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PRIME: Studying Low-Velocity Impacts in Microgravity

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Abstract

We report on the results of the third PRIME (Physics of Regolith Impacts in Microgravity Experiment) campaign on-board the NASA C-9 airplane in August 2014. The objective of the PRIME experiment is to study low-velocity impacts of cm-sized particles into dusty regolith under asteroid level- and microgravity conditions. First data analysis shows that this latest campaign successfully extended the previous measurements of coefficient of restitution and ejecta velocities to much lower impact energies.

1. Introduction

The dusty regolith of ring particles, proto-planetesimals, planetary satellites, and asteroids is subject to collisions at low velocities (v ~ 0.01-100 m/s) in addition to the hypervelocity ($\gtrsim$ 1 km/s) impacts from the interplanetary micrometeoroid flux. In some regions of Saturn's rings, for example, the typical collision velocity inferred from observations by the Voyager spacecraft and dynamical modeling is a fraction of a centimeter per second [3]. These inter-particle collisions control the rate of energy dissipation in planetary rings and the rate of accretion in the early stages of planetesimal formation. Dust on the surface of planetary ring particles and small (1 cm – 10 m) planetesimals helps dissipate energy in the collision, but may also be knocked off, forming dust rings in the case of ring particles and slowing or inhibiting accretion in the case of planetesimals. Secondary impacts on asteroids and small planetary satellites occur at speeds comparable to the escape velocity from the object, or a few m/s for objects ~10 km in radius or smaller. We report on impact experiments performed during the third PRIME campaign in the reduced-gravity environment of the NASA C-9 aircraft at speeds between 4 and 53 cm/s into simulated regolith.

2. The PRIME Experiment

The Physics of Regolith Impacts in Microgravity Experiment (PRIME) flies on the NASA C-9 and can perform impacts into granular materials at speeds of ~5-50 cm/s in microgravity. The experiment is conceptually identical to The COLLisions Into Dust Experiment (COLLIDE), which has flown on the space shuttle twice [1, 2] and has flown on the NASA KC-135 plane during two previous campaigns in 2002 and 2012 [2].

Impacts are performed in vacuum as ground-based experiments at 1*g* have consistently shown a strong effect of ambient air on the behavior of regolith in low-velocity impacts. Projectiles are spherical particles launched by a spring designed to provide the desired impact energy. The target materials studied in the work presented here are quartz sand and JSC-1 lunar regolith simulant, filled to a depth of 2 cm in the target tray. Projectile materials are quartz, brass, and stainless steel, providing a range of masses with the same projectile radius. Impacts are performed in isolated chambers (Figure 1) and up to 8 experiments can be performed per flight.

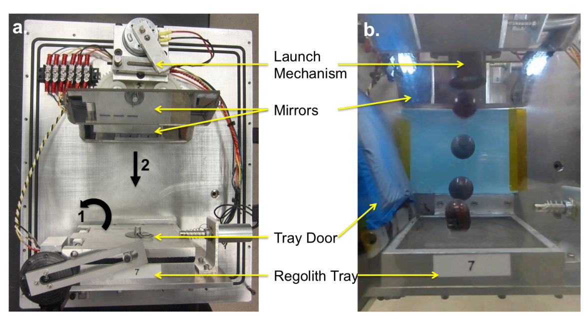

Figure 1: PRIME hardware inside the vacuum box. a. Before flight. Regolith is stored in the regolith tray that opens (1) to allow for the launched marble (2) to impact. The launch mechanism mainly consists of a spring, which constant, in coordination with the marble mass, determines the launch velocity. b. During flight. Montage of 7 recorded frames of a marble impact and rebound on a JSC-1 bed. The marble is much slower after impact.

The data collected consists of video recordings of the produced impacts, taken with a high-speed video camera at 120 frames per second. The camera views the impact with the line of sight parallel to the target surface and perpendicular to the projectile trajectory in the image plane (Figure 1.b). Two mirrors inside the impact chamber provide additional views of the impact (Figure 2.b).

3. Results and First Data Analysis

During the PRIME-3 flight campaign in August 2014, the experiment flew 4 times allowing for the recording of up to 8 impacts per flight. As asteroid gravity-level parabolas were flown during this campaign, 7 impacts were performed at 0.05g.

The successful impacts observed resulted in 9 marble rebounds and 15 impacts with ejecta (7 of which at 0.05g). Figure 2 shows an example of an impact into sand at 26 cm/s in microgravity.

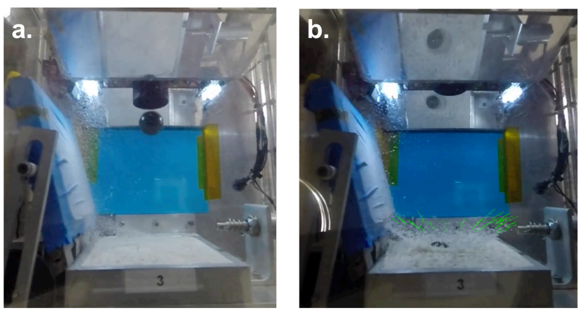

Figure 2: PRIME impact into sand in microgravity, a. just after marble launch, b. just after marble impact. The trajectories of manually tracked ejecta particles are shown in green.

For each rebound observed, the coefficient of restitution of the impact can be measured. Figure 3 shows that the PRIME-3 campaign successfully extended the region of the parameter field explored by investigating impacts at velocities lower than observed during the COLLIDE campaigns [1].

For each collision with ejecta, the highest number possible of individual ejected particles was tracked manually. For most of the impacts, the ejected particles had a normal velocity distribution. Figure 4 shows the mean ejecta velocities for the microgravity impacts compared to the former COLLIDE and PRIME campaigns. Here again, the PRIME-3 campaign successfully allowed for the exploration of much lower impact energies than in previous campaigns.

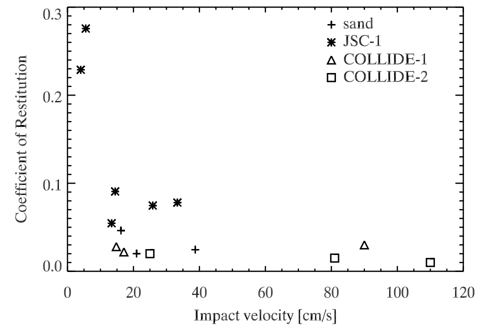

Figure 3: Coefficients of restitution of a marble on a bed of regolith measured during the PRIME-3 campaign. Data from the COLLIDE-1 and -2 campaigns is also shown [1].

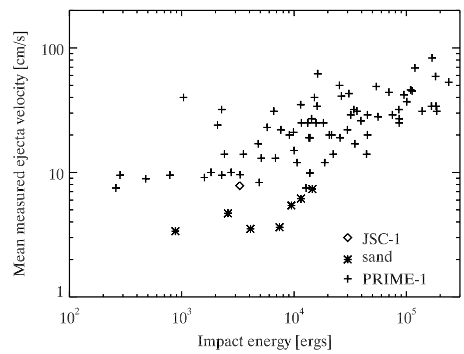

Figure 4: PRIME mean ejecta velocity in relation to the impact energy for microgravity impacts. Data from previous PRIME campaigns [2] is also shown.

Acknowledgements

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