MASCOT2, a Lander to Characterize the Target of the Asteroid Kinetic Impactor Test (AIM) Mission

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Introduction

In the course of the AIDA/AIM mission studies [1,2] a lander, MASCOT2, has been studied to be deployed on the moon of the binary Near-Earth Asteroid system, (65803) Didymos (figure 1)

The AIDA technology demonstration mission, composed of a kinetic impactor, DART, and an observing spacecraft, AIM, has been designed to deliver vital data to determine the momentum transfer efficiency of the kinetic impact and key physical properties of the target asteroid. This will enable derivation of the impact response of the object as a function of its physical properties, a crucial quantitative point besides the qualitative proof that the asteroid has been deflected at all.

A landed asset on the target asteroid greatly supports analyzing its dynamical state, mass, geophysical properties, surface and internal structure. The lander's main instrument is a bistatic, low frequency radar (LFR) to sound the interior structure of the asteroid.

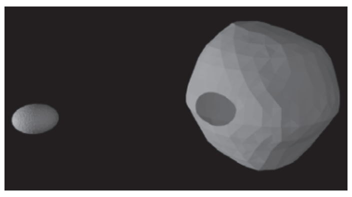

Figure 1 Sketch of the Didymos system. Diameter of primary: (shape from radar) 775 m ±10%, diameter of secondary (shape assumed) 163 m ±10%, bulk density 2146 kg/m³, system semimajor axis 1180 m, orbital period and assumed rotation period of secondary 11.92h, rotation period of primary 2.26 h.

MASCOT-2 payload (table 1, figure 3)

Besides the lander unit of the LFR, a camera will provide high-resolution images of the landing area, and accelerometers will interpret the bouncing dynamics. During the DART impact, MASCOT2 would be able to detect the seismic shock with its accelerometers. Exact timing could give valuable information on the internal structure (from the velocity of p-waves). A radiometer (MARA) will determine the thermal inertia at the rest sites. An magnetometer (MASMAG) is optional.

MASCOT2 will also serve as a technology demonstrator for asteroid landing and extended operations, powered by a solar generator.

- ☑ MASCAM [4] – 1 Mpx Si-CMOS b/w (60°)² field of view camera, IRGB-LED illumination
- ☑ MARA [5] – 6-band multispectral thermal infrared radiometer, 5…100 µm
- ☑ LFR [3a,b]: bistatic radar for deep internal structure, spatial resolution <30m, also for precise mass of the secondary by tracking during descent.
- ☑ MASMAG [6] would investigate the interplanetary medium interacting with the binary system while on site on the moonlet as it orbits the primary, and the remanent magnetization of the Moonlet's during the descent, landing, and relocation hopping phases.
- ☑ DACC [9] – a triaxial accelerometer to observe the interaction of MASCOT2 with the surface during bouncing and potentially to observe the impact shock wave.

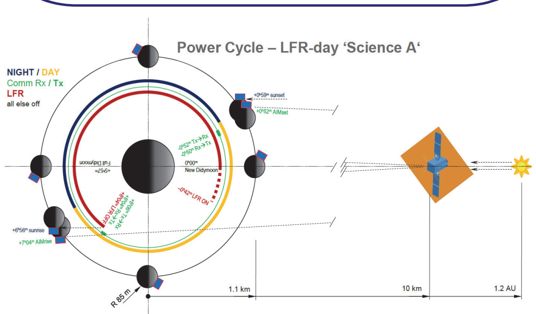

Figure 7 Active LFR measurement geometry

MASCOT2 Operational concept (table 2)

The MASCOT2 operational concept is driven by the payload operations:

- CAM images and MARA measurements at each resting position
- DACC measures particularly during motion
- MARA measurement at least during one whole Didymoon day per rest location
- Seven LFR measurements to scan the bodies interior (figure 7)
- GNC and Bus sensors support by environment data
- All could be repeated after DART impact to look for changes

The bus operational characteristics are as follows:

- For thermal management, MASCOT2 (bus) can run continuously or intermittently
- Units can be used as smart heat dissipation sources
- System operation, payload operation and COM is possible during charging of battery , and during day or night
- System power consumption is adjustable to insolation by novel power management technologies

MASCOT-2 design (figures 2, 3)

MASCOT2 is a small (~13kg) lander, based on the design of MASCOT, which is part of the Hayabusa2 mission [8].

The long-lived lander will be deployed from the mother spacecraft in close vicinity to and soft-land on "Didymoon". After several passive bounces and likely re-location (steerable) and self-righting by an internal mobility mechanism (2 excenter masses instead of 1 for Mascot), it will operate for several months on the asteroid surface and provide detailed information about the asteroid's interior, its landing site and key physical properties (mechanical, thermal, structural) of the surface material.

System sensors include Optical proximity sensors and photoelectric cells on each face.

Deployables

MASCOT2 will carry deployable LFR antennae (one for descent, one for on-surface ops) and a deployable photovoltaic top panel for power generation. The deployment mechanisms have been studied in detail. Full deployment is only triggered at final measurement position.

Power and Data

A rechargeable Li-Ion battery will be supplemented by a solar generator with MPPTs. A large Mass memory will buffer the science data (total ~1.5 Gbit) for transmission to AIM in the 10's kbit/s range

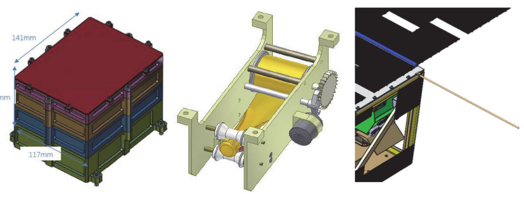

Figure 3 LFR (lander). LFR main elements: E-Box, main antenna including deployment mechanism, short antenna

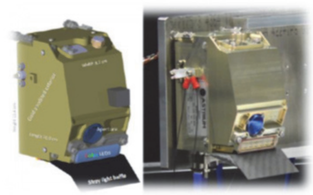

Figure 4 MASCAM

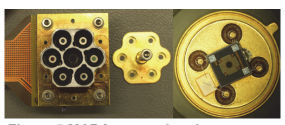

Figure 5 MARA sensor head

	CBE mass (kg)	Maturity margin	Effective margin (kg)	Mass including margin (kg)
LFR	1.2525	20%	0.2525	1.5050
DACC	0.11	20%	0.02	0.134
MARA	0.18	5%	0.01	0.192
CAM	0.40	5%	0.02	0.422
Total				2.2525

Table 1 – payload mass budget

Phase	LFR	CAM	MARA	DACC
SDL	4 hours	5 pictures	On	On
Orientation		14 pictures	On	
Relocation	1 hour	5 pictures	On	On
DCP-2	7 scans	14 pictures	On	
Impact	Beacon		On	
DCP-3	7 scans	14 pictures	On	

Table 2 – operational phases. The duration of the phases is as follows: Orientation , up to 24h; DCP-2, DCP-3: each 60 moon days; impact, 30 moon days

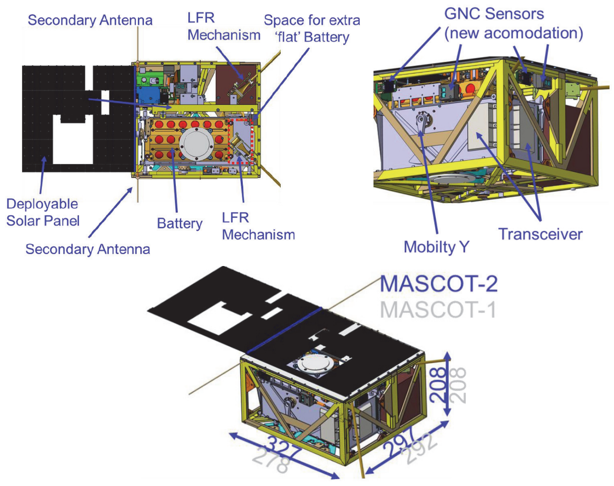

Figure 2 – MASCOT2 design. Note that all faces are covered with solar cells

MASCOT Mission Analysis, Landing strategy

Analysis of the deployment of the MASCOT2 lander on the secondary of the binary asteroid has been performed under consideration of the natural features of the Restricted 3-Body Problem (R3BP), as explained by Tardivel and Scheeres [10]. Rather than struggling with the irregular gravity field that an asteroid exhibits, it was utilized to design a simple deployment strategy in which the spacecraft releases the lander in the vicinity of a saddle equilibrium point (classically, L1 or L2).

Contrary to Keplerian deployment on a single body with a defined escape velocity, the deployment proposed here leads to a dynamical trapping of the lander on the surface despite impact velocities near classical Vesc if only very little damping is present. Surface regolith properties cannot be reliably estimated prior to launch. Moreover, the presence of rocks at the surface, that present a hard surface, is likely. Thus, the damping should be considered as the damping of MASCOT2 on a very hard surface (such as basalt). This will give a coefficient of restitution of <0.6 from the MASCOT2 structure alone.

Robust deployment (meaning at 3sigma probability) of MASCOT2 on Didymoon is possible even from an altitude of 200m (L2 side), provided these conditions are fulfilled, in order of importance:

1) the velocity dispersion (sum of spacecraft velocity dispersion and the one by the separation device) is low enough (order of < 1 cm/s at 3sigma)

2) the combined coefficient of restitution (surface and structural, worst case only structural) is low enough (< about 0.6)

3) and the positional dispersion at the point of release is low enough (order of dozens of m)

Then the resting ellipse dispersion on the surface is also small enough to virtually guarantee sufficient elevation of the Sun such that MASCOT2 can determine its attitude and can relocate (autonomously or commanded) to the desired operational site in about 2 hops (**figure 6**).

A sizable libration (geometric libration at orbital eccentricity 0.16) is no hindrance to successful deployment.

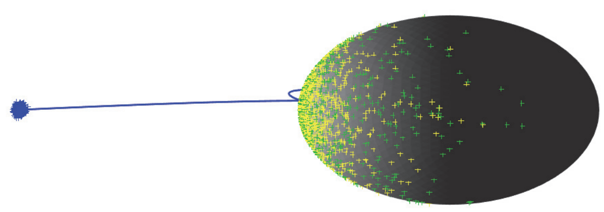

Figure 6 Typical deployment through L2. COR = 0.60 (constant); Spring delta-v: possible range 3 to 15 cm/s, nominal 5 cm/s, speed accuracy +/-30% at 3sigma, angular accuracy +/-15° at 3sigma. Spacecraft: state vector known, at time of release, to +/-25 m and +/-5 mm/s , both 3sigma. Altitude of release fixed at 200m. Success rate is 100% of trajectory impacted. 99.9% of trajectories are eventually settled (i.e. 1 trajectory out of the 1000 bounced back). Yellow symbols: 1st touchdown. Green symbols: final rest positions

Conclusions

MASCOT2 as a long-lived, hopping lander for the AIDA/AIM mission will significantly enhance our understanding of the beta factor for kinetic deflectors due to bistatic radar determination of the interior structure of the target and, from its other experiments, understanding the surface mechanical and thermal properties. Design studies have proven its feasibility; there is also a strong heritage from MASCOT flying on the Hayabusa2 mission [8]. AIM funding has not been fully confirmed by ESA Member States during the ESA ministerial council meeting in 2016, yet the concept of MASCOT2 stays valid. DART development in the U.S. is going ahead.

We support flying MASCOT2 on a full AIM mission even if 2 years later than planned.

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