Interacting with granular materials on small body surfaces: a case study based on the MMX rover

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Small bodies, such as asteroids, comets, and moons, can be covered by a layer of loose grains, referred to as regolith. The shape and size distribution of the surface grains, not to mention their bulk material properties, can vary drastically from one body to another. The low-gravity found on small bodies coupled with the surfaces’ unknown properties makes it difficult to predict and understand the macroscopic behavior of the regolith. Fortunately, recent missions like OSIRIS-REx (NASA) and Hayabusa2 (JAXA) have provided us with new and fascinating insights into this problem [1, 2]. The OSIRIS-REx sampling mechanism met little resistance when it touched down the surface of the asteroid Bennu [3]. In contrast, the MASCOT rover deployed by the Hayabusa2 spacecraft rebounded several times off of the surface of the asteroid Ryugu [4]. Though surprising, the fluid-like response of Bennu’s surface and the rebound of the MASCOT rover are not completely unexpected. In this work, we examine how granular materials behave differently under terrestrial and low-gravity conditions by analyzing lander-regolith interactions within the context of different phenomenological models.

First, we present the results from low-gravity drop-tower impact experiments [5] and soft-sphere discrete element method simulations [6] in order to show how the landing and sinking behaviors of a projectile or lander scale by gravity. With the help of this experimental and numerical data, we introduce a new collision model that that can be used to predict penetration depth for slow granular impacts on small body surfaces [7]. If the penetration depth of the impactor is known, then this model can also be used to constrain the bulk density and the internal friction angle of a surface material. Next, we discuss how gravity influences other types of granular interactions, like the behavior of wheeled rovers on planetary surfaces. We use the same scaling relationships as those that describe impact behavior to illustrate how rover traction varies as a function of both driving speed and gravity. This second study is inspired by the MMX rover, which will be deployed to the surface of Phobos during the upcoming Martian Moons eXploration mission (JAXA) [8]. Understanding the relationship between rover traction and gravity is important not only for surface operations, but also for surface science. Based on the information that we gain from observing wheel-regolith interactions, such as measured rover sinkage and tracked particle motion, we can estimate the bulk properties and strength of Phobos’ surface regolith using predictive models from the fields of terramechanics and granular mechanics. We conclude this work by discussing the link between a rover’s driving behavior and material properties of regolith like friction and cohesion.

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