49*, Abstract # 2083.