LOFTED REGOLITH SAMPLING OF SMALL BODIES. J. W. McMahon[1] and B. Cheetham, [1]Aerospace Engineering Sciences, University of Colorado Boulder, 431 UCB, Boulder, CO, 80309, jay.mcmahon@colorado.edu, [2]Advanced Space, LLC, 2100 Central Ave., Boulder, CO, 80301, cheetham@advanced-space.com.

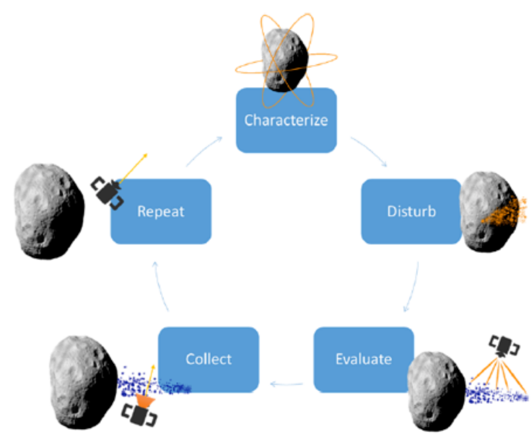
Introduction: In-situ resource utilization is technical ability that could dramatically influence how future missions to explore the solar system are designed. Probable (and plentiful) sources of useful materials include asteroids, comets, and moons - particularly Earth's and Mars' moons. The first step along the path to in-situ resource utilization is understanding what is where. Therefore, it is important to acquire and analyze as many samples from these bodies as possible, allowing us to identify and characterize the available resources. The focus of this work is to improve the ability of spacecraft to obtain and characterize samples from Near Earth Objects (NEOs). These bodies are currently the most accessible class of small bodies and can also provide information about the resources available in small bodies throughout the solar system.

Acquiring samples from small bodies in order to characterize and better understand them is a complex but important endeavor. Traditionally, such missions have consisted of an orbiting spacecraft that must touch, land on, or deploy a second vehicle to the surface of the small-body to obtain physical samples that can be characterized. In contrast to this traditional and high risk approach, we propose an innovative architecture and concept of operations that permits reliable, safe, and repeated sampling of small bodies. This architecture, referred to in this proposal as the Lofted Regolith Sampling (LoRS) architecture, is based on advanced astrodynamics and autonomy capabilities that are robust to target-body uncertainties, and is adaptive during operations. Based on several key phases that ultimately lead to a thorough char- acterization of the target body and collection of multiple samples while avoiding complex and highly unpredictable landing requirements, the LoRS architecture will also permit sampling from areas of a small body that might not otherwise be accessible to a spacecraft such as craters, cliffs, and boulder fields.

The ongoing work is evaluating the feasibility of this innovative architecture and identify key hardware and software requirements for future development. In completion, this effort will have developed a detailed mission architecture and concept of operations, evaluated autonomous approaches to key operations, and identified technologies required for lofting, remotely characterizing, and collecting surface materials. If the LoRS architecture is found to be feasible, it will enable a NEO prospecting and characterization mission in the near-term with only a small amount of new technology development.

The fundamental results found in the feasibility study of the LoRS are presented here.

Concept of Operations: The LoRS concept of operations allows for maximum flexibility of a mission to prospect at a small body. The start of the LoRS architecture is upon arrival at the target body Arrival considerations for LoRS are similar to most exploration missions - without significantly increasing fuel costs it is desirable to approach from the sunlit side of the body for early optical acquisition of the target to ensure a successful close approach and orbit insertion. The spacecraft will then characterize the target by performing a number of flybys and/or orbits. There are four sub-steps which provide crucial knowledge for lofting and capturing regolith – mapping the gravity field, the shape, surface features, and identifying lofting targets. The spacecraft will then loft material with one of a variety of possible methods. Upon coming back to the lofted debris, the material can be remotely characterized, and a decision can be made to either collect material or not. Finally, this can be repeated at the current small body, or the prospector spacecraft could move onto another small body target.

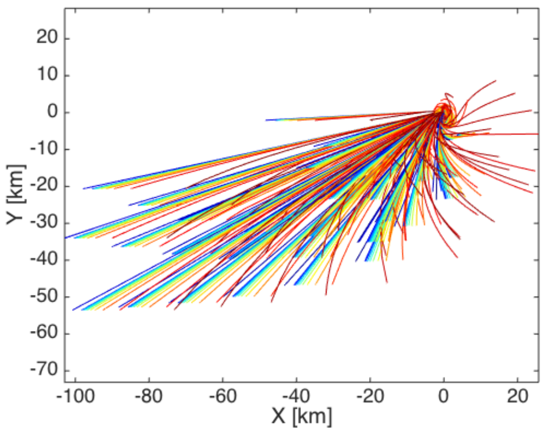


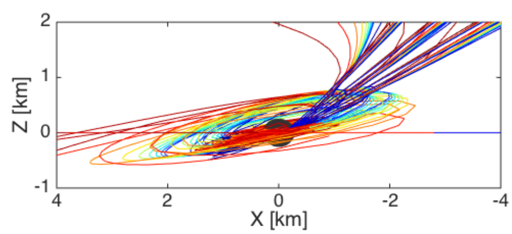
Debris Dynamics: The key to the LoRS architecture is based on the natural dynamcs which govern the motion of objects in the vicinity of a small body. The relatively large influence of solar radiation pressure on small objects works to size sort the material naturally over the course of days. Many simulations have been run over the parameter space shown in Table 1 to test that this holds for a variety of conditions.

Table 1: Parameter space for lofted regolith trajectories

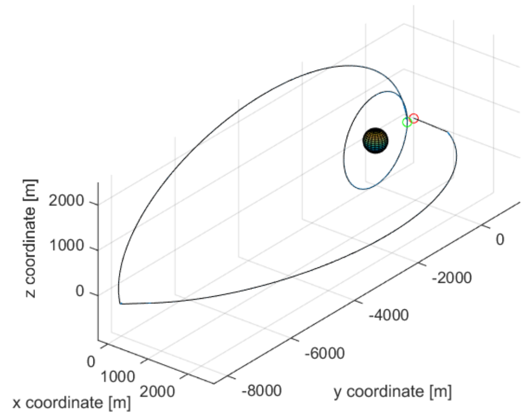
Parameter	Values Tested
Particle Radius	[100, 10, 8.9, 7.8, 6.6, 5.5, 4.4, 3.3, 2.1, 1] cm
Latitude	[80, ±64, ±48, ±32, ±16, 0] deg
Longitude	[0, 36, 72, 108, 144, 180, 216, 252, 288, 324] deg
Launch Azimuth	[0, 90, 180] deg
Launch Elevation	[10, 30, 45, 90] deg
Launch Velocity	[3, 5, 7, 9, 11, 13, 15] cm/s

The figures below show the trajectories from many debris particls lofted from Bennu at the 108 degree longitude site. The color coding indicates the size of the lofted particles – the smaller particles are red and the larger are blue. The size sorting is clear, and holds rather robustly for the conditions tested in Table 1.

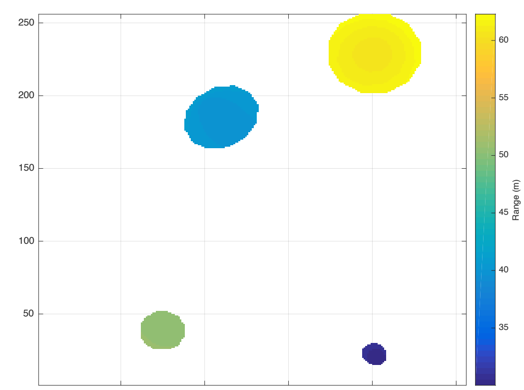




Spacecraft Control: The controllability of the orbit has been investigated under the power of a low thrust ion engine. Using Dawn's ion engine (90 mN thrust, 3100 s I_{sp}) [1] and assuming a 2000 kg spacecraft, all manner of maneuvers are possible. In the following figure, we show a trajectory where it costs only 7 cm/s to raise apoapse from 1 to 8 km, then 3 cm/s to change the inclination by 90 degrees, for a total of only 6.5 g of fuel. This trajectory could be useful for LoRS as from the early low orbit the debris could be lofted, with the spacecraft moving to a higher altitude to stay safe from the lofted debris, before returning to a lower altitude to characterize and collect material. Given the low fuel costs of such a maneuver, this profild could be repeated many times with a typical spacecraft fuel load.



In order to intercept the debris, we need to find and track it. One possible way to do this is using flash LIDAR instruments. An example simulated image is shown in the following figure for a 256 x 256 flash LIDAR array with a 20 degree FoV and a 10 m focal length. Many algorithms are available to track the objects as they move across the field of view relateive to the spacecraft. Guidance algorithms have been developed which will allow the spacecraft to home in on observed objects in order to collect the debris objects if desired.



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References:

[1] http://dawn.jpl.nasa.gov/mission/ion prop.asp