An experimental study on low-velocity low-gravity collisions into granular surfaces

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The Japanese Space Agency (JAXA) is scheduled to launch the asteroid sample-return mission, Hayabusa-2, to target body 1999 JU_3 in December 2014 [1]. The spacecraft will arrive at the C-type near-Earth asteroid in mid-2018 and deploy several science payloads to its surface. Among these payloads is a 10-kg lander, the Mobile Asteroid Surface Scout (MASCOT), provided by the German Space Agency (DLR) with cooperation from the Centre National d'Etudes Spatiales (CNES). MASCOT will reach the asteroid's surface with an anticipated impact speed of 10–20 cm/s. In addition to housing four instruments for in-situ science investigation, MASCOT contains a mobility mechanism that will correct its orientation and enable it to "hop" to various measurement sites [2].

Based on thermal infrared observations [3,4,5] and previous space missions [6,7], it is strongly believed that 1999 JU_3 is covered by loose regolith. The asteroid's granular surface, in combination with the low surface gravity, makes it difficult to predict the lander's collision behavior from existing theoretical models. However, to ensure that MASCOT can successfully fulfill its mission, it is vital to understand the rebound dynamics of the lander in the asteroid surface environment.

The objective of this work, derived from the needs of current and future asteroid missions, is to present an experiment designed to study low-velocity, low-gravity collisions into granular surfaces. The experiment measures the amount of energy lost during impact via a projectile's coefficient of restitution and also the acceleration profile of the projectile during collision.

The key challenge to designing an asteroid collision experiment is finding a way to simulate reduced gravity conditions on the Earth so that the prevailing forces in micro-gravity collisions can be reflected in the experimental results. The proposed way to achieve this goal is to let a free-falling projectile impact a surface with a constant downward acceleration, or an acceleration less than that of gravity, so that the effective surface acceleration felt by the grains at impact is very small. In reducing the effective surface acceleration of the granular material, the medium's inter-grain cohesion forces will become more important compared to its weight force [8], and the properties of the granular material will become more representative of those on an asteroid's surface.

The concept of effective acceleration drives the design of this experiment and results in the following key features: First, the granular surface is given a constant downward acceleration using an Atwood machine, or a system of pulleys and counterweights. Next, the projectile and surface are simultaneously released from rest using a magnetic solenoid and hook assembly. The starting height of the surface container and the initial separation distance between the projectile and surface are variable and chosen to accommodate collision velocities of 10–20 cm/s and effective accelerations of 0.3–1.0 m/s^2. Finally, wireless accelerometers, placed on the surface container and in the projectile, provide acceleration data, while high-speed cameras capable of recording 100,000 frames per second capture the collision and act as secondary data sources. The experiment is built into an existing 6-m drop-tower frame and requires the custom design of all components, including the projectile, surface sample container, release mechanism, and deceleration system. This work will present the detailed design of the asteroid-collision experiment as well as a discussion on the planned experimental trials. The experimental results, once obtained, will be used to create a scaling law that will help predict a projectile's rebound and acceleration behavior during a low-velocity collision into a granular surface in micro-gravity conditions.

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