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Studying the influence of target and projectile properties on low-velocity collisions

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Abstract

To improve our understanding of landing on small bodies and of asteroid evolution, we have performed new experiments of low-velocity impacts into granular material in both normal and reduced-gravity. We study the influence of the target material, the projectile shape and orientation, and the gravitational acceleration.

1. Introduction

The number of small-body missions involving surface interactions has flourished in recent years. From the recent Rosetta and Hayabusa missions, to the current and future missions such as Hayabusa 2, OSIRIS-REx and AIDA. Given the small escape velocities of these missions' targets, the impact velocities of the landers are likely to be small (10s of cm/s or lower) in order to minimize the risk of rebounding into space. The understanding of low-velocity impacts is, therefore, important for missions involving surface interactions and will influence the lander deployment strategy, the mission design and operations, and even the choice of payload for the future missions. In addition to being of high importance for future space missions, the physics of low-velocity collisions in low-gravity, and the mechanical properties of small bodies and regolith, also have consequences for our understanding of planetary accretion processes, planetary ring dynamics, cratering processes and asteroid geophysical evolution.

Previous analysis of the results of the Rosetta *Philae* landing indicated the possibility of studying the surface mechanical properties from the landing data. Indeed, using the crater depth and rebound dynamics Biele et al. (2015) [1], estimated the compressive strength of the two landing sites of Philae to be ~1 kPa, and at least 2 MPa, respectively. However, the difficulties faced by this mission highlighted the complexities of small-body landing, and also our lack of knowledge on the physical properties of the regolith that composes the surface of these bodies.

2. Low-velocity collisions into granular material

Given that asteroids are covered with substantial regolith [2], the landing can be seen as a low-velocity and shallow impact onto a granular material, with velocities in the order of cm/s to 10's cm/s. Impacting a projectile into a granular layer has become a classical problem in granular physics studied from theoretical, numerical and experimental points of view.

Our previous low-gravity experimental results of impacts of a spherical projectile into quartz sand [3] indicate that the transition from the quasi-static regime to the inertial regime occurs for impact energies two orders of magnitude smaller than in similar impact experiments under terrestrial gravity. The lower energy regime change may support the notion that the quasi-static regime reduces as the effective gravity becomes lower, but may also be due to the increased hydrodynamic drag of the target material in our initial experiments.

Starting from the previous experimental works on this problem, we intend to study the influence of the target material in low-velocity collisions in order to identify the reason for the observed regime change. We will also verify and further the previously evidenced scaling laws [e.g., 4-6] by including the influence of the target material type, the projectile shape and orientation. Finally, we will also study the influence of varying the gravitational acceleration.

3. New Experimental trials

To further our previous experimental findings [3] we have performed a new campaign of experiments in both normal and reduced-gravity. In these trials, two different projectile shapes are considered: spherical (10 cm diameter) and cubic (10 cm wide). See Fig. 1. Both are metallic (fabricated out of 2017 aluminum alloy) and weigh ~1 kg. The cubic projectile can be oriented to initially impact the material on one of its sides, one of its corner or one of its faces which allow us to observe the importance of the impact

Figure 1: The two projectiles used in the experiment. Left: spherical projectile in an experiment with quartz sand. Middle: cubic projectile positioned to impact the quartz sand on the projectile edge. Right: cubic projectile positioned to impact the basalt gravel on the projectile corner.

orientation on the collision dynamics. Two inertial measurement units consisting of three-axis accelerometers and gyroscopes are contained within the projectile. Diverse target materials are tested in order to study the link between the collision dynamics and the mechanical properties of the material. The materials used are quartz sand (1-2.5 mm), basalt gravel (6 – 14 mm), three different sizes of soda lime glass beads (1.5, 5 and 10 mm) and, finally, polystyrene beads (2.5 mm).

3.1 Static trials

In the static case (1*g* gravitational acceleration), the target material is contained in a container dimensioned to avoid any boundary-effects during the low-velocity impact. The projectile drop-height (and consequently the impact velocity) is controlled by an adjustable rod to which the projectile is attached (and released from) using an electromagnet. To make the experiments as reproducible as possible, the target material is removed and then poured back into the container before each trial, to get rid of any prestrain effects. From the accelerometer data we can obtain the values of the collision duration, penetration depth and acceleration peak at various impact speeds and for different target materials.

3.2 Reduced-gravity trials

Experiments have also been performed in reduced-gravity (~ 0.02 – 0.1*g* effective gravitational acceleration) using our novel drop-tower facility [7]. The drop tower uses a system of counterweights and pulleys to adjust the acceleration of the surface container and consequently to simulate a reduced gravitational acceleration (Fig. 2). These experiments will allow us to study how the collision characteristics change with varying gravitation acceleration.

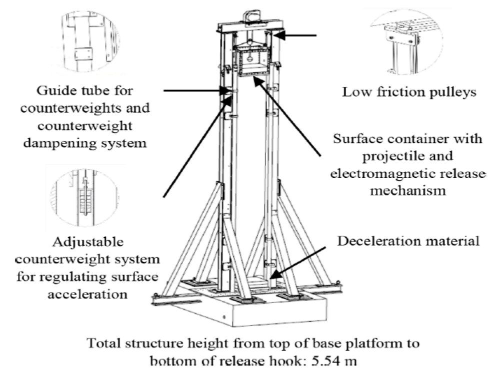

Figure 2: Isometric line drawing of the experiment and existing drop tower structure from [7]

4. Results

We will present our findings for the trials performed under both terrestrial and reduced-gravity conditions. Specifically, we will show how the collision dynamics (duration, peak accelerations, penetration depth) are influenced by the different target materials and the projectile shape for varying impact velocities.

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References

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