

## Numerical Simulations of Low Speed Impacts on to Granular Material in Micro-gravity

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We present a study of low-speed impacts on to granular material, in order to better understand spacecraft interactions with asteroid regolith. We have developed software that can simulate the physical interaction of a spacecraft with a regolith bed as it lands. In order to ensure that the code accurately models reality, we calibrate the code by comparing simulations of low-speed impact experiments on to granular materials to laboratory results. These experiments were done with a variety of granular materials at speeds on the the order of a few m/s. We demonstrate that the simulations are able to accurately match the experimental results in Earth gravity. Then, we are able to extend our results to scenarios that are difficult to reproduce in the lab (such as low-gravity environments, and experiments that involve the actual spacecraft or lander). By performing similar simulations in a low-gravity environment, we found that the amount of penetration an intruder is able to achieve does depend on the local gravity. However, unlike previous results that suggested the gravity dependence is due to a change in the lithostatic pressure, we have shown that this is not the case. Instead, this variation is likely due to a change in the granular flow properties with gravity. Further numerical and experimental results (at micro-gravity levels) are required to develop a predictive theory for penetration into regolith beds in low-gravity environments. The results of these studies can enhance the science return of sample return missions to asteroids. By creating an atlas of simulation results, we can reconstruct the moment of a spacecraft's interaction with the surface, allowing us to make some determination of the grain properties (size, surface roughness, shape). Specifically, our simulations have been used to study the interaction of NASA's OSIRIS-REx mission with its target asteroid (101955) Bennu. OSIRIS-REx's sampling device, TAGSAM, will impact Bennu's surface at 10 cm/s, providing a unique opportunity to study the response of granular material to a low-speed impact in micro-gravity.

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