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Regolith Penetrometry in Microgravity

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Abstract

We describe the results of penetrometry simulations between two impactors, a cylindrical sampling device and a small right-circular cone, into a granular bed settled in a micro-gravity environment. For low contact speeds we find that the regolith provides fluid-like drag that acts on the penetrator.

1. 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 2023. A crucial aspect of the mission occurs when the spacecraft descends to touch and sample the surface of the asteroid. The geopotential low on this asteroid, where sampling may occur, has a surface acceleration on the order of micro-Gs. Beyond this specific mission, significant interest has been expressed in developing methods to probe the subsurface of an asteroid's regolith with a penetrator shot into the surface. In both cases, the physical interaction between a sampling device and the regolith in this environment occurs in conditions that cannot be reconstructed on Earth, and which are very difficult to reconstruct on-orbit. This makes computer simulations our best tool to evaluate the possible outcomes of these interactions.

This abstract reports the formulation and results of simulations performed since 2010 to model the interaction between the sampling devices and a regolith bed that has been settled in a micro-gravity environment.

2. Simulation Method

The simulation program we use for this research applies a Soft-Sphere Discrete Element Method [1, 2] to simulate interactions between two types of surface interaction devices. A rigid sampling head that descends into a regolith bed and a right-circular cone shot into the surface of a granular bed. 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 [3, 1]. Particle-intruder interactions are handled in the same way. The dynamics of the intruders are also driven by their interactions with the regolith.

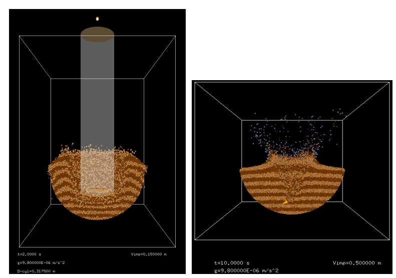

Figure 1: Soft-Sphere DEM simulations; TAGSAM-like sampling head (left) and cone shot at the granular bed (right).

3. Regolith and Impactor 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). A significant aspect of our simulations were the method used to settle the regolith grains in a micro-G environment. This methodology [1] results in a porous and weakly coupled regolith. This is one extreme of how regolith may be settled; in these runs it represents settling in a relatively undisturbed and uncompacted environment.

The sampling head was modeled as being combined with a spacecraft (total mass = 1300 kg). The sampling head was modeled as a right cylinder with a diameter of 32 cm and an inner "sampling" chamber cut symmetrically in the bottom with a diameter of 21 cm and

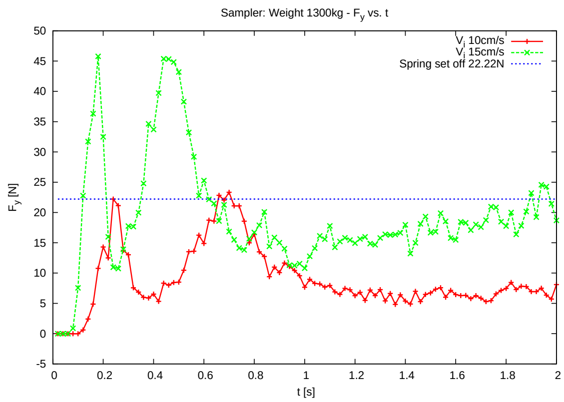

Figure 2: Vertical force on the sampler head vs. time for contact speeds of 10 and 15 cm/s into a monodisperse regolith.

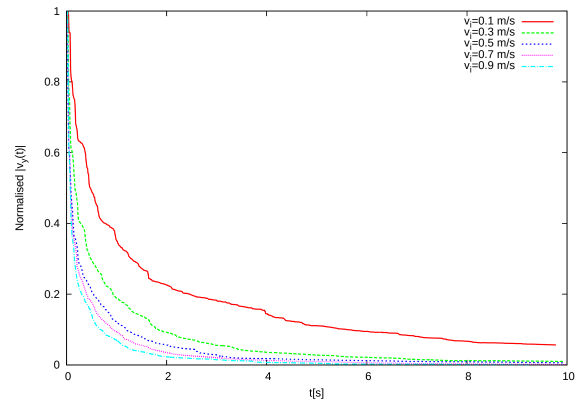

Figure 3: Normalised vertical velocity vs. time plot of the cone after impacts on the granular bed at 0.1 (red), 0.3(green), 0.5 (blue), 0.7 (magenta) and 0.9 (light bue) m/s.

a depth of 3.5 cm (Fig. 1). The cone was 6 cm high, 3.2 cm in diameter and was modeled as a 6 DOF body.

4. Results

Fig. 1 (left) shows a snapshot of the cylinder simulation at t=2s (15 cm/s impact). A close examination of the velocity fields generated by the particles shows that the particles in the first layer of the granular bed, and a short radial distance beyond the edge of the sample head, can acquire vertical speeds 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. Fig. 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 the regolith, and the second when the inner chamber contacts the regolith. Following these peaks the force is approximately constant for a few seconds until the sampler head "feels" the bottom of the container (Fig. 1). 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. The force variation is smoother for the polydisperse case as compared to the monodisperse one, implying that a range of grain sizes acts to distribute the force loads more evenly throughout the regolith.
Fig. 3 shows a velocity (v_y) vs. time plot where each line is the average of 5 simulations with the same initial impact velocity, but with a granular bed that has a different random arrangement. Here we have normalized the lines with the impact velocity of the impactor to show the tendency of the behavior and help us find the right fit. For them, we found that the velocity can be fit by:

$$\frac{v_y(t)}{v_i} = \frac{1}{at+b} + c \qquad (1)$$

Which leads to:

$$a_y(t) = Av_y^2(t) + Bv_y(t) + Cv_i \qquad (2)$$

where the quadratic term is the most influential [4].

Acknowledgements

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