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# Numerical simulations of a lander's interaction with a low-gravity asteroid regolith surface: application to MASCOT on board Hayabusa2

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## Abstract

We ran a campaign of simulations of Hayabusa2's lander MASCOT impacting the regolith surface of its target asteroid Ryugu, and looked at the outcome for different parameters linked to the characteristics of the impact and of the regolith. The aim is to provide valuable information a posteriori on the regolith properties from data on MASCOT's first impact and to support the landing site selection.

## 1. Introduction

The JAXA Hayabusa2 sample return mission is currently visiting the C-type near-Earth asteroid Ryugu and will come back to Earth in 2020 with samples. In early October, Hayabusa2 is planed to release the DLR/CNES lander MASCOT (Mobile Asteroid SCOuT) [1] that will perform in-situ investigations of Ryugu's surface. However, since the surface's properties of Ryugu are still poorly constrained, the observation by the cameras onboard Hayabusa2 of the traces left by MASCOT at first impact will provide insightful information about the nature of the regolith and simulations of the impact can help inferring unobserved properties.

We performed hundreds of numerical simulations of MASCOT's low-speed impact on the surface, for different impact and regolith characteristics. The purpose is both to support the landing site selection and finding MASCOT on the asteroid, as well as to expand our knowledge of Ryugu's regolith from the observations of MASCOT's traces.

## 2. Method

Our simulations were performed with the N-body gravity tree code *pkdgrav*, using a Soft-Sphere Discrete Element Method (SSDEM) to compute interactions between the regolith grains [2]. In our simulations, regolith particles are initially at rest in a 75-cm radius cylinder, under Ryugu's gravity (about $2.5 \times 10^{-4}$ m s$^{-2}$). The particle size distribution is assumed to be gaussian with a 1-cm mean radius, a 33% standard deviation sigma, and a cut-off at one sigma. We considered two types of friction between the grains: a moderate friction and a gravel-like one, which differ from their angles of repose, as well as three bed depths (15 cm, 30 cm, and 40 cm). MASCOT is numerically made of "reactive" walls (inertial walls that interact with particles), joined in a 10-kg cuboid with a small prominence representing the spectrometer MicrOmega. The impact speed is set at 19 cm s$^{-1}$, for three different orientations (landing flat, with its back corner first or with its front one) and five impact angles (from 0 to 60° from the vertical). We analyzed the behavior of MASCOT after the impact, in particular the traveled distance, its speed and spin after impact, and the traces left on the surface after the first bounce, which will be observed from the main spacecraft. These traces are linked to the distance MASCOT will travel and their observations will be valuable for an engineering purpose to deduce MASCOT's final position and a posteriori to deduce regolith properties.

## 3. Results

### 3.1. Influence from sensitive parameters

The largest traveled distances as well as the highest outgoing speed and spin are obtained with grazing impacts, with MASCOT landing on its back corner first, on a shallow gravel-like-regolith bed [3].

Moreover, a moderate-friction regolith results in a more homogenous and deeper crater than a gravel-like regolith (see Fig. 1). A back-corner-first orientation and gravel-like regolith combination leads to a recognizable feature on the ground: a two-hole crater (see Fig. 1).

In order to expand our results to multiple bounces, we also checked the influence of impact speed. We find that the outgoing-to-incoming speed ratio (or coefficient of restitution CoR) seems to change (here, to increase) only for very slow incoming speeds (about 2 cm $s^{-1}$). As expected, slow impact speeds lead to shallower craters and less pronounced features.

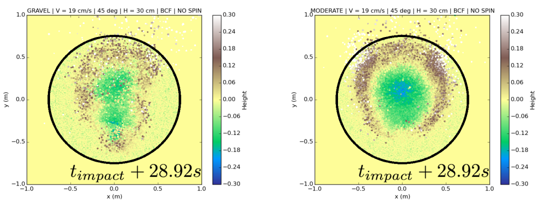

Figure 1: Characteristics of the trace left by MASCOT on the regolith (in cm) 29 s after the impact for gravel-like (left) and moderate-friction regolith (right).

### 3.2. Presence of a boulder

Since the resolution of Hayabusa2's optical navigation camera may not be able to detect relatively small boulders at the moment of landing site selection, we ran simulations with a grains' aggregate representing a 5-kg boulder in the regolith bed. We found that a boulder buried at a depth of 15 cm in the regolith bed has no big influence on the results presented previously. However a boulder on the surface or just covered by a thin layer of regolith significantly increases the outgoing speed and the stochasticity of the impact. We also checked that buried boulders located on the side of the impact point have no big influence on MASCOT's behavior.

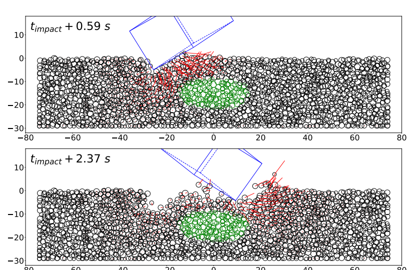

Figure 2: Cross-section snapshots of MASCOT (in blue) impacting the regolith bed, taken 0.59 s and 2.37 s after the impact. Green particles represent the boulder and red lines are particle 2-D projected velocities.

## 4. Summary and Conclusions

We found that several sensitive parameters play a role on the outcome of the impact, linked to MASCOT's impact geometry or to the regolith characteristics (friction and bed depth). The speed of the impact does not seem to change the CoR whereas it has an expected influence on the depth of the traces and the traveled distance. We are currently running simulations to see the influence of a slope on the impact, as the lander may encounter non-flat surfaces as it repeatedly bounces on the asteroid. We also plan to investigate the influence of a power-law size distribution for the grains and to add cohesion to our model, as well as to compare our results with the real MASCOT impact(s) expected for the beginning of October. This database of simulations will be used to infer regolith properties of Ryugu from MASCOT's traces.


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