

PDC2021
Vienna, Austria

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A physical model for low-velocity penetration into granular media

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Keywords: Asteroids, Surface properties, Experiments, Data analysis

ABSTRACT

The number of space missions involving an interaction between a probe and the surface of a small-body has flourished in recent years. Given their regolith-covered surfaces, the process of landing on a small body can be considered as an impact at low-velocity onto a granular material in reduced-gravity. In order to study the influence of the surface material, projectile shape, and gravity on the collision dynamics, we used two experimental configurations (one for terrestrial gravity experiments and one for reduced-gravity experiments) to perform low-velocity collisions into different types of granular materials: quartz sand, and two different sizes of glass beads (1.5 and 5 mm diameter). Both a spherical and a cubic projectile (with varying impact orientation) were used.

Using the data obtained from the collisions of the spherical projectile impacting quartz sand under terrestrial gravity, we validate an analytical model

linking the peak acceleration, the final penetration depth, and the collision duration to the collision velocity. The analytical model assumes that the drag force exerted by the material on the projectile is composed of both a (quasi-static) frictional and a hydrodynamical contribution. The transition from a frictional to a hydrodynamical drag regime is shown to occur at lower impact velocities in reduced-gravity trials than in terrestrial gravity trials, indicating that regolith has a more fluid-like behavior in low-gravity. The reduced quasi-static friction of a granular material under low-gravity conditions leads to a reduction in the strength, resulting in a decreased resistance to penetration and larger penetration depths (see also Sunday et al., this conference).

By analyzing the results, we also explore the limits of validity of the analytical model. With the goal of improving the collisional model currently used, we experimentally measure how the frictional and hydrodynamical contributions to the drag force model vary as a function of penetration depth. These models are important for understanding the mechanics of spacecraft - surface interactions in order to improve our knowledge about the landing phases of space missions, to prepare spacecraft operations, and to interpret the results of measurements made during surface interactions. The models involved for granular materials are also fundamental in rheology to connect fluid and solid media, with concepts of equivalent viscosity and non-linear dissipation.

Acknowledgement: The authors acknowledge funding support from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870377 (NEO-MAPP project).

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