Painted papers category

AIM/MASCOT-2

Executive Summary

DLR

Document properties

Title	Executive Summary
Subject	AIM MASCOT-2 Asteroid Lander Concept Design Assessment Study
Institute	Institute of Space Systems
Compiled by	Tra-Mi Ho
Participants	Jens Biele, Caroline Lange
Checked by	
Release by	
Date	20.02.2016
Version	1.0
File Path	

1. Introduction

The MASCOT (Mobile Asteroid Surface Scout) lander onboard JAXA's Hayabusa 2 sample return mission to C-type Near Earth asteroid Ryugu is a lightweight (~ 10 kg) and compact (0.3 x 0.3 x 0.2 m^3) landing platform with the capability to carry various in-situ experiments with a total mass of up to ~3 kg. Thus a system to payload mass ratio of 7:3 can be achieved. These characteristics make the MASCOT concept especially for missions to investigate small bodies attractive resulting in a Phase A study from April 2015 – Feb 2016 of a similar lander, namely MASCOT-2, for ESA Asteroid Impact Mission (AIM) to be launched in October 2020.

MASCOT, which was developed by the German Aerospace Center (DLR) with contributions from the Centre Nationale d'Etudes Spatiales (CNES), carried a payload of four scientific instruments: a camera (MASCAM, DLR PF), a radiometer (MARA, DLR PF), a magnetometer (MASMAG, TU Braunschweig) and a hyperspectral microscope (MicrOmega, IAS). Since the primary objective of the technology AIM mission is the demonstration of asteroid threat mitigation the scientific inclusion of a bistatic low frequency radar (LFR) into MASCOT-2 as primary science payload is required. The available limited space and mass would allow consecutively only small and light payloads such as the camera (CAM) and radiometer (MARA), similar to the ones as flown on MASCOT, and an accelerometer (DAAC).

In addition, few modification of the MASCOT system needs to be addressed in order to fulfil specific AIM mission requirements such as long-term surface operation (~ 3 months) and orientation/relocation capability.

2. Mission Overview

The launch of the AIM spacecraft is scheduled for October 2020 with an arrival and operation at the binary asteroid system Didymos in 2022. The deployment of the MASCOT-2 lander is foreseen in Mid 2022 at an altitude of up to 200 m above the Didymoon surface. The lander will fall onto the asteroid surface under the effects of its weak gravity field (see Figure 2-1), followed by a bouncing period of unknown duration, and depending on the surface characteristics strengths before it comes to rest in an unknown orientation. During Separation Descent & Landing (SDL) the LFR will be active, performing tracking of the lander. The communication subsystem will continuously send housekeeping (HK) information to the AIM spacecraft.

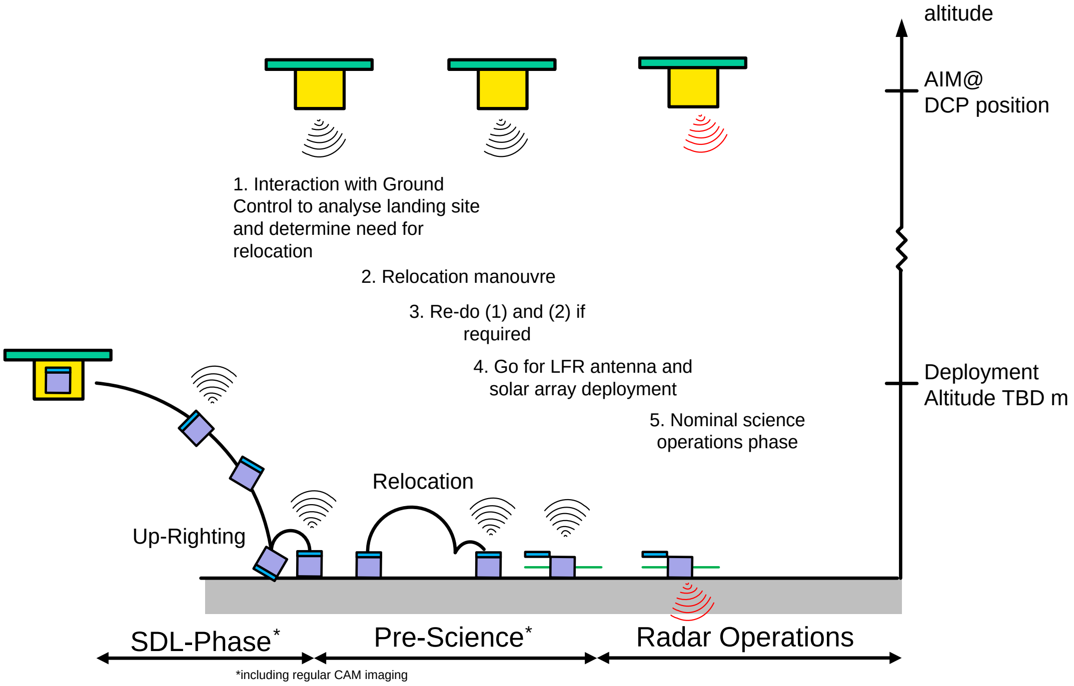

Figure 2-1: Schematic showing high level mission sequence. SDL: Separation, Descent and landing. DCP: Detail Characterisation Phase

When the lander will perform orientation activities it will localize itself on the surface and will also determine its attitude. Depending on this information the lander will be able to perform relocation. The loop of orientation and relocation will be performed until the operational site has been reached – based on the current analysis covering the maximum or worst case distance 2-3 relocation phases are expected. The final relocation phase ends with the uprighting of the lander, i.e. correct side to soil, and the deployment of the solar panel and LFR antennae.
On-surface operations are dominated by science (radar) operations with intermittent periods of only low system level activity used for battery recharging of the lander via its solar arrays (active standby).

Since operation close to the opposite point (far side - point in opposition by regards to Didymain, defined as 0°) doesn't allow Didymoon sounding due to eclipse the operational site longitude from a scientific point of view should thus be either -120° to 60° or 60° to 120° from the far side and its operational latitude -15° to +15° (see orange bands in Figure 2-2). Moreover, the +/- 60° constraint on the latitude ensures that MASCOT-2 top and side panels are illuminated at least once during a Didymoon day.

Landing analysis results

The latest deployment simulations which has been performed with following parameters

- Coefficient Of Restitution = 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 "over L2"

give a success rate of 100% of trajectory impacted. All trajectories are eventually settled (i.e. 0 trajectory out of the 1000 bounced back). The total number of significant (>0.5 cm/s) bounces is ≥3 with a probability of >98%.

Conclusion for deployment:
Robust deployment (meaning at 3sigma probability) of MASCOT2 on Didymoon is possible even from an altitude of 200m (L2 side), provided two 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 M2 can determine its attitude and can relocate (autonomously or commanded) to the desired operational site in about 2 hops.
A sizable libration (geometric libration for orbital eccentricity 0.16) is no hindrance to successful deployment. Aiming can be done for latitude band (here: equator), but not longitude. Relocation mechanism will probably have to be used if the operational site shall be reached.
Illumination (important for lifetime and attitude determination in the relocation phase): A |latitude|>60° may lead to no illumination on GNC sensors for whole Trot (for solstices = worst case); this happens with a fraction of 0.7% of the trajectories, will be treated as a contingency case.

3. System Overview

The MASCOT-2 system consists of three elements: lander, mechanical and electrical support system (MESS), and payload suite. The MESS remains on the AIM spacecraft after lander deployment. The payload suite includes abistatic low frequency radar (LFR), a 3-axis accelerometer, a compact wide angle camera (CAM) and a radiometer (MARA). They are described in Section 4. The MESS and lander subsystems are described in the next sections.

3.1. Structure

The lander structure design is closely similar to MASCOT-1. The main components are made from separate CFRP/foam sandwich framework walls that are assembled at the edges via CFRP straps. The lander structure includes a common aluminium electronics box (E-box) that integrates all bus electronics, except the communication subsystem, and the back-end electronics of the payloads, except LFR and CAM. The MESS is the interfacing part to the main-S/C. It has been redesigned for MASCOT-2. It is an X-stiffened CFRP-honeycomb sandwich plate.

The lander dimensions and the overall stowage envelope on the main-S/C are shown on Figure 3-1. The current total mass of the MASCOT 2 system (Lander Module, MESS and Payload suite) is less than 15 kg (incl. maturity margin). The configuration of some subsystems is shown on Figure 3-2.

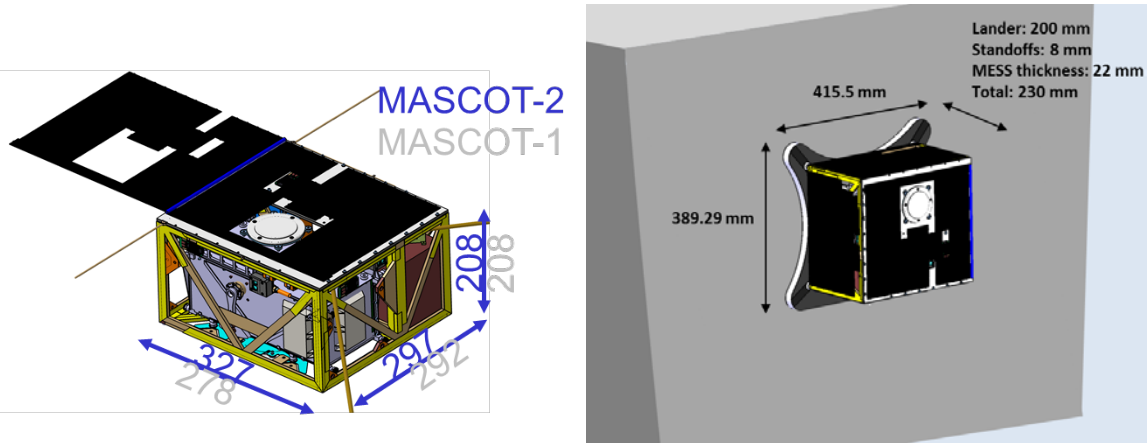

Figure 3-1: Left: MASCOT-2 lander dimensions (blue) – Right: Lander + MESS (stowage configuration) envelope

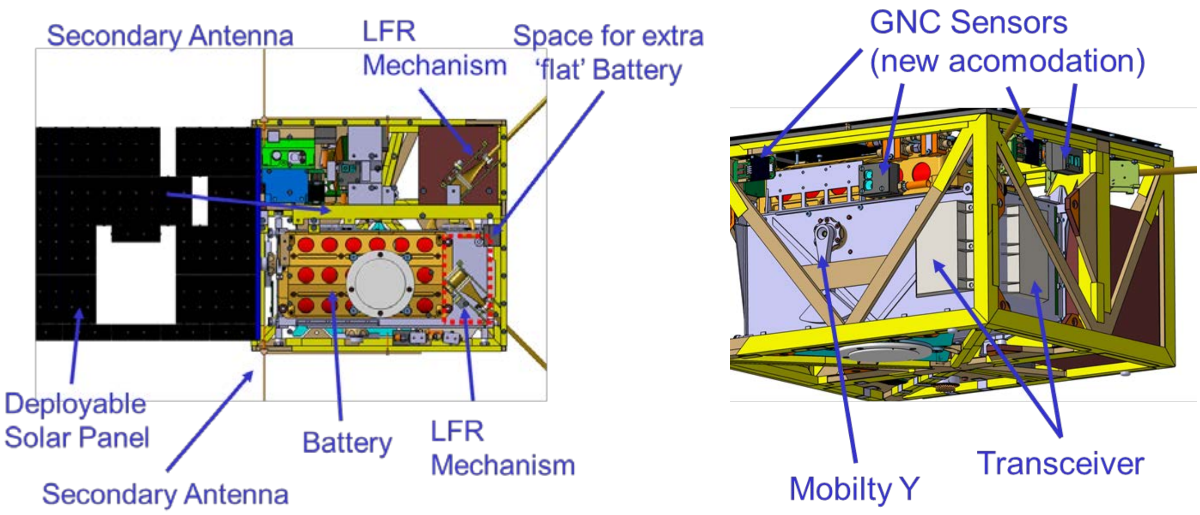

Figure 3-2: Lander baseline configuration

3.2. Power Subsystem

The required mission lifetime of ~ 3 months cannot be met with the non-rechargeable battery of the MASCOT-1 power subsystem. A photovoltaic energy generation and a rechargeable battery for energy storage at night on Didymoon are necessary. The battery capacity is determined by the minimum duration and required power for one LFR sounding pass. The photovoltaic input is determined by the power required for long-term continuous operation of the MASCOT2 bus and also the MARA instrument minimum continuous operation requirement combined with an acceptable operate-recharge cycle for the LFR operations.

The MASCOT-2 power subsystem design, Figure 3-3, consists of a battery charging photovoltaics (PV) and battery charge regulator (BCR) section, the battery (based on relatively new ABSL 18650NL cell), and a power conversion and distribution section (PCDU) for direct battery power.

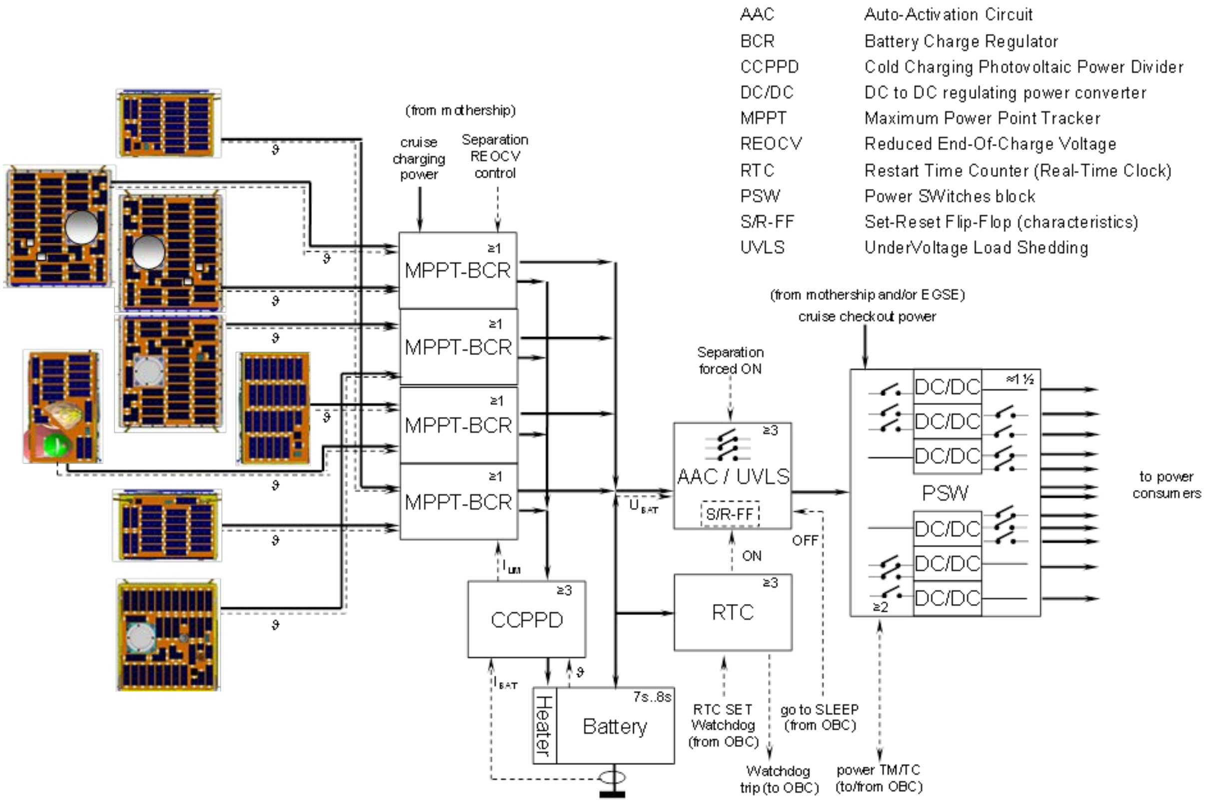

Figure 3-3: MASCOT-2 Power subsystem block diagram

3.3. Data Handling

The OBC design for MASCOT-2 is based on a mature and flight proven design of the MASCOT-1 OBC. It is based on a redundant CPU and IO design and is single failure tolerant. Two CPU boards – which are cold redundant – are powered by a Leon3 CPU @ 40 MHz

The OBC's main tasks are to interface with the payload instruments for TC distribution, TM collection and the control of the lander's equipment, like the power subsystem, mobility mechanism, attitude sensors, RF communication system. The OBC executes control routines for the mobility equipment and other subsystems as well as instrument specific algorithms for science data processing such as CAM configurable functions for auto-exposure evaluation, all-black/all-white image rejection or down-prioritization, and data .

3.4. Thermal Control

The MASCOT2 Thermal Control System (TCS) includes both active and passive components. The active components are the hibernation heaters and the thermostats operated during cruise in order to keep the internal and external MASCOT2 units temperatures above the non-operational temperature limits. During on-surface operations, MASCOT2 is running in low power/dissipation for long periods (weeks/months). Therefore, operational heaters have been included in the TCS to avoid that the internal temperatures drop below the non-operational thermal limits. The passive components are the sensors and the single layer isolation (SLI) separating the MASCOT2 warm compartment from the external cold part. Finally, the TCS relies also on the coatings and paintings properties of the MASCOT2 components.

3.5. Mechanisms

To fulfil its planned asteroid landing operation including its separation from the AIM S/C, descent and landing phase as well as its relocation and long term operation capabilities, the MASCOT-2 system mechanisms includes:

3.5.1. Separation Mechanism

The separation mechanism ensures the separation of the lander from the MESS. The design is inherited from MASCOT-1. The mechanism was constructed in favour of mass reduction as a simple single-shot device but featuring high reliable parts. As shown on Figure 3-4, it consists of 4 main elements: a Pre-load Release Mechanism (PRM), a Non-Explosive Actuator (NEA), an Umbilical Separation Connector (UMC) and a miniaturized spring-loaded pusher plate (Push-off). The separation mechanism operates as a two-stage system. The first stage (Pre-load Release) is activated and controlled during one of the first cruise check-out activities soon after launch; the second stage (Eject Manoeuver) is triggered by the main-S/C which initiates the terminal separation sequence while being close to the Didymoon surface.

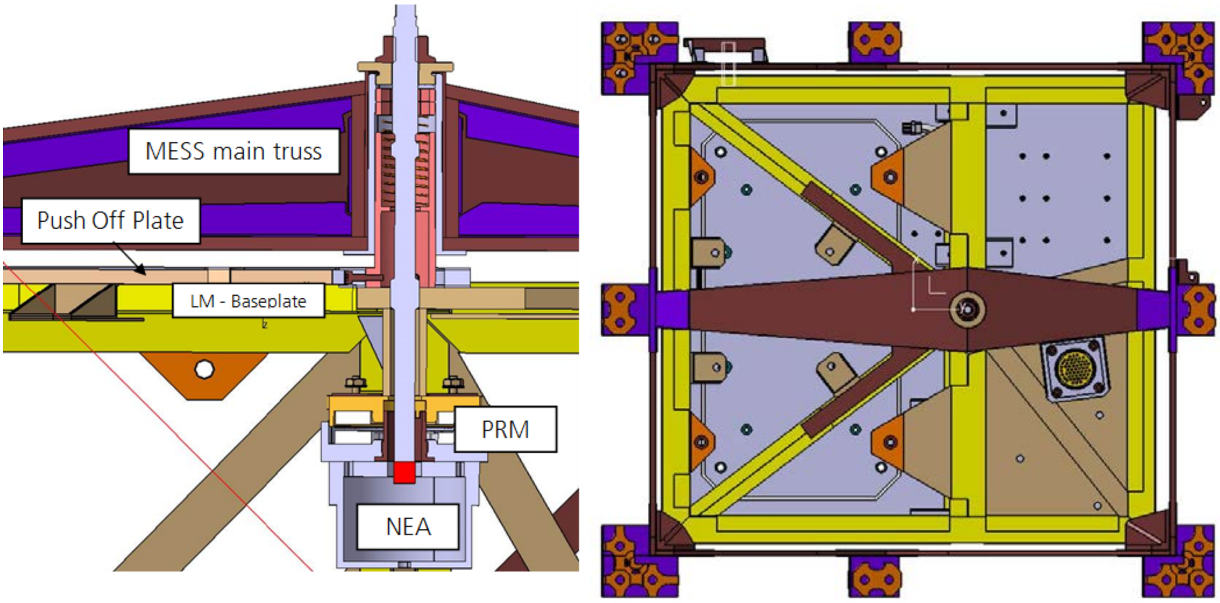

Figure 3-4: MASCOT-2 Separation Mechanism

3.5.2. Mobility Unit

The mobility mechanism ensures the lander uprighting, i.e. landing on a side which is not favourable to payload operations and the lander relocation or hoping, i.e. landing outside the specified operational site. Its design is inherited form MASCOT-1 and consists of two elements: the mechanism itself and the control electronics. The mechanism is attached to the E-Box, see Figure 3-2, whereas the electronics are accommodated inside the E-Box. The mobility mechanism's functionality is based on the angular impulse-momentum principle, where the mechanism provides a momentum to the lander which results in a reactive motion relative to the surface. The mechanism consists of an eccentric mass at the end of the lever arm, and a motor and gear combination which provides the arm and mass acceleration and deceleration. The maximum drive speed, stop location and deceleration define the energy impact into the structure and thereby the respective reactive motion.

Finally, to achieve the required steerability, the MASCOT-2 lander is equipped with two mobility mechanisms accommodated perpendicular to each other, each of the two capable of moving the lander around one axis, thus conjointly providing a steerability of the lander.

3.5.3. Solar Panel Deployment Mechanism

The solar panel deployment mechanism is used to unfold the solar panel on the topside of the lander, thereby increasing the surface area and the available energy for on-surface operations. The top panel is held down by a redundantly designed thermal knife type hold-down and release mechanism. Once opened, the hinge will unfold the top panel by either using a built-in and carefully chosen spring or an active driving mechanism.

3.6. Communication

The communication subsystem architecture design, Figure 3-5, is inherited from MASCOT-1. It consists of two transceivers, in hot redundant mode for the receiver and cold redundant mode for the transmitter, connected to two S-band patch antennas using couplers. The two antennas, mounted both on the top and bottom side of the landing package, allow an omnidirectional link.

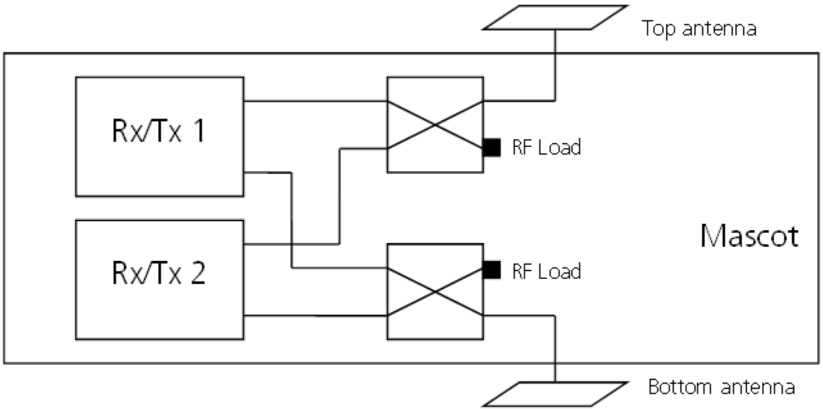

Figure 3-5: MASCOT-2 Communication Architecture

The link budget has been estimated under the assumptions reported in Table 3-1. It shows a comfortable link margin of 21.3 dB for the uplink of data from the Didymoon surface to the main-S/C at 10 km. Note: the link margin for the main S/C at 100 km is 1.3 dB.

Parameter	Value	Unit
Downlink frequency	2200	MHz
Mother Spacecraft	10	km
G/T Uplink	-22	dB/K
Data Rate	1000	kbps
TX power	3	dBW
cable and connector losses	2	dB
TX Antenna gain	0	dBi
EIRP	1	dBW
pointing losses	0	dB
Downlink path loss	119.3	dB
C/N_0	88.3	dBHz

Coding gain Convolutional coding	5.5	dB
Bit-SNR E_b/N_0	33.8	dB
Required Bit-SNR E_b/N_0 BPSK BER 10^{-8}	12.5	dB
Link margin DE_b/N_0	**21.3**	**dB**

Table 3-1: Link Budget for main-S/C at 10 km

3.7. Attitude Determination

MASCOT-2 reuses MASCOT-1 heritage sensors for side to soil and motion status determination. The attitude determination system is suitable in illuminated conditions and consists of three types of sensors: Optical Proximity Sensors (OPS), Photoelectric Cell Sensors (PEC) and Thermal Sensors, distributed over the MASCOT body, plus an on-board algorithm for measuring the motion state (free fall, in proximity, at rest).

In case the lander comes to rest in a dark area it is not possible to track or integrate the sun vector over time and thereby translating this into a location and orientation on the asteroid surface. Therefore, additional LEDs are foreseen that are operated in a combined "inverted Sun sensor" and "coastal lighthouse" concept, the former for directionality, the latter for signal coding of directionality at large distances. The LEDs are activated in a predefined time pattern which is synchronized with an observation/illumination sequence of the camera on-board the main-S/C. By analysing the imaging sequence on ground, it is possible to (i) locate the lander as a brightening pixel and (ii) to identify the orientation of the lander by the time sequence of brightness changes of this pixel.

4. Payload Suite

The MASCOT-2 payload suite contributes to AIM primary research objectives on i) Deep internal structural of the moonlet (Didymoon) an ii) Geophysical surface properties, topology and shallow subsurface. Its total mass is less than 2.3 kg, including maturity margin, and consists of four instruments.

4.1. Bistatic Low Frequency Radar (LFR)

The LFR is a bistatic radar measuring the propagation of wave between lander and the main-S/C and thus will probe the deep interior of Didymoon, Figure 4-1. In addition, the LFR is a secondary contributor to determine the mass and the dynamical state of the binary system by measuring the S/C to lander distance during the lander delivery phase or after. The LFR will also possibly contribute to the AIM secondary objectives especially the post-DART Didymoon characterisation characterization.

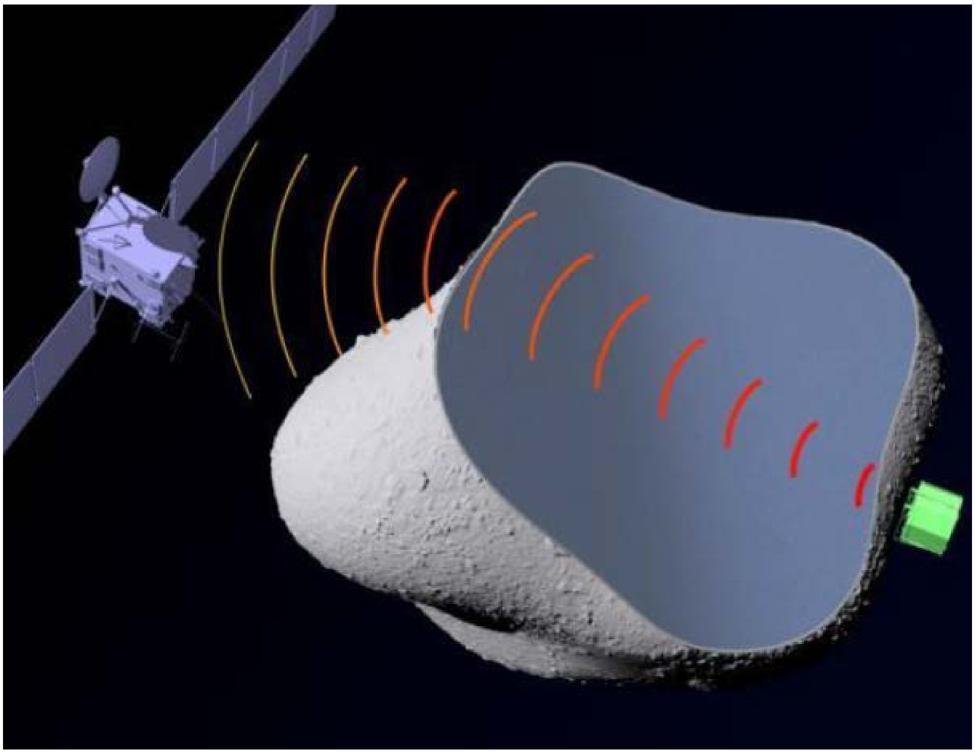

Figure 4-1: Bistatic LFR Radar Configuration Concept

The LFR consists of two parts: one on-board the main-S/C and one on the lander. Each part includes the electronics box, antennae and deployment mechanism. Four monopole antennae, transmitting circular polarized waves from the orbiter to the lander at the Didymoon surface, are mounted at the corners of the main-S/C in x-y-plane. The antenna system should cover a bandwidth of 20 MHz at a centre frequency of 60 MHz. Two monopole antennae are mounted at the edges of the central body of the lander. The angle between the lander body and the deployed antenna arms is 135°, Figure 4-2 (left) **Fehler! Verweisquelle konnte nicht gefunden werden.**. The antenna configuration is able to receive and transmit circular polarized or linear polarized electromagnetic signals, depending on the phase shift adjusted between both antenna arms. In the baseline design, a linear polarization is considered in order to reduce accommodation constraints while allowing a slightly higher bandwidth. A circular polarization could also be envisaged for the final design.

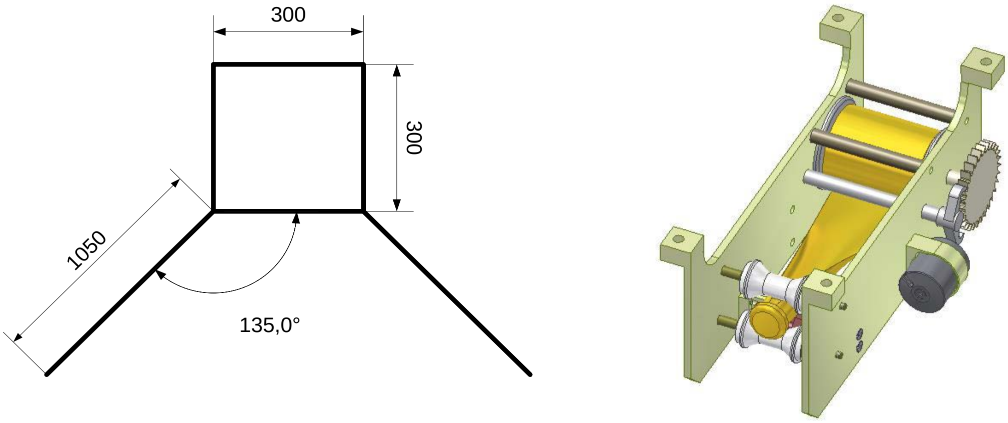

Figure 4-2: On the left: Top view of Lander and Deployed Main Antenna System (length in mm). On the right: Lander Main Antenna (stowed configuration) Deployment Mechanism Concept.

The lander main antenna principle of operation is based on tubular boom technology. The tubular boom acts as a self-deploying spring - once released the antenna extends itself by spring energy released during transformation of the imposed flat profile to the original round one. In the proposed solution, Figure 4-2 (right), the storage reel is joined with the antenna structure and only the leading end of the tubular boom is deployed. To prevent the dynamic and rapid deployment action the escapement-based mechanism is implemented. It provides a dual complementary action – it moderates the deployment speed acting as a kind of damper, and at the same time it can add extra energy to the driving spring (in case of unexpected boom jam), making the system more reliable.

4.2. Camera (CAM)

MASCOT-2 camera is based on MASCOT-MASCAM, Figure 4-4**.**, designed and built by DLR’s Institute of Planetary Research, with Astrium Germany and FISBA Optics.
The camera will provide the ground truth for the main-S/C remote sensing observations. In addition, it will characterize at several locations on the Didymoon surface the geological context, mineralogy and physical properties such as rock and regolith particle size distributions (Jaumann et al, 2016).

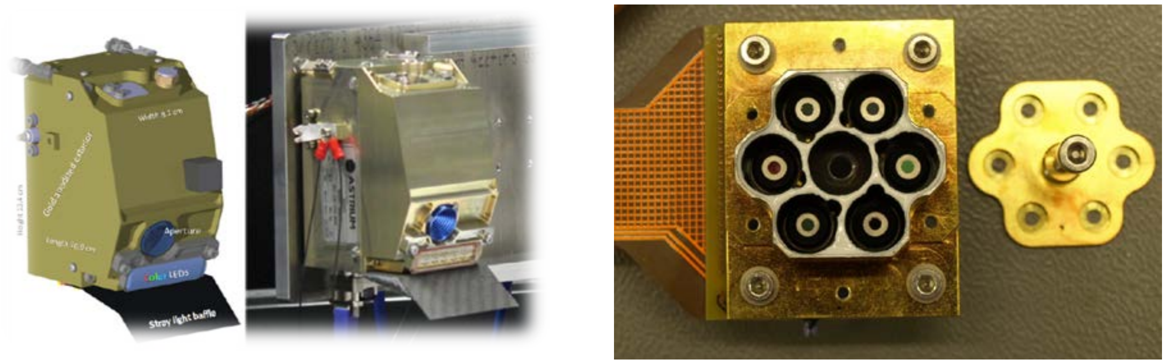

Figure 4-3: MASCOT CAM - CAD Drawing and Flight Model (left). MARA Sensor Head Flight Model (right)

4.3. Radiometer (MARA)

MASCOT-2 radiometer is based on MASCOT-MARA, Figure 4-4, designed and built by DLR's Institute of Planetary Research. The MARA instrument will perform radiometric determination of the surface brightness temperature for a full asteroid rotation at several locations on the Didymoon surface. From this observation, the surface thermal inertia can be derived. By using 4 bandpass filters emissivity ratios can be constrained and the results to laboratory spectra can be compared to give identification of the asteroid surface mineralogy (Grott et al., 2016)

The integration of MARA within the MASCOT-2 lander is such that its FOV is located inside the CAM FOV, see Figure 4-5, in order that the regolith structure can be retrieved from the CAM images.

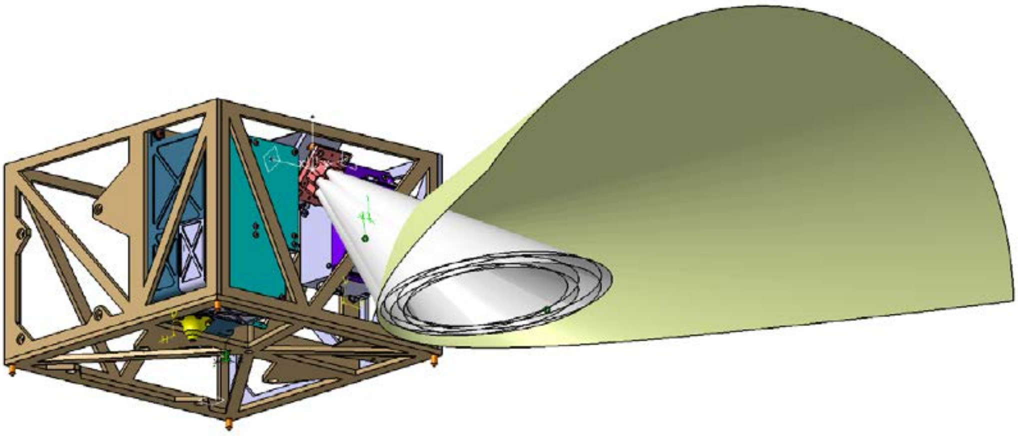

Figure 4-4: Overlapping FOVs of MARA and CAM

4.1. Accelerometer (DACC)

The accelerometer will provide data on surface mechanical properties such as the effective E-module of the soil & lander, the damping properties, strength of regolith material and friction coefficients between soil and Lander, at several locations on the Didymoon surface. Several accelerometers, weighting a couple of grams, will have to be used to span the whole range of possible surface properties. The accelerometer signal gives a rough evaluation of the compressive strength. The E-module, friction and damping requires a finale analysis of the accelerometer measurements. Candidate 3-axis accelerometers are the Bruel & Kjaer 4506 accelerometer. This accelerometer was used in the SESAME payload of PHILAE lander (Seidensticker et al., 2007).

5. Conclusion and Recommendation

The design assessment study of the MASCOT-2 asteroid lander proposes a feasible concept for a derivate of the MASCOT lander as currently onboard the Hayabusa2 (JAXA) asteroid sample return mission also for ESA's AIM missions

Although several subsystems requires to be adapted to fit to the new mission and system requirements of the AIM mission such as operational life time of ~3 months implying the need of rechargeable batteries and photovoltaics instead of the primary cells or the LFR instrument as prime scientific P/L instead of the MMEGA instrument onboard the MASCOT lander, all to be newly developed or modified technologies are feasible. Most of them are of the shelf components or are based on MASCOT heritage that requires minor changes such as the electronic box by increasing its dimension.

However, to meet the current schedule of AIM to be launched in October 2020, we recommend performing following pre-development activities in the upcoming Phase B2:

1. Activities to better define the orientation phase (including relocation) i.e. activities that can help defining technological requirements that stem from the need to have an orientation phase as well as to verify that the current system design can comply with these requirements.
2. Activities devoted to deployment mechanisms in the micro-gravity environment, i.e. activities required for successful lander and instrument operation and the analysis and simulation of their activation peculiarities in the micro-gravity environment.
3. System level activities for interface consolidation, i.e. activities grouped hereunder shall be done in the frame of the ongoing work in the Phase B1 studies of the orbiter.

The details on the specific tasks of these activities are outlined in D6.

6. References

M. Grott , J. Knollenber, B. Borgs, F. Hänschke, E. Kessler, J. Helbert, A. Maturilli, N. Müller
The MASCOT Radiometer MARA for the Hayabusa 2 Mission, submitted to Space Science Review (2016)

R. Jaumann, N. Schmitz, A. Koncz, H. Michaelis, S. Schroeder, S. Mottola, F. Trauthan, H. Hoffmann, T. Roatsch ,D. Jobs, J. Kachlicki, B. Pforte, R. Terzer, M. Tschentscher, S. Weisse, U. Mueller, T.-M. Ho, M. Grott, J.P. Bibring, J. Biele, S. Ulamec, B. Broll, A. Kruselburger, L. Perez-Prieto, The camera of the MASCOT asteroid lander on board Hayabusa-2 , submitted to Space Science Review (2016)

Seidensticker, K. J., et al. "SESAME–an experiment of the ROSETTA Lander Philae: objectives and general design." *Space Science Reviews* 128.1-4 (2007): 301-337.

D6 MASCOT-2@AIM Design Definition and Justification Document

- ***End of Document -***