Landing MASCOT on asteroid 1999 JU3: solutions for deploying nanosats to small-body surfaces .

S. Tardivel[1,3], E. Canalias[2], M. Deleuze[2], A. T. Klesh[1], D. J. Scheeres[3]. [1]Jet Propulsion Laboratory, California Institute of Technology (4800 Oak Grove Drive, Pasadena CA 91101, simon.tardivel@jpl.nasa.gov), [2]Centre National d'Etudes Spatiales (18 avenue Edouard Belin, Toulouse 31055 Cedex, France), [3]University of Colorado Boulder (429 UCB, Boulder CO 80309-0429, USA).

Introduction and Motivation

Hayabusa-2 left the Earth on December 2nd 2014 (UTC). The JAXA spacecraft should reach its target, 1999 JU3, in July 2018 and study it for a year and a half. The probe's main goal is to collect at least one sample of the asteroid and bring it back to Earth, in December 2020. But Hayabusa-2 also carries a small landing package called MASCOT[1], a joint project by DLR and CNES, that will perform in-situ investigations. The research presented will show the analyses on MASCOT's deployment and how it can be optimized, within constraints.

This study uses the surface model currently available[2]. This approach involves modelling the asteroid surface by its fully faceted shape (here obtained by lightcurve), and considering a stochastic rock collision model.[3]

The lander MASCOT

The Mobile Asteroid Surface Scout (MASCOT) is a small lander, weighting only 10 kg and carrying four scientific payloads: CAM (DLR visible light camera), MARA (DLR radiometer, inherited from Philae's MUPUS-TM), MAG (magnetometer, similar to Philae's ROMAP) and MircrOmega(Infrared hyperspectral telescope, like Philae's CIVA/MI from the French IAS institute).

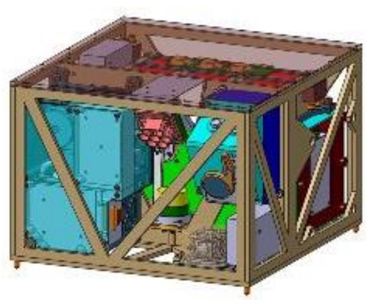

Figure 1. Design of the lander MASCOT

After the arrival of Hayabusa-2 at 1999JU3, a phase of asteroid characteristation will start. During this phase, realistic models based on observational data will be derived for the asteroid's shape, gravity field and surface temperature, among others. MASCOT will then be separated and it will descent to the asteroid surface. The exact separation date is yet to be chosen, but it should ideally be after the asteroid characterization phase (beginning of 2019) and before JAXA's impactor experiment, planned for the end of August 2019.

MASCOT descent and landing will be totally passive, as it has no propulsion system neither anchoring system whatsoever. Therefore, a bouncing trajectory on the asteroid's surface before stabilization seems unavoidable. Moreover, the lander is not equipped with solar panels, so its lifetime and capability to perform science is strictly limited by the duration of the batteries. As MASCOT will start consuming energy shortly after separation from the mother-ship, one of the challenges of the mission analysis studies is to be able to predict the duration of the bouncing trajectory, and if possible, to shorten it with the aim of maximizing the time available for in-situ science activities. When the first science sequence is completed, the mobility system will make MASCOT *jump* to another asteroid location in order to perform other experiments.

Optimizing the deployment of MASCOT

As a secondary payload, the delivery of MASCOT is not the main objective of the mission. The safety of the mothership Hayabusa-2 is the prime concern and a minimum altitude of 100 m is imposed for the deployment. Moreover, the spacecraft baseline strategy for the release is to adopt a inertial-hovering configuration, positioned on the line asteroid-Earth, its main antennas always pointed at the Earth. This line defines the ***z***-axis of a frame centered on Hayabusa, the ***x***-axis being oriented towards the sun, and ***y*** completing the trihedron. Still in this nominal strategy, the lander should separate at 5 cm/s (inertial speed) with its mothership, in the plane ***zy***, with an elevation of -15° and an azimuth of 90°.

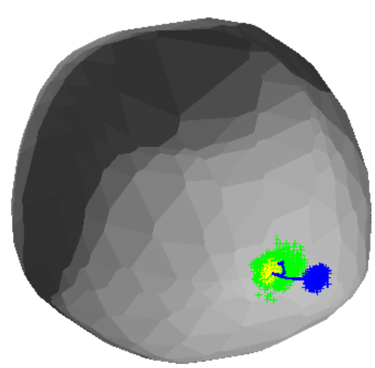

Figure 2. Example of a deployment of MASCOT to 1999 JU3, on the 20th of January 2019, around 4°W longitude 3°N latitude.

This strategy completely determines, for a given deployment data, all variables (nominal position and velocity) of the release. Simulations are presented that describe the permance of such a strategy considering uncertainties the GNC position. However, much better performance can be obtained by rotating Hayabusa-2 on its ***z***-axis, thus maintaining complete communication link with Earth but orienting the MASCOT panel in the prograde direction of the asteroid rotation. For instance, the landing spread can be cut by half with this simple, minor change in the release strategy (see Fig.2 and 3.).

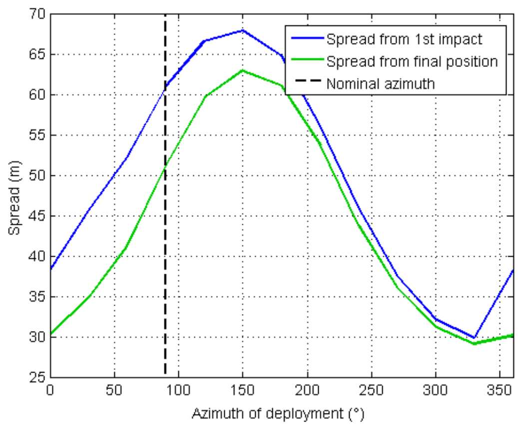

Figure 3. The accuracy of the deployment of MASCOT to the surface depends on the orientation of the spacecraft at the moment of release. The graphs shows a possible optimization for a deployment on the 20th of January 2019.

Paving the way for nanosat exploration

Small landers, like MASCOT, and the Japanese nanorover Minerva, showcase the potential for small craft to provide new measurement capabilities to scientists, at a notionally lower cost. Their limited size constrains the science objectives (and instruments) to be extremely focused, but the continued miniaturization of parts has yielded impressive capability. Indeed, the proliferation of so-called "CubeSats" in low-Earth orbit has motivated the investigation of nanospacecraft beyond Earth – JPL's INSPIRE [4] and MarCO missions will pave the way for advanced technologies (miniaturized deep space transponder, instruments, and software). And NEAScout (Near Earth Asteroid Scout) [5] will demonstrate the ability for nanospacecraft to depart from Earth and travel independently to a small-body object for scientific observation.

Between MASCOT, INSPIRE, and NEAScout, the capability will soon exist for Earth-based small spacecraft to travel and then land upon small objects. With a multitude of unexplored asteroid families, the target list is long. Indeed, several companies have now been established to survey and retrieve resources of commercial interest. Yet, the possibility of expanding our scientific exploration capability is even more astounding – the low cost of these missions allows for many more mission opportunities than has been traditionally supported.

Nanospacecraft have significant disadvantages – limited payload, power, and propulsive capacity most notably. Yet, augmenting the current portfolio of larger missions with targeted small missions may provide a new strategy for affordable scientific missions spanning the solar system.

References

[1] Lange et al. (2010), *Proceedings of the 7th IPPW*. [2] Müller et al. (2011), *Astronomy & Astrophysics, 525* [3] Tardivel et al. (2014), *Journal of Spacecraft & Rockets, 51 (6)*, p. 1857-1871. [4] Klesh et al. (2013) *AIAA Space*. [5] Castillo et al. (2014) *Small-Body Assesment Group*

Figure 2. INSPIRE Flight Spacecraft, ready for launch