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Exploring small bodies: Nano- and microlander options derived from the Mobile Asteroid Surface Scout

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Abstract

The MASCOT lander currently flying on-board of the Japanese Hayabusa2 spacecraft, both set to explore the C-type Near-Earth Asteroid (162173) Ryugu, is not the first, but certainly one of the more complex nanolander systems having been designed for being carried along a bigger interplanetary spacecraft. Other concepts and current missions have shown the attractiveness of the class of nanosystems now increasing its application range from Earth orbiting cubesats to interplanetary scientific exploration endeavors, from orbiting to landing missions. This paper is intended to investigate nanolander options derived based on the MASCOT lander concept. For this purpose we gather interesting target bodies and analyze their respective environmental properties as well as their influence on the nanolander design, for example the landing system, the surface mobility, the power subsystem and the communication architecture. Further, an expansion of the scientific objectives of the current MASCOT lander from geological surface scout to other scientific objectives opens a range of new possibilities. For deeper analysis on this, we provide an overview over possible alternative payloads to the ones already flying on MASCOT and analyze their influence on the system design as it is. Obviously, the experience that has been gained with MASCOT provides us with a head start for future missions, if it is properly exploited. With this paper we intend to recommend MASCOT type of nanolanders for a range of possible future applications.

Keywords: Asteroids; Exploration; Small body landing; Missions; Nanolander

1. Introduction

An increasing number of larger missions have flown or are being planned to explore the small bodies of the solar system: NEAR Shoemaker, which landed on Eros (Cheng, 2002), the Hayabusa Sample Return Mission that returned a sample from asteroid (25143) Itokawa (Kawaguchi et al., 2008) and the Comet Explorer Rosetta with the lander Philae (Bibring et al., 2007) as well as recently launched OSIRIS-REx (Beshore et al., 2015) to (101955) Bennu or JAXA's planned Martian Moons eXploration (MMX) mission to Phobos (Kuramoto et al., 2017), only to name a few. In contrast to other missions to small bodies, all of these mission have some aspect of surface interaction, be it via landers or hoppers or only for a final end-of mission interaction. This is also true for another one of the currently flying missions: the Japanese (JAXA) Hayabusa2 (HY2) mission (Tsuda et al., 2013). Launched in December 2014 this mission is currently on its way to its target destination: (162173) Ryugu. On-board of the probe is a small landing package called

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MASCOT, Mobile Asteroid Surface Scout (Ho et al., 2017), which has been developed by the German Aerospace Center (DLR) jointly with the French Centre National d'Etudes Spatiales (CNES). Together HY2 and MASCOT will arrive at Ryugu in June - July 2018.

The lander's main objective is to perform scientific in-situ measurements of surface composition, topology, temperatures, and magnetism on the asteroid's surface. It is thus enhancing the Hayabusa2 (HY2) main mission objective, which aims at returning a sample of the asteroid back to Earth. In order to fulfill the scientific objectives, the lander carries an hyper-spectral infrared microscope called MicrOmega (MMEGA), a camera with night-time illumination (MASCAM), a thermal infrared radiometer (MARA) and a magnetometer (MasMag) (see Fig. 1). The lander is designed to fly piggyback on the HY2 carrier. Once separated, it performs a ballistic descent down to the asteroid and comes to rest on the surface after a number of bounces reducing its kinetic energy. The lander is expected to operate on two asteroid days using primary batteries and passive thermal control. During this time, it acquires scientific data at one landing site at least, measuring with each of its four scientific instruments at least once. It transmits all generated data to Earth using the main spacecraft as a relay station, but in general operates autonomously, i.e. independently from ground-based command. For that purpose, an autonomy manager (MAM) runs on the on-board software. The lander is a small (0.2 × 0.2 × 0.3 m) and lightweight system weighing only 9.5 kg and the size of a shoe box. Fig. 1 shows the lander with all its instruments and bus units. The top and front structures and the single-layer insulation foil surfaces are omitted for clarity. The figure also shows the MASCOT mobility system attached to the common electronics box (E-Box), designed to fulfill uprighting as well as hopping functionality on the surface. More details on the surface mobility concept and future advancements are provided in Section 3.2.

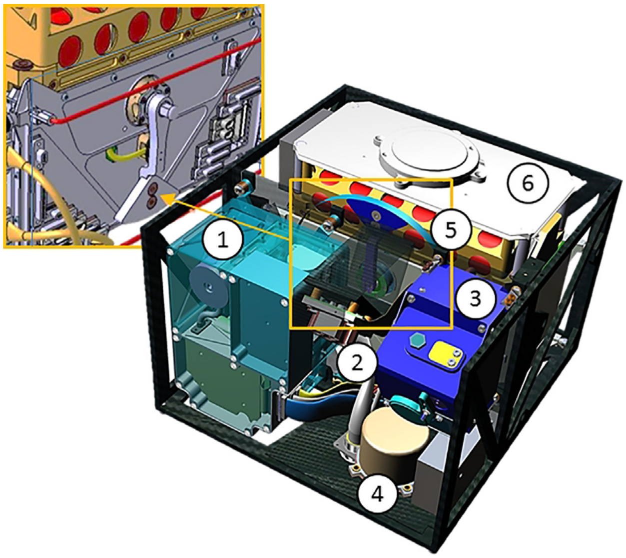

Fig. 1. This figure shows the lander with some of the top and front structures and the single-layer insulation foil surfaces omitted for clarity. In the front lies the payload compartment containing the four instruments: (1) hyper-spectral infrared microscope MicrOmega (MMEGA), (2) thermal IR radiometer (MARA), (3) Camera, (4) Magnetometer. The back houses the bus equipment (5) electronics box and battery with attached mobility mechanism and (6) sub-radiator with mounted top antenna. The mobility mechanisms is shown in greater detail in the top part of the figure.

Typically, small body missions, be it fly-bys, orbiting spacecraft or landing systems are big spacecraft probes, whose development costs range in the hundreds of millions up to more than one Billion USD. Several small body missions have been proposed for the NASA Discovery and New Frontiers programs, which have cost caps of $450 M and $1B, respectively. The European comet mission Rosetta was realized with approximated $1.5B (Kane, 2015). Lately though a common understanding is developing that even these scientifically highly valuable missions can be enhanced, if the main mission provides carrying-along capabilities for smaller systems (Lange et al., 2015; Staehle et al., 2013). One example is the aforementioned MASCOT lander aboard HY2 which carries also three new versions of the Minerva lander, the surface landing element that already flew on Hayabusa (Yoshimitsu, 2004) in its first version. Other noticeable concepts are the PANIC surface science package (Schindler et al., 2011), the JPL Hedgehog (Reid et al., 2014) and also the MASCOT2 mission concept which has been formulated in the frame of the AIDA/AIM (Asteroid Impact Monitoring) mission defined by ESA (Ho et al., 2016). It is generally agreed that dedicated, small landing or instrument packages can scientifically enhance many kinds of main missions, either by providing ground truth for the larger mission's orbital investigations, exploring niches on the surface or adding complementary investigations. To be prepared when the next flight opportunity arises, with this paper we intend to discuss implications of reusing and adapting the MASCOT design concept for upcoming missions. In order to do so, we present anticipated mission scenarios and analyze design aspects related to separation and landing strategy, including a set of technology building blocks and their combinations with the aim of providing an overview of possibilities with and limits to the MASCOT-type of system design.

The MASCOT lander and other mentioned concepts opens up a new class of spacecraft, the 'nanolander'. Nanolander are small low mass systems landing on or interacting with a planetary surface, with the prefix defined in analogy to commonly used small Earth satellite class definitions primarily by mass of the spacecraft separated from its carrier. While there is no consensus on mass boundaries between classes in the many academic as well as practical definitions around, we also consider other implicit criteria related to schedule, team size, development and assembly complexity, integration and verification (AIV) requirements or cost (United Nations Committee on the Peaceful Uses of Outer Space, 2015; Fortescue

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