A nanolander for the RAMSES mission: how MASCOT at Apophis can contribute to planetary defense

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Introduction: The concept of a 10-15 kg lander ("nanolander") equipped with a customized suite of instruments designed to complement its carrier spacecraft's science payload has proven to be a valuable scientific addition to both, orbit observations, and sample return, as demonstrated with the MASCOT surface science package on the Hayabusa2/JAXA mission [1,2,3]. MASCOT, the Mobile Asteroid Surface sCOuT, successfully landed and operated on the asteroid (162173) Ryugu on October 3rd, 2018. The discovery of the conditions on the surface of the asteroid has shown how in-situ science can provide ground truth to the results of orbiter instruments, and bridge the gap between them and possible samples sent back to Earth [4,5,6].

In the meantime, several studies for small surface packages, based on the MASCOT design and mission concept have been conducted. They have been considered for a number of different asteroid missions, such as the ESA mission study AIM [7] to (65803) Didymos and Dimorphos, or for a possible Chinese Asteroid Mission by the CNSA to the active main belt asteroid 133P/Elst-Pizarro [8].

This paper will describe how the MASCOT design can be adapted to the technical and scientific requirements of the Ramses Mission in 2029 to asteroid (99942) Apophis.

Various MASCOT Concepts: The original MASCOT flown on the Hayabusa2 mission had a total mass of 9.64 kg and a size of 292 x 278 x 208 mm^3. It was attached to the mother spacecraft via a MESS (Mechanical and Electrical Support Structure) which carried also the separation mechanism to eject the lander towards the microgravity target, in this case asteroid Ryugu. MASCOT carried four scientific instruments: MicrOmega, MASCAM, MARA and MASMAG, see also Figure 1 (top). Communications with ground used a multi-landing probe link infrastructure; i.e. the MASCOT lander shared the link with the two Minerva rovers.

A derivate, referred to as MASCOT2, was studied in 2015/16 as part of ESA's AIM project [7] to be deployed on Dimorphos, the minor body of Didymos, a binary near-Earth asteroid system. In contrast to the short lifetime of MASCOT of only 17h based on primary batteries only, MASCOT2 would have been able to support long-term operations allowing e.g. determining the 3D internal structure as well as further geophysical properties of the asteroid. This was possible as, MASCOT2 would have carried solar generators and rechargeable batteries, see Figure 1 (lower left). As a result of these design changes, the lander volume increased to 329 x 297 x 208 mm^3 and its total mass including MESS was approximately 15 kg. Compared to the MESS design for MASCOT (Figure 2, left) in a recessed configuration, the MESS of MASCOT2 is flat allowing a very flexible accommodation of the nanolander on any spacecraft, see Figure 2 (right). Based on the MESS design for MASCOT2, the MECSS (Mechanical and Electrical Chassis Support Structure) attaching the Idefix rover to the JAXA spacecraft, MMX, was developed and verified [9]. Eventually, the AIM mission was not approved in 2016 but replaced later with the Hera mission, which, unfortunately does not include a MASCOT2 lander.

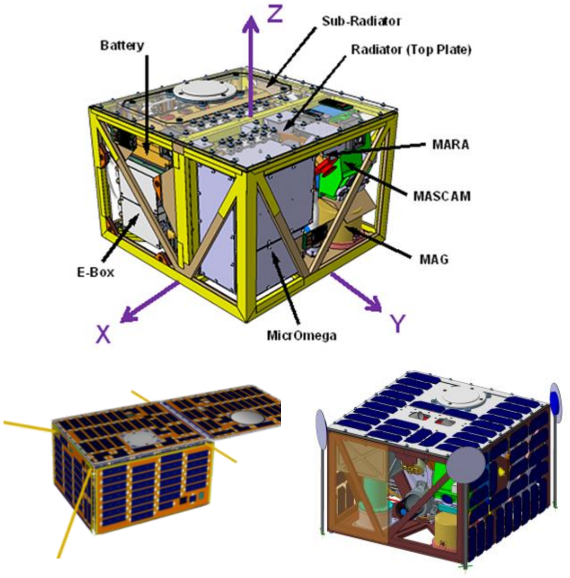

Figure 1: MASCOT nanolander onboard the Hayabusa2 mission (top). MASCOT2 nanolander design for the AIM/ESA mission (lower left). CALICUT nanolander concept for the Chinese Asteroid Mission/CNSA (lower right)

Another MASCOT variant, called CALICUT (Figure 1, lower right), was studied as part of the Chinese asteroid mission to the active asteroid 133P/Elst-Pizarro [8]. Also, in this case, the mission aimed at a long-term operation of the scientific instruments. In order to cope with the energy requirement in the lower solar flux at distances of the main belt, the volume of CALICUT had to be expanded to 392 x 378 x 308 mm3. However, the total mass was limited to a maximum of 13 kg including its MESS.

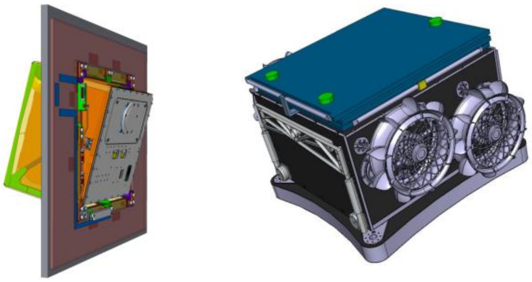

Figure 2: MESS of MASCOT on Hayabusa2 spacecraft (left). MECSS + Idefix rover on MMX spacecraft (right).

CALICUT was designed to carry a suite of compact instruments, i.e. a camera, a gamma-ray-spectrometer, a wideband ground-penetrating radar, and a Multi-Science Package (MSP) containing a magnetometer, a radiometer, an electric field sensor experiment, a neutral density gauge and an accelerometer. Their masses varied between 100 – 400 g, each. The MSP also included a set of ground penetrators (“Darts”) to be catapulted into the ground by a recoil-less mechanism, to support the electric field and thermal environment experiments. The reaction masses ejected at the same time contained tracking equipment to explore the gravity field.

MASCOT3 for RAMSES: We have studied several options of MASCOT-type landers with different scientific instrumentation and demonstrated the feasibility of such concepts. The science payload fraction in most cases exceeds 35% and can be as high as 50%. Typically, the science payload is comprised of one or two main instruments, or an MSP-like topical-synergetic and mutually complementary set of instruments. The main science payload can be complemented by smaller instruments supporting landing and relocation operations as well as providing location context to the main instruments. The instrument suites studied covered diverse science topics such as surface structure and composition, volatiles, gravity, seismicity, and the internal structure. The mobility of a MASCOT-type lander allows measurements to be taken at multiple sites and their evolution over time to be observed. e.g. in relation to a specific event such as DART’s impact on Dimorphos [10] which would have been witnessed by MASCOT2 from the surface at a distance of <89 m, or the flyby of Apophis at Earth.

Because of its high TRL and flexible design, it is recommended to integrate a flat MESS as the mechanical interface between the MASCOT3 lander and the RAMSES spacecraft.

Based on RAMSES’ currently estimated closest approach distances of 5 km above the surface of Apophis prior to the close Earth encounter, the MASCOT3 lander will have to carry thrusters to enable the longer travel/descent distance to the asteroid surface [11], although the much smaller gravity of Apophis relative to Ryugu could allow a higher free-fall altitude and larger relocation leaps. However, MASCOT3 will keep much of the original flight-proven concept such as the carbon fiber reinforced structure, at least one excentre mass for mobility attached to a common electronic box [2] combined with off-shelf available technology meanwhile developed also e.g. for CubeSats, its agile implementation approach [12], and its resilience given the unknown nature of the surface of an asteroid being visited for the first time [13]. Its actual size will depend on the final selection of the instrumentation, their concept of operations, and the resulting power requirements.

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