Regolith behavior under asteroid-level gravity conditions: low-velocity impact experiments

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The dusty regolith covering the surfaces of asteroids and planetary satellites is very different from terrestrial soil particles and subject to environmental conditions very different from what is found on Earth. The loose, unconsolidated regolith is produced by hypervelocity micrometeoroid impacts on asteroids and planetary satellites, leading to angular particles in a broad size distribution. In contrast, terrestrial soils are formed by erosional processes leading to more rounded particles with narrower size distributions. In addition, the regolith covering small airless bodies is evolving in a low-pressure and low-gravity environment.
The response of this planetary regolith to low-velocity impacts, such as those that may accompany manned and unmanned exploration activities, may be completely different than what is encountered in terrestrial regolith. Further, the microgravity environment of small asteroids and moons can lead to new behaviors. Dust particles from regolith pose a hazard to equipment. The regolith itself is a possible resource for in-situ processing of minerals and elements, and equipment may need to be anchored to the loose regolith. Experimental studies of the response of planetary regolith in the relevant environmental conditions are thus necessary to facilitate future exploration activities.
We carried out a series of impact experiments into simulated planetary regolith in zero- and reduced-gravity conditions using two experimental setups and a range of microgravity platforms. The Physics of Regolith Impacts in Microgravity Experiment (PRIME) flew on-board the NASA KC-135 and C-9 airplanes for a total of 3 flight campaigns recording impacts into granular materials at speeds of ~4-230 cm/s. An identical experimental setup (PRIME-Drop) was used in the laboratory drop-tower of the Center for Microgravity Research (CMR) at the University of Central Florida. This drop-tower allows for 0.75 s of microgravity and impacts into granular material could be performed at speeds of ~30-150 cm/s. The COLLisions Into Dust Experiment (COLLIDE) is conceptually close to the PRIME setup. It flew both on the Space Shuttle in 1999-2001 and more recently on the Blue Origin New Shepard rocket, recording impacts into simulated regolith at speeds between 10 and 120 cm/s.
Results of these experimental campaigns found that there is a significant change in the regolith behavior with the gravity environment. In a $10^{-2}g$ environment, no rebound of the impactor was observed and ejecta production was very low. Once at microgravity levels ($<10^{-4}g$), the lowest impact energies produced impactor rebound without ejecta production. Under these conditions, we observed that the coefficients of restitution of a spherical marble on a bed of regolith decrease by a factor of 10 with increasing impact speeds from ~10 cm/s up to 100 cm/s. This means that, under a certain impact speed, the impactor is much more likely to bounce off the bed of regolith. At the same time, the production of ejecta was observed only for impact speeds above ~25 cm/s and the velocity distributions of ejected particles show a power-law dependence on the impact energy with an index of ~0.5. This means that, at these low velocities, the average ejecta speed scales with the impact speed and the propagation of the impact energy through the regolith is carried out by displacement of the material rather than by a large amount of discrete grain collisions. These results on regolith response to low-velocity impacts under microgravity conditions indicate that there should be an optimized impact speed for the touchdown of a spacecraft on an asteroid surface, combining a low coefficient of restitution to avoid bouncing off, and low-velocity ejecta production, to avoid hazards to spacecraft hardware.

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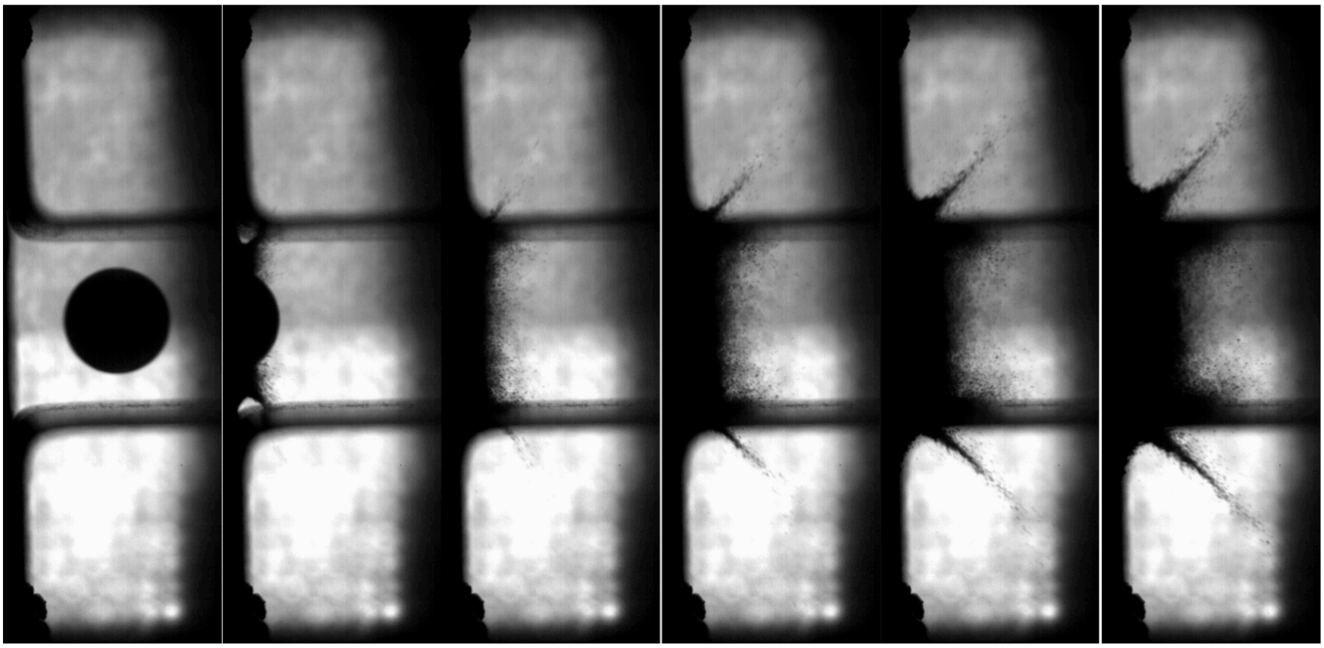

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