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Numerical simulations of asteroid surface interactions: application to MASCOT lander and Hayabusa2 sampling mechanism

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Abstract

We ran several sets of numerical simulations to model the interactions between Hayabusa2 sampling mechanism and a granular surface under Ryugu's low gravity, in order to study the cratering process, compare with the actual sampling, and assist potential following samplings. We also continued our simulations of Hayabusa2 lander MASCOT, in order to better understand a posteriori its trajectory and learn about the regolith properties.

1. Introduction

The JAXA Hayabusa2 mission, currently visiting near-Earth asteroid Ryugu, has released the DLR/CNES lander MASCOT [1] last October, which successfully landed on the asteroid surface. Since then has begun a reconstruction work to understand the lander's trajectory, as well as constraining Ryugu's surface physical properties. In February 2019 took place the first sampling. Hayabusa2 on-board cameras were able to capture the sampling, i.e., the impact of the sample horn with the surface and the outcome on the outside parts of the horn of the impact of the projectile.

To interpret these events as well as to predict new ones, we modeled the interactions of both MASCOT and Hayabusa2 sampling mechanism [2] with a granular surface under Ryugu's low gravity. Our aim is to increase our understanding of the surface properties by interpreting the observations, as well as to expand our knowledge of behaviors in low-gravity environments for different impact speeds (19 cm s^{-1} to 300 m s^{-1}).

2. Method

Simulations were done using the Soft-Sphere Discrete Element Method (SSDEM) version of the N-body code `pkdgrav` [3]. For both cases, we consider a regolith bed at rest inside a cylinder under Ryugu's gravity ($\approx 1.2 \cdot 10^{-4}$ m s^{-2}), and used a Gaussian particle size distribution with gravel-like friction properties. We model the sampling mechanism with walls whose contact with the surface is neglected and considering only the effect of the projectile's impact on the surface. Both the projectile and MASCOT need to react to particles, and we use inertial walls, or "reactive" walls, enabling them to react to particles and either bounce or penetrate inside the bed.

From Hayabusa2 optical navigation camera (ONC), Ryugu appears covered of boulders and large rocks, that MASCOT could possibly have impacted. Following our work on MASCOT impacting a regolith bed, [4], we consider now a boulder (an aggregate of particles) inside or over the bed, and in a second time a particle wall (particles stuck to a wall), and we determine the outgoing-to-incoming speed ratio that can result from a 19 cm s^{-1} impact.

For Hayabusa2 sampling mechanism, we consider a regolith bed with spherical particles small enough (0.25 cm mean radius) to go through the filter located near the top of the sampling horn, whose aim is to prevent jamming in the storage and transfer unit.

3. Results

3.1. MASCOT bouncing

We first conducted simulations of MASCOT impacting a rigid ≈ 25 cm–diameter boulder, under or on the regolith surface. We find that, for a buried boulder, the outgoing-to-incoming speed ratio generally increases with the height of the boulder. If the boulder is buried under a 15 cm granular layer, or located near the impact point but never in contact with MASCOT, it has no influence on the outcomes. Otherwise, the results become much more stochastic. We find that a surface boulder does not necessarily mean a high outgoing-to-incoming speed ratio. Even with a hard boulder, MASCOT can hit multiple times the boulder and then bounce, leading to a speed ratio as small as 0.3.

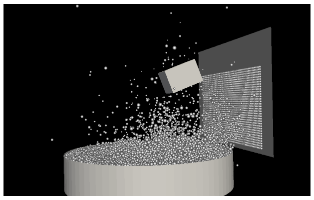

Figure 1: Snapshot of a simulation of MASCOT impacting the regolith and then a particle-covered wall.

We also looked at MASCOT impacting first a regolith bed and then a rigid wall covered of particles (see Fig. 1). Particles stuck to the wall have the same physical properties as the ones in the regolith bed (normal coefficient of restitution of 0.5). Considering initial impact angles between $15°$ to $45°$ from the vertical, we get for the whole impact (bouncing on the bed then on the wall) total speed ratios from 0.09 to 0.33. Thus, the total interaction can result in very low speed ratios, even considering a rigid wall/rock.

3.2. Hayabusa2 sampling mechanism

We first characterized the 300 m s^{-1} impact in the regolith bed without the sampling horn and find similar results as 1-g experiments [5]. Also, we find that particles are mostly ejected with an angle around $50°$ and that early ejecta from upper layers can be represented with the Z-model [6].

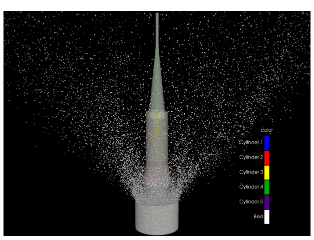

Figure 2: Snapshot of a sampling simulation.

We then added the sampling horn (see Fig. 2) and monitored the number of grains in each part of the horn for several simulations. We usually get at least one collected particle in the top part, meaning that for most of our simulations the scientific aim of Hayabusa2 of collecting 100 mg is fulfilled after 1 s [2]. Accounting for the teeth at the bottom of the horn and considering smaller grains would lead to an even higher sample amount. We also find that a second shot 0.2 s after the first one does not necessarily increase the number of particles in the highest parts of the sampler.

4. Summary and Conclusions

Low speed ratios of MASCOT bouncing are compatible with hard boulders or surfaces, due to the angular geometry of the lander. Thus, material properties cannot be inferred on the sole basis of the speed ratio. We also modeled a 300 m s^{-1} impact and were able to find similar patterns as previously stated from 1 g experiments. Finally, the Hayabusa2 sampling mechanism from our simulations with a granular bed almost always fulfills its scientific aim of collecting 100 mg.

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