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Wheel-regolith interactions on small-body surfaces

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Abstract

We conduct experiments using a single-wheel testbed and simulations using the Soft-Sphere Discrete Element Method to study wheel-regolith interactions on small-body surfaces. We analyze wheel sinkage and traction on different surface materials and we discuss the influence that low-gravity has on rover maneuverability.

Introduction

Wheeled locomotion systems have been successfully operated on the surfaces of the Moon and Mars for decades. Though wheeled rovers have been proposed for small-body exploration [1], they have yet to be tested on the surface of a small moon or asteroid. Driving on a granular surface in a milli or micro-gravity environment will be challenging, but possible. In fact, a rover will be deployed to the surface of Phobos as part of the upcoming Martian Moons eXploration mission [2]. The MMX rover will not only demonstrate the feasibility of driving in low-gravity, but it will greatly improve our understanding of regolith dynamics on small body surfaces.

In addition to the navigation cameras, the MMX rover includes two additional cameras, known as the WheelCams. These cameras will capture the direct interaction between the rover's wheels and the surface of Phobos [2]. The WheelCam images will be used to determine surface properties like grain size distribution and shape, friction angle, cohesion, and bearing strength. In anticipation of the MMX mission, we are using experimental and numerical methods to develop techniques to analyze and interpret the WheelCam images. In fulfillment of this objective, we are conducting single-wheel driving tests on different surface materials and are studying the influence that friction, cohesion, and gravity have on the flow behavior of the regolith and the driving performance of the rover.

Experiments

The WheelCam testbed at ISAE-Supaéro (Fig. 1) [3] is being used to analyze wheel and regolith behavior from the perspective of the MMX rover WheelCams. In this set-up, a motor is used to rotate a 3D printed wheel at a constant speed, and a set of horizontal and vertical sliders allow the wheel to move freely in the horizontal and vertical directions. Various sensors are used to measure

the sink and slip of the wheel, and two cameras are positioned to capture the wheel-regolith interaction from the same perspective as the MMX WheelCams. Tests are conducted in different granular materials in order to catalogue the resulting trench forms and sinkage levels, and to capture any observable disturbances caused by the wheel's grousers.

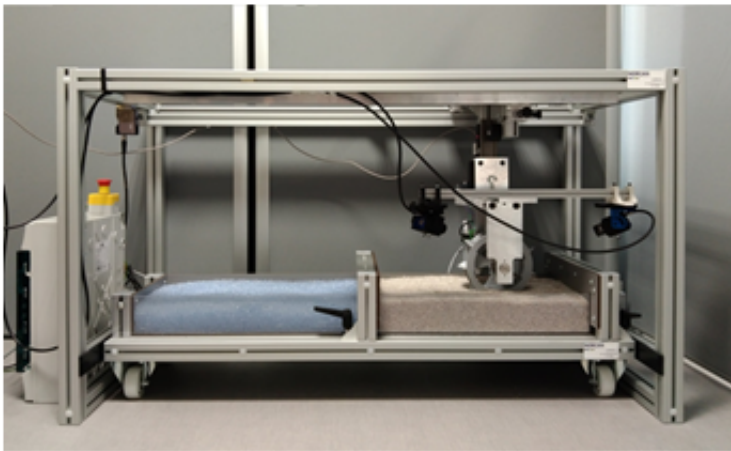


Fig. 1: The ISAE-Supaéro WheelCam testbed [3]

Simulations

In addition to conducting experiments, we also simulate the rover wheel traversing a bed of granular material using the Soft-Sphere Discrete Element Method (SSDEM) and the open-source code Chrono [4, 5]. The wheel geometry is based on a simplified version of the MMX rover wheel design [6], and the granular bed consists of approximately 200,000 spherical particles which are 5.5-6.5 mm in diameter (Fig. 2). In the simulations, the wheel sinks into the bed under gravity and then rotates at a constant and controlled velocity. The wheel's behavior is evaluated using metrics like sinkage and slip, and its performance is compared for different types of surface materials (i.e., different friction and cohesion levels) and different gravity levels.

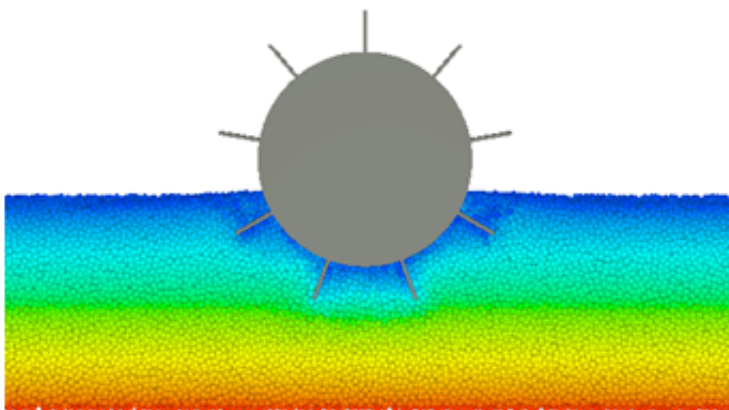


Fig. 2: Simulated rover wheel sinking into a bed of cohesion-less spherical beads under Phobos gravity. The particles are colored by initial distance from the surface of the bed.

Results

By combining the experimental and numerical results, we can analyze wheel-regolith interactions for a wide range of material cases. We see that wheel sinkage varies drastically according to the friction

angle and the cohesion of the surface material. However, the sinkage remains constant across different gravity levels. This observation is consistent with findings from parabolic flight experiments [7]. The numerical simulations allow us to study the flow of the regolith directly under the rover wheel in more detail. Recent impact experiments have shown that granular material becomes fluidized more quickly under reduced gravity conditions [8]. Here, we look for the transition from the quasi-static to the inertial flow regime when the rover starts moving to see if fluidization of the material in low-gravity restricts the maneuverability of the rover.

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