# BASELINE DESIGN OF A MOBILE ASTEROID SURFACE SCOUT (MASCOT) FOR THE HAYABUSA-2 MISSION

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**ABSTRACT**

The Hayabusa-2 mission is currently being studied by JAXA/JSPEC as a sample return mission to the C-type near-Earth asteroid 1999JU3. Marco Polo has been discussed and studied in the framework of the ESA Cosmic Vision as a M-class mission for the same purpose. At the DLR (German Aerospace Center) Institute of Space Systems a small separate landing package called MASCOT (Mobile Asteroid Surface Scout) has been studied, originally for the Marco Polo mission but later following an invitation by JAXA/JSPEC for the Hayabusa 2 mission in addition. The study assessed different concepts for a lander and converged to a package with a total mass of 10 – 15 kg incl. 3 kg of payload.
This paper gives an overview over the current concept and system baseline design of the mission. We will present details on the study results for key mission elements, such as descent and landing analysis, dimensioning of the power and communication S/S and other dedicated functions, such as the on-surface mobility. Also we will provide details on the current baseline operational strategy and the basic scientific objectives for the landing package.

## 1. INTRODUCTION

### 1.1 Background

The return of surface samples from a primitive body of the population of the near-Earth objects (NEO's) which are thought to either originate from the main asteroid belt or be extinct or at least dormant comets is intensively discussed in current and recently finished mission studies worldwide. One of these has been the Marco Polo mission, which was investigated in the ESA Cosmic Vision framework as a possible M-class mission. The mission design had foreseen remote sensing during the proximity operations phase at the asteroid, but also a descent to the surface. While the further has been proposed for identifying candidate sampling sites, the latter should have had the purpose to acquire samples of surface material, with a total mass of several 10's of grams, which would have subsequently been brought back to Earth for closer investigation [1]. This would have already been a challenging task given the tight budgetary limitations and turned out even more challenging given the experience from the Hayabusa mission conducted by JAXA/ISAS, which has pioneered small asteroid sample return and will return to Earth in June 2010 (Fig. 1) [2]. After the down selection of M-class missions in the Cosmic Vision framework early in 2010, which postponed the further development of a European asteroid sample return mission, the topic did not vanish, but a parallel study of a similar mission performed by JAXA/JSPEC, called Hayabusa-2 remained in the international interest as a successor of the Hayabusa mission.

In the framework of the Marco Polo mission and also following an invitation from JAXA/JSPEC an additional, dedicated landing package has been suggested early in the respective concepts study phases. Having identified the needs for such a landing package, a European consortium of research institutes under the lead of the DLR Institute of Space Systems has been found already in 2008 and responded to the Marco Polo Declaration of Interest (DOI) call, where it proposed to ESA a study of a dedicated lander package as part of the Marco Polo mission which was subsequently selected and recommended for study. Later during the study the package design was also identified as being suitable for a Hayabusa-2 mission.

Fig. 1: Artist's rendition of the JAXA/ISAS Hayabusa spacecraft having approached the surface of asteroid Itokawa for sampling, in November 2005 [JAXA]

Early during the concept proposals it has been found that such a separate landing package for in situ measurements could significantly enrich not only the respective mission's science return but also its robustness, by providing additional in-situ context measurements and a scouting function for the selection of the sites to be sampled by the main spacecraft. Also, lander-based exploration would enrich the spatial as well as the temporal coverage of the main mission and allow the investigation of the surface material at the time and the place of interest.

### 1.2 Study History

Very early in the MASCOT study phase the requirements and constraints on the system design have not been fully known and fixed. Thus, the study started with a preliminary assessment of lander type, landing mode, mobility options and their impact on minimum achievable mass and volume. The trade space included legged and capsule type landers with different degrees and means of mobility ranging from none (e.g. Penetrators and Impactors) to advanced mobility using attitude and landing stability controlled devices (e.g. as used for the Rosetta Philae lander). Considering the mass and volume constraints which were yet unknown in the early stages of the concept study, 4 options had been chosen for assessment in dedicated concurrent design studies using the Concurrent Engineering Facility (CEF) at DLR Bremen. The 4 options were:

- a ~ 95 kg lander, closely based on the Rosetta lander Philae but with enhancements,
- a ~ 70 kg downscaled Rosetta type lander,
- a ~ 35 kg lander without mobility,
- a ~ 10 kg package (Xtra-Small, or MASCOT-XS)

Fig. 2 shows three of these concepts.

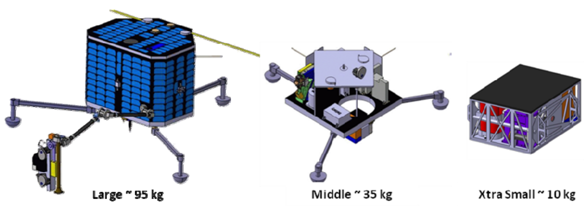


Fig. 2: Study results for 3 of the 4 MASCOT concepts

To meet the constraints finally emerging from the Marco Polo and Hayabusa-2 mission studies, it turned out that a MASCOT lander to be viable for the mission had to have no more than 10-15 kg in mass. As the feasible lower limit for a legged lander was found to be in the 40 kg range, the study team had to turn to a 'capsule' type concept without any attitude control or stabilization during descent in order to meet that mass target. Such a 'passive' capsule or package concept, MASCOT-XS, would land in an uncontrolled attitude but could have an uprighting mechanism for proper positioning on the surface, which in principle may also be used for post-landing mobility (e.g. by tumbling and/or hopping). A 2-week concurrent design session using the CEF in Bremen was dedicated to the definition of MASCOT-XS in the Summer of 2009, followed by a more intensive offline phase-A type study as well as consecutive CE-studies for design-commissioning since then.

## 2. THE SCIENCE CASE BASELINE

In order to endorse the need for a dedicated landing package, the science case for MASCOT has been extensively studied and objectives as well as requirements have been developed. The baseline case is the one, where the MASCOT lander would augment the science capabilities of the main-S/C. There have been identified a number of ways to do so, which will be described in the following subsection. Based on the established science objectives and requirements, a range of instruments has been investigated and a subset of these has been chosen for a strawman P/L.

### 2.1 Science Objectives and Requirements

Basically, the lander has been proposed to fill the gap between the remote sensing investigations and the sample return. While the further can provide the global context including the link to telescopic data as well as support the sampling site selection the latter provides the microscopic view, by virtue of linking returned samples and their analysis data to meteoritic and cosmic dust collection data. In between these two parts, the in situ investigations performed by MASCOT would realize the local study of the target body, thus providing the cross-scale link between the main-S/C data and sample analyses.

Based on these overall goals, MASCOT provides a three-fold role [3]:

1) **'Context science'**, which is realized by means of coordinated and complementary observations of the instruments onboard MASCOT, on the main spacecraft and in combination with the lab analysis of the returned samples.

2) **'Stand alone science'**, which would be performed by MASCOT in its role as a dedicated lander, via unique investigations which cannot be performed otherwise. This includes geophysics, the analytical characterisation of the elemental, isotopic and molecular (organic and mineral) composition of the NEO's surface material in its natural state,

astrobiological investigations (since the prime targets of the sample return mission is a C-type NEO) and visual documentation at the level of microscope scale. If any kind of mobility is being incorporated into the system design, the compositional and structural homogeneity and heterogeneity of the asteroid could also be determined.

3) The **'Reconnaissance & scouting'** function of MASCOT could be used for assessing candidate sampling sites before samples are acquired. This implies however, that enough lead time for MASCOT deployment can be accounted for in mission operations before sampling.

The identified three roles led to a number of science requirements, such as:

- Characterize the landing site and up to 2 further spots regarding structures, textures, mineralogy and organic composition
- Perform 360° imaging in VIS and IR including DEM production
- Characterize subsurface material composition
- Determine mechanical and thermal soil properties
- Detect impacts of meteoroids within the landing packages lifetime

### 2.2 Payload Options and Strawman Payload

Huge interest has been identified in the science community to propose an instrument for the MASCOT lander. The range of payloads includes spectrometers, e.g. an APXS, Raman, Moessbauer Spectrometer or X-Ray Diffraction/X-Ray Fluorescence (XRD/XRF), but also analytical instruments such as the Evolved Volatile Ion Trap Analyzer (EVITA) or an Ion Laser Mass Analyser (ILMA). Other proposals considered the usage of an Instrumented Mole, a Micro-Seismometer or Radar Tomography Instruments. This list shows the great variety of possible payloads and hints at the range of different science objectives and is by no means complete.

During the concept study phase, the instruments have been assessed based on their scientific objectives and the compliance with the overall mission science objectives and requirements. Due to the strict mass limitations of the lander (see the next section for more details) a subset of 3 instruments, according to their compliance with the MASCOT science requirements, has consequently been chosen as strawman payload. This payload package of 3 kg comprises:

- ILMA (Ion Trap Mass Spectrometer) or XRD/XRF or Bi-static radar of 2 kg
- VIS and Infrared Microscope of 0.7 kg
- Wide Angle Camera of 0.3 kg

## 3. MISSION DESCRIPTION

### 3.1 Mission Requirements and Constraints

The relevant mission requirements and constraints for the MASCOT lander have been determined in close collaboration with JAXA/JSPEC and are based on the interface requirements with the main-S/C as well as the challenging environmental conditions during cruise and on the asteroids surface. They are more thoroughly described in the Mission Requirements Document [4], but a basic overview over the most important design drivers is given in the following section.

#### 3.1.1 Hayabusa-2 mission timeline and interfaces

The Hayabusa-2 mission, which is to be approved in Summer 2010, will be launched in late 2014. During cruise it will provide the MASCOT lander with the required energy for monitoring and commissioning activities as well as heating. Starting on arrival at the asteroid in June 2018, the spacecraft will perform remote sensing activities for the global characterization of the asteroid, with a first complete characterization anticipated to be finished in February 2019. (See Fig. 3 for a schematic sketch of the mission timeline.) The candidate points for touchdown and sampling will be selected during the characterization. After the complete characterization the main-S/C will start performing sampling rehearsal manoeuvres, during one of which the lander will be deployed. After the deployment of MASCOT, the main-S/C will perform its sampling manoeuvres and will ultimately send an impactor to the surface and investigate the processes occurring and materials released during the impact. The Hayabusa-2 mission will be finished in December 2019, when the main-S/C departs for its way back to Earth.

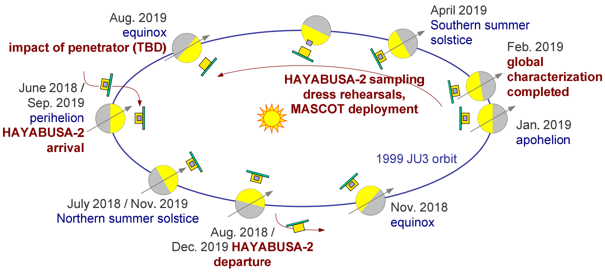


Fig. 3: Schematic showing asteroid during Hayabusa-2 mission timeline wrt. its cornerstones

The main constraints for the MASCOT design coming from the Hayabusa-2 spacecraft are the mass and the physical envelope. Currently, an upper mass limit of 10 kg including interface parts remaining on the main-S/C, as well as a volume with the dimensions of 0.3 x 0.3 m side length and 0.2 m depth shall be met by the

MASCOT design. The lander will be stowed on the +/-Y-Panel of the main-S/C (with the Y-axis being perpendicular to the fixed axis between spacecraft and Sun and the axis of the flight direction of the spacecraft), which has to be considered for the separation and landing phase.

As displayed in Fig. 3, the orientation of the main-S/C in the two-body system asteroid-Sun will be fix throughout the mission timeline, with the spacecraft always remaining inline between the asteroid and the sun. This constraint arises from the fixed solar arrays of Hayabusa-2, however, it excludes any communication between the main-S/C and MASCOT during night-time. To allow for at least 3 daytime communication cycles, the mission lifetime of the MASCOT-lander thus is required to be of two asteroid days, with landing occurring at noon.

Though the requirements coming from the main-S/C are comparably challenging, the following chapters will show that there is a huge potential to meet these requirements with a small, compact design that still offers a great science return.

### 3.1.2 Asteroid environment

MASCOT will land on the yet uncharacterized asteroid 1999 JU3. This asteroid is a C-type asteroid comparable in size with ITOKAWA (Fig. 4), which has been the goal of the Hayabusa mission, and is likely to be a rubble-pile type asteroid. Other specifications of 1999 JU3 are given in Tab. 1.

Tab. 1: Specifications of 1999 JU3 [5], [6], [7]

| Prelim. Designation | Taxonomic Type | Estimated Diameter | Rotation Period |
|---|---|---|---|
| 1999 JU3 | Cg | 0.9 - 0.98 km | 0.3178 d / 7.6272 h |

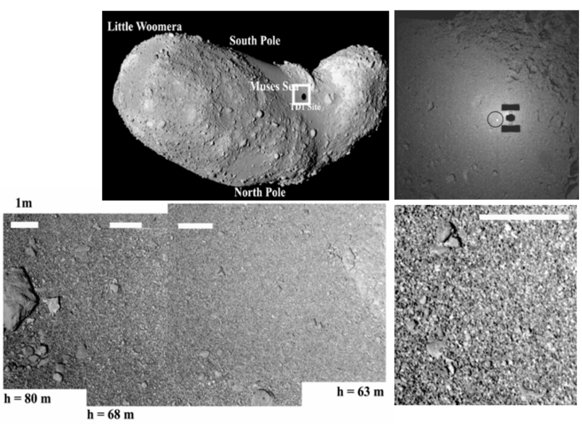


Fig. 4: Images at variable spatial resolution of Hayabusa's landing site on the asteroid Itokawa [8]

The thermal environment of the asteroid largely influences the design of the lander and also the preferred landing site. Using the orbital and rotational parameters of the body and the thermal properties of the soil, a temperature map of the asteroid over the operational timeframe of the mission has been established (Fig. 5) [9]. The inputs, which will be used for further investigations of the thermal design of the lander, show that the temperature has its total maxima at the northern and the southern summer solstice respectively. The global temperature range at the asteroid is between -200 and 120 °C, with -50 to 25°C being suitable for lander survival within the operations timeframe. Fig. 5 also shows the subsolar point, around which the landing will take place, as well as the favored separation window between ~ day 245 and ~ day 435 after perihelion.

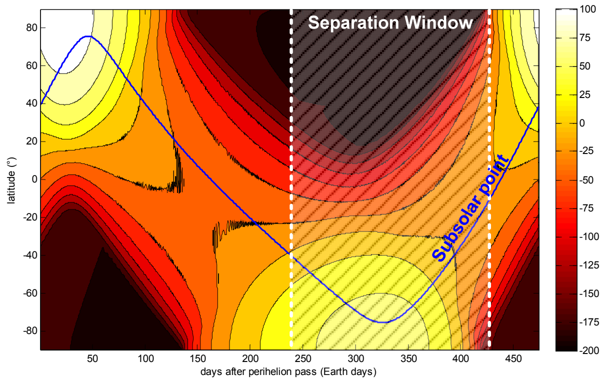


Fig. 5: Average daily temperature on the surface of the asteroid during MASCOT operational timeframe [9]

### 3.1.3 Communication

In general, any communication between MASCOT and the ground station is linked through the main-S/C. For the nominal mission operation the communication link is predominantly one-way, i.e. for down linking science and housekeeping data, and no active commanding from ground is foreseen due to the long turn-around time for command cycles, which would likely restrict available science time of the lander on the surface. Thus, it is planned that operations are conducted via a pre-programmed timeline, which may be altered autonomously based on system operational states, such as orientation on the surface, environmental conditions and availability of the link to the main-S/C. However, handshaking between the lander package and the main-S/C is required for controlling the communications sessions and for signal validation. Furthermore, based on the lessons learned during earlier missions (e.g. Beagle-2), one major requirement for the design of the communication subsystem is the enabling of communication throughout all mission phases, including the descent phase. By maintaining this requirement, it can be assured that every available bit of information is sent to the main-S/C, even in case of a failure during the separation and landing phase.

### 3.1.4 Mobility

Due to its limited size, the implementation of any active attitude control during the descent has not been an option for the baseline design of the lander. Consequently, the on-surface attitude after the landing is a priori not determinable. However, the instruments require a certain field of view and attitude towards the surface, thus uprighting of the system from any arbitrary on-surface attitude is a prime requirement for the design of the mobility S/S. The byproduct of having a possibility to relocate the lander via a hopping functionality would certainly enhance the overall science return, especially if the target asteroid will be comparable in surface heterogeneity as ITOKAWA. (See Fig. 4 for a general impression.)

### 3.1.5 Planetary Protection

Due to the chosen asteroid-type planetary protection aspects also have to be taken into account for the system design. Since the asteroid is a C-type asteroid and one of the main scientific goals is the search for organic molecules on its surface, one requirement has been that all material brought to the surface shall be readily distinguishable from surface material of the NEO. This includes structural material as well as potential contaminants.

## 3.2 Mission Operation

Fig. 6 gives an overview over the mission operational phases including the SDL (Separation, Descent and Landing) phase and the on-surface operation. More details are given in the following sections.

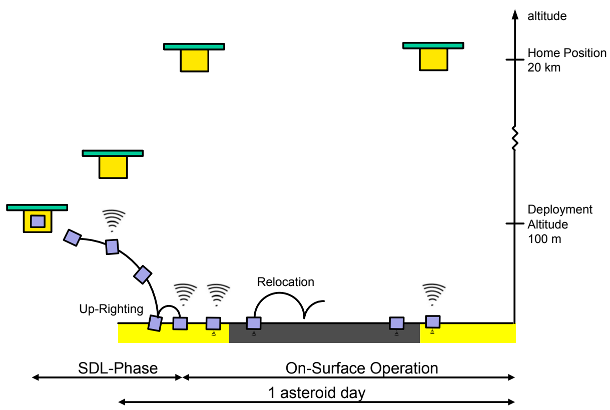


Fig. 6: Schematic of MASCOT Operational Sequence

### 3.2.1 Separation, Decent and Landing

The MASCOT lander will be deployed during one of the sampling dress rehearsal maneuvers from a low altitude of approx. 100 m. This constraint offers a passive and reliable landing strategy for MASCOT, while not disturbing the overall timeline or operations of the main-S/C. The envisaged separation window is also chosen to be ideal in terms of the thermal environment (Fig. 5). The deployment is performed by a pre-stressed spring, which will separate the lander with a few cm/s from its lateral storing position. After a ballistic descent of 20 to 30 min the lander impacts the asteroid surface and will bounce until it comes to rest on the surface in an arbitrary attitude. Due to the unknown soil properties an additional time span of 30 min is currently taken into account for this. After the deployment of the lander, the main-S/C will return to its home position in an altitude of 20 km and will provide the communication link from this position.

For the descent analysis, which has been performed using STK, a tri-axial ellipsoid shaped asteroid with two different effective diameters, 920 m and 980 m respectively, was assumed. The resulting inhomogeneous gravitational acceleration is very low, in the range of $10^{-4}$ to $10^{-5}$ m/s$^2$. For safety reasons the landing velocity was limited to half the escape velocity (with $v_{ESCAPE}$ being 32 to 36 cm/s), thus restricting the delta-v and the altitude of the separation. The position and velocity inaccuracies of the main-S/C result in a landing site and landing time dispersion for MASCOT, which has to be accounted for e.g. in the operations timeline. Due to the lateral deployment direction and a relatively high lateral velocity error a landing ellipse with a semi-major axis of 75 to 100 m was estimated.

### 3.2.2 On-Surface Operations

As displayed in Fig. 6, the on-surface operational phase directly follows the SDL-phase, which is finished after the lander has brought itself into the correct operational position, which means that the lander lies with the upper side orientated in main-S/C direction (i.e. to space) and the instruments-view-side orientated to the asteroid surface. This phase is expected to start roughly 1.5 hrs after the deployment, i.e. after midday in asteroid time. During the remaining daytime, the lander will start performing science operations with those instruments that allow or require daytime measurements, while a continuous communication link to the main-S/C is established and maintained. Approaching the terminator, the communication link will worsen until it breaks off and communication will be disabled during nighttime. Scientific investigations will go on, especially those investigations that require darkness will be performed and respective data will be stored for the next communication cycle. After one complete experiment cycle at the landing site, the lander will introduce a relocation/hopping manoeuvre. Section 4.8 gives a short overview over the design of the respective subsystem. Based on the ongoing numerical simulations, which account for different lift-off velocities and soil properties of the asteroid surface, a hopping distance of 10 to 70 meters is estimated.

After the lander has come to rest at the second site, an uprighting manoeuvre is initiated if necessary to realize the required measurement attitude. Otherwise, if all prerequisites are fulfilled, the second measurement cycle begins with nighttime measurements and all obtained data is stored in the onboard mass memory, until a second communication period can be started when the communication link is re-established at daybreak. This describes the basic cycle during on-asteroid operation, which will be repeated until the end of the lander's lifetime after 15 hrs of operation. However, please note that this is the ideal operation scenario and does not account for any off-nominal behaviour of the system.

## 4. LANDER DESIGN

### 4.1 System Overview

The baseline design for the MASCOT lander, as established and commissioned during the CE-Studies in 2009 and early 2010 is specified as follows:

- **Structure:** Aluminium-based support structure and casing with sandwich base and top plate
- **Configuration:** Prismatic body with fixed instrument accommodation, integrated electronics compartment/common E-box, no attitude control, no attitude stabilization during descent
- **Mechanisms:** Separation mechanism (relative to main-S/C) and a mobility mechanism for uprighting and hopping
- **Thermal:** passive thermal control
- **Power:** Primary battery (solar generators are optional)
- **Communication:** non-redundant, omnidirectional UHF-Band link between MASCOT and main-S/C
- **DHS:** Redundant on-board computer
- **Attitude Determination:** on-board sensors for determining movement and on-surface attitude

A mass breakdown of the current system configuration is shown in Tab. 2. For each subsystem, the dry mass is given based on the expert estimations. In addition to that, an effective margin is applied, which is based on the internal standard for CE-Studies and uses 5%, 10% and 20% margins for fully developed items, items to be modified and items to be developed respectively. The total mass of the lander including all margins has been estimated of being 9.5 kg. In addition to that, interface parts remaining on the main-S/C have been sized, which include e.g. an electrical support system and the release mechanism. The subtotal mass of the landed system and the parts remaining on the main-S/C of 11.3 kilograms is increased by a final system margin of 20%, which is a standard for a phase-A study as well. This leads to the total estimated mass of 13.5 kg.

Tab. 2: Mass Breakdown Table

| | **Dry Mass [kg]** | **Eff. Margin %** | **Wet Mass [kg]** |
|---|---|---|---|
| Structure | 2.90 | 0.0 | 2.90 |
| Thermal Control | 0.41 | 15.4 | 0.47 |
| Mechanisms | 0.48 | 17.8 | 0.57 |
| Communications | 0.36 | 10.0 | 0.40 |
| DHS | 0.40 | 20.0 | 0.48 |
| Power | 1.00 | 12.0 | 1.12 |
| Harness | 0.30 | 0.0 | 0.36 |
| Payload | 3.00 | 20.0 | 3.00 |
| Attitude Determination | 0.20 | | 0.24 |
| Landed Mass | 9.1 | | 9.5 |
| Interface Parts | 1.5 | 13.0 | 1.7 |
| Subtotal | | | 11.3 |
| Total incl. 20% System Margin | | | **13.5** |

### 4.2 P/L accommodation and structural design

Based on the requirements from the main-S/C as well as from the thermal design, surface mobility, payload accommodation, and spacecraft landing stability, the current design for the MASCOT structure is that of a prismatic body in which the instruments are accommodated in three instrument bays and other subsystems, e.g. the batteries, the transceiver and the common E-box are allocated in an optimized way using the remaining space. Fig. 7 shows the baseline configuration.

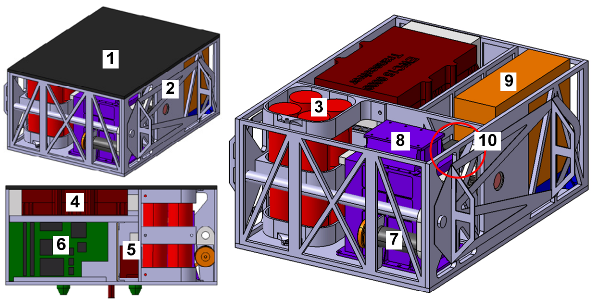


Fig. 7: MASCOT configuration isometric and side view with (1) sandwich top plate, (2) main aluminium structure (3) battery pack, (4) transceiver unit and (5) Rx-filter, (6) common E-box, (7) motor and gear for the mobility mechanism, (8) MicroOmega, (9) ILMA, (10) Camera

Regarding the instruments placement, a few requirements were identified as follows: The analytical instrument and the combined optical microscope and IR spectrometer shall be accommodated in a way that they view the surface material underneath the MASCOT package. No sample acquisition, transfer and preparation is necessary, but a certain minimum attitude regarding the distance to the surface as well as the angle has to be guaranteed. The camera shall be placed in such a way, that an acceptable height, thus range of the picture is guaranteed.

In general, the MASCOT structure relies on high integration of all components, i.e. avoiding any double walls if possible, leading for example to a common E-box whose walls are part of the supporting structure. The structure itself has been optimized for minimum weight and to sustain the launch loads, using various advanced design principles. A bending stiff base plate has been designed, reinforced by an isogrid structure, to introduce the loads from the main-S/C via the mechanical interface into the MASCOT structure. The body of the lander consists of a lightweight aluminium framework structure which is partially closed e.g. at the common E-box side and will be covered with MLI (Multi-Layer Insulation). The top-plate is an aluminium sandwich structure.

### 4.3 Power supply

The conceptual design of the power subsystem was driven by the MASCOT operating modes and operations timeline with ~85 Wh estimated total energy to be provided for the surface mission. This power has to be supplied for a time of 15 hrs during on-surface operation. The current baseline design for the power supply is a primary battery pack with ~160 Wh for 0.8 kg consisting of 6 cells SAFT LSH-20. A degradation of 15% during 5 years (one year before launch until MASCOT operations) has been considered. The bus voltage will be 6 V in 2p3s configuration and the battery allows ~10 W power consumption on average with 35 W peak power consumption and even 72 W for 100 ms pulse duration. A very simple PDCU in the form of a single PCB as part of the MASCOT electronics is foreseen.

A redundancy concept is implemented as follows: intrinsic redundancy is in the PDCU; two or three strings in parallel in the battery provide 50% or 33% of energy in case of failure of one string.

### 4.4 Thermal design

The thermal control concept has been designed to comply with the constraints and boundary conditions given by the target asteroid, as discussed in section 3.1.2. These conditions account for the on-surface operational phase as well as the times between separation and landing and during relocation. Due to the tight mass, power and volume budget, the current baseline design for the thermal S/S during the on-surface operational phase is passive, i.e. relying only on coatings of the equipment and on insulation materials. The current concept includes the following specifications:

- internal boxes (subsystems) are painted black on the outside
- the upper shell is black on the inside and white on the outside (to avoid excessive heating by the Sun)
- the lower shell has low emissivity and low absorptive coatings
- spacers and feet-mounted housings are used for instruments for decoupling of equipment from the bottom shell
- Multi-Layer Insulation (MLI) is used

Opposed to this, a heating unit has been estimated to be required for maintaining a minimum temperature during the cruise phase as well as for warm-up before the separation. The heater would be powered by the main-S/C and would consume 4.5 W during cruise and roughly 20 W for 1.5 hrs for warm-up.

### 4.5 Telecommunication Unit

The design of the communication S/S was driven severely by mass limitations, but also by the requirement of having omni-directional communication, as well as by the total accumulated data volume during operation. For the frequency, UHF-band has been chosen, which provides a good compromise between antenna size and free space loss. The current baseline favours the usage of a very lightweight (only 250 g) solution of single-chip transceiver IC's (COTS), allowing a flexible implementation with low component count, which is also very power efficient (3.3 V, 50 mA in receive mode). Using a data rate of 32 kbps, the total accumulated science data of 0.7 Gbit could be transmitted with a margin of 44%. Other details of the communication S/S are as follows:

- Configuration: 1 transmitter and 1 receiver on both spacecraft (the main-S/C and the lander); no redundancy foreseen otherwise
- Full-duplex communications
- A local protocol will be used that still has to be defined
- Loop antenna which allows omni-directional communication
- Commandability is possible, but only for foreseen in hazardous cases; handshaking for signal validation and access knowledge will be used

As a second option, the usage of common communication equipment on the main-S/C together with another landing package, called Minerva is currently under discussion and implications of using this option will be investigated further.

### 4.6 Data handling and management

The Onboard Data Handling System (OBDH) manages the MASCOT operations during all mission phases, including the following functions:

- gathering, storing, and processing housekeeping data from the lander's equipments
- providing data processing and data storing capabilities for the scientific instruments (including commanding, if required)
- monitoring of the health of the spacecraft
- autonomous control of the lander

The OBDH essentially consists of two identical units, one of which is located in the lander itself and the other one as part of the electrical interface onboard the main-S/C. During the cruise phase the interface unit is linked to the Hayabusa-2 data management system and fulfils all tasks required for monitoring and commissioning.

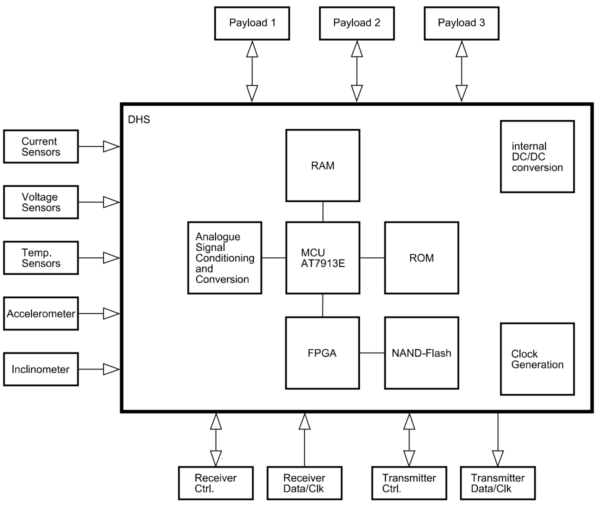


Fig. 8: Block diagram of the OBDH-System

During the operations on the surface of the asteroid, the OBDH unit onboard the lander manages the different operational modes and provides the platform for the autonomous decision making. Instruments are controlled or activated, data (H/K and science data) is gathered, processed and stored in the mass memory (which is sized to store all the total data volume expected during the lifetime) and telecommands are processed and actions derived. For these functions, the OBDH is connected to analogue sensors (temperature, voltage, current, acceleration), to the communications equipment, to the power subsystem and to the scientific instruments. The current baseline of the OBDH, with all its components is shown in the block diagram in Fig. 8.

### 4.8 Mobility

The main reason for the implementation of a mobility concept into the MASCOT design has been the realization of uprighting functionality from any arbitrary on-surface attitude, which is needed to sustain the suitable field of view to the surface for the instruments operations. The time constraint for the baseline design was set to be 30 minutes. In addition a second mode was implemented which allowed a relocation of the lander via a hopping manoeuvre, with the time constraint of 60 minutes.
A trade-study has been performed to narrow down the various concepts under investigation, with the basic requirements of robustness, low complexity and adequate adjustability/controllability of the energy to ensure a limited lift-off velocity (for safety reasons lower than 50% of the escape velocity), while assuming uncertain and various soil properties. The different concepts have been dynamically simulated using Multi-Body Simulation (MBS), which took into account the surface interaction (surface hardness, roughness etc.) and the mechanical design of the mobility subsystem. While the first concept was using so called lever arms to provide the mobility, the current most suitable solution resulting from the trade-off is a concept using momentum created by a defined stop of a motor excenter mass. By using this concept, several moving scenarios from different attitudes are possible, also using different accelerations and stop positions for the mass. The current mobility S/S thus consists of the actuator, i.e. a RoboDrive25 motor and a harmonic drive, a yet to be built controller and the excenter mass.

### 4.7 Attitude Determination

With the inclusion of a functionality to change the attitude of the lander, a determination of the same has been a prime requirement. The main tasks of the attitude determination or GNC S/S thus are as follows:

- Evaluate S/C attitude on ground (especially discovering the upright position, but also the angle and distance to the surface)
- Detect end of bouncing (after SDL and relocation)
- Provide opportunity science (e.g. the magnitude of bouncing shocks depends on type of surface)
- Support mobility S/S operation during uprighting (e.g. measurement of attitude rates)

For the mentioned tasks, a combination of MEMS gyros for detecting changes in attitude rates, accelerometers and a yet to be defined distance sensor (e.g. gravity-based, infrared or microwave) are currently under investigation.

## 5. OUTLOOK

The MASCOT-project is currently leaving Phase-A, having demonstrated the general feasibility of a 10 kg landing package with 3 kg of P/L for the Hayabusa-2 mission to be launched in 2014. Work will be finished regarding some open subsystems aspects, especially the detailing of the attitude determination and the mobility S/S and the modification of the communications S/S. After the approval of Hayabusa-2, we will start the subsequent phase B study work with more detailed subsystem investigations, optimization and breadboarding of the high-risk subsystems, e.g. the DHS and structure. Furthermore, the autonomy concept, which is only sketched so far, will be investigated in detail and tested with a FE2E (functional end-to-end) simulator using a stepwise SIL/HIL-approach (Software/Hardware-in-the-Loop).

In the meantime the final payload selection process will be initiated with close collaboration of all national and international partners.

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