Simulations of Regolith Interactions in Microgravity

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Interactions between a rigid sampling device and regolith settled in a micro-gravity environment are shown. The results are relevant for the OSIRIS-REx mission.

Introduction:

NASA's OSIRIS-REx mission will travel to the carbonaceous asteroid 1999 RQ36, acquire a sample of regolith from its surface and return the sample to Earth in September 2023. A crucial aspect of the mission occurs when the spacecraft descends to touch and sample the surface of the asteroid. One region of the asteroid where the sampling may occur is in the equatorial region of the body. This region is the geopotential low over the entire asteroid, and has a total surface acceleration (gravity minus centripetal) on the order of micro-Gs. The physical interaction between a spacecraft sampling device and the regolith resident in this environment occurs in a realm of physics that cannot be reconstructed on Earth, and which would be very difficult to reconstruct on-orbit. Thus the prime manner to evaluate the possible outcomes of these interactions is through direct, first-principles simulations of a sampling head contacting a regolith in a micro-gravity regime.

This abstract reports the formulation and results of a suite of simulations to model the interaction between a sampling device and a micro-gravity regolith bed. These simulations were performed to provide insight into one possible regime of interaction for the OSIRIS-REx mission's surface sampling. Results of these interactions show that low-speed contacts between a sampling head and the regolith can introduce a fluid-like response in the regolith. The forces are found to act similar to an aerodynamic drag, and thus increasing the contact speed can supply greater resistance from the regolith. In contrast, settling the grains in a higher gravity field also increases the resistance of the regolith on the sampling mechanism. Understanding these interactions is important, as the forces between regolith and a sampling device may play a role in designing and predicting the sampling phase of any future missions to asteroids in similar environments.

Simulation Method:

The simulation program that is used for this research applies a Soft-Sphere Discrete Element Method [1, 2, 3, 4] to simulate interactions between a rigid sampling head descending to the surface and the regolith granular aggregates on the surface. The regolith particles are modeled as spheres that follow a predetermined, but randomized, size distribution and interact through a soft-repulsive potential when in contact. This method considers that two particles are in contact when they overlap. For each particle-particle contact, the code calculates normal and tangential contact forces as described in [5, 1]. Interactions between particles and the rigid sampler head are handled following the same methodology.

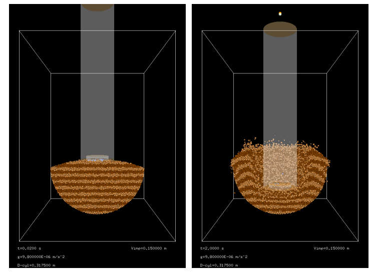

Figure 1: Time evolution of a 15 cm/s contact. The snapshots correspond to t = 0.02, 1.0 and 2.0 s and show a cross-sectional cut of the granular bed. The sampling head has been made semi-transparent.

Regolith and Sampling Head Models:

We assume that the gravitational field is constant and independent of the particle positions, as our study focuses only on a small volume located on the surface on the asteroid. Two sets of simulations were carried out, one used a monodisperse-continuous size distribution (10mm, 20% dispersion); the other used a polydisperse, 1/D size distribution (5-22 mm). The sampling head was modeled as being combined with a spacecraft with a total mass of 1300 kg. The sampling head was modeled as a right cylinder with diameter 32 cm and an inner "sampling" chamber cut symmetrically in the bottom with a diameter of 21 cm and a depth of 3.5 cm (see Fig. 1).

Results:

Figure 1 shows the time evolution of a 15 cm/s contact at 0.02, 1.0 and 2.0 seconds after initial contact. A close examination of the images and the velocity fields generated by the particles will show that the particles in the first layers of the granular bed, and a short radial distance beyond the edge of the sample head, can acquire vertical speed of the same order of magnitude of the contact speed. The simulation also shows that after the initial contact the regolith trapped in the chamber will remain there for the entire simulation.

Figure 2 shows the time evolution of the net vertical force on the sampler at initial speeds of 10 cm/s and 15 cm/s for the monodisperse case. For both cases the initial peak occurs when the outer annulus contacts

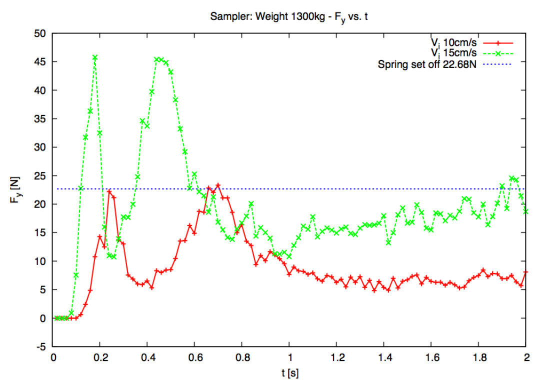

Figure 2: Vertical force on the sampler head vs. time for contact speeds of 10 and 15 cm/s into a monodisperse regolith.

the regolith, and the second peak occurs when the inner chamber contacts the regolith. Following these peaks the force is approximately constant for a few seconds until the sampler head starts to "feel" the bottom of the simulation chamber (see Fig. 1). The peaks in force are approximately proportional to the contact speed, implying that the force is due to momentum transport from the sampler head to the regolith. The force magnitude following the peaks is approximately proportional to the square of the speed of the sampler head, implying that the force experienced by the sampler head is similar to a fluid drag acting on the body.

Figures 3 show the time evolution of the net vertical force at an initial speed of 10 cm/s into a monodisperse (top) and polydisperse (bottom) regolith. Note that the force variation is smoother for the polydisperse case as compared to the monodisperse case, implying that a range of grain sizes acts to distribute the force loads more evenly throughout the regolith.

Implications:

These simulations predict that for regolith settled in a micro-gravity environment, a low speed interaction with a rigid sampling head may behave more like a fluid interaction than as a rigid material interaction. This is an unexpected result of the simulation, but follows directly from the first-principles calculations. The model developed here is but one extreme that may be encountered at asteroids, and continued refinements will clarify the role of cohesion, friction, and coefficients of restitution.

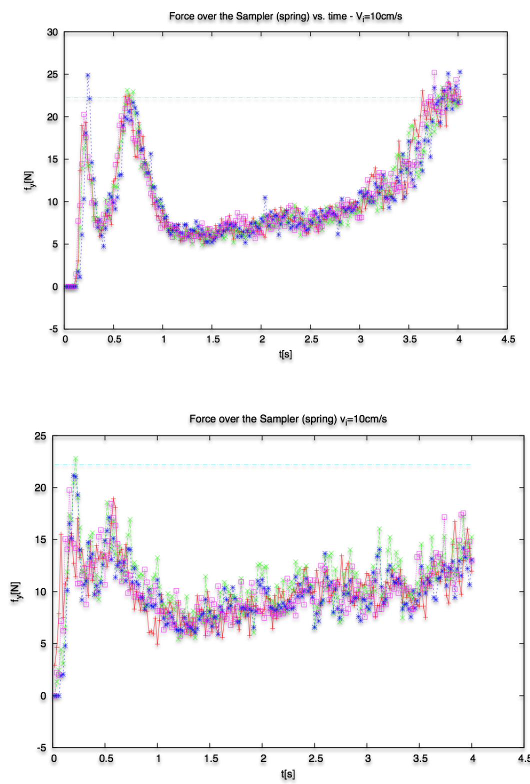

Figure 3: Vertical force on the sampler head vs. time for an contact on a monodisperse (top) and polydisperse (bottom) sample for a 10 cm/s contact.

References: [1] P. Sánchez, et al. (2011) *The Astrophysical Journal* 727(2):120. [2] P. Cundall (1971) in *Proceedings of the International Symposium on Rock Mechanics* vol. 1 129–136 -, Nancy. [3] P. A. Cundall, et al. (1992) *Engineering Computations* 9(2):101 http://dx.doi.org/10.1108/eb023851 doi. [4] M. P. Allen, et al. (1989) *Computer Simulation of Liquids* Oxford science publications Oxford University Press, USA, New York ISBN 0198556454. [5] H. Herrmann, et al. (1998) *Continuum Mechanics and Thermodynamics* 10:189 ISSN 0935-1175 10.1007/s001610050089. [6] D. Scheeres, et al. (2010) *Icarus* 210(2):968 ISSN 0019-1035 http://dx.doi.org/DOI: 10.1016/j.icarus.2010.07.009 doi. [7] L. E. Silbert, et al. (2001) *Phys Rev E* 64(5):051302 http://dx.doi.org/10.1103/PhysRevE.64.051302 doi.

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