MASCOT – A LIGHTWEIGTH MULTI-PURPOSE LANDER PLATFORM

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ABSTRACT

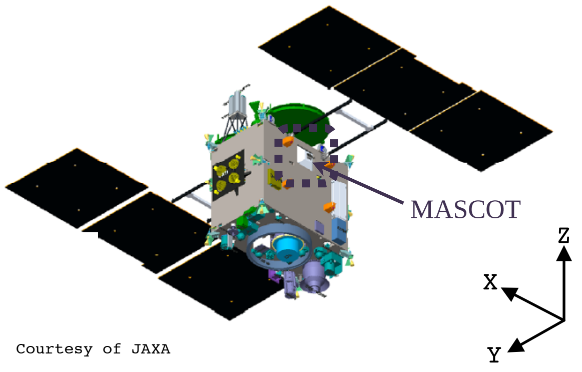
The Mobile Asteroid Surface Scout (MASCOT) is a small box shaped ~9kg lander, developed to support and enhance larger S/C's scientific possibilities. Its P/L compartment includes currently 3 experiments of in total 3kg. Further a mobility mechanism is on board which allows hopping manoeuvres on the asteroid.

The system consist of two structures, a lander unit and a mechanical I/F structure. Both are designed as framework structures made of solid CFRP and CFRP-foam sandwich respectively. By designing consequently under the use of the materials orthotropic properties and additional design features (e.g. insertless) a very lightweight and stiff structure has been realised. With respect to a fully aluminium design a save of 75% structural mass for the lander unit was achieved and the structure is ready to enter Phase C.

Being part of JAXA's Hayabusa 2 mission the launch date will be in December 2014 heading to the C-class asteroid 1999JU3.

1. INTRODUCTION

Asteroid missions are of high interest for finding a missing link in the development of life on Earth. Still the step from atoms to the formation of higher molecules is not yet clear. One theory is the impact of asteroids on Earth bringing these molecules with them. By an asteroid sampling mission this theory could be confirmed.



Courtesy of JAXA

Figure 1. Hayabusa 2 S/C with view to the -Y-Plane and deployed solar arrays (SA). In launch configuration the MASCOT system is allocated behind the SA.

As developed for the Hayabusa 2 (HY-2) mission MASCOT is a system of two separate structural main parts. On the one hand there is the landing module with a mobility mechanism, MASCOT itself. On the other hand there is the so called MESS (Mechanical-Electrical Support System), which remains on board of the mother S/C (HY-2).

Providing two structural parts is necessary, since the HY-2 S/C doesn't possess a MASCOT dedicated interface (I/F), but only a volume and cut-out in its -Y-Plane for accommodation (Fig. 1). Accordingly next to the lander a mechanical I/F, i.e. an appropriate mounting structure (MESS), has to be provided by the MASCOT system, too.
The MESS is rigidly connected to the mother S/C's -*Y*-Panel with an inclination of -15° (Fig. 2). This is due to the fact that in deployed configuration directly above the MASCOT system a solar array panel (SA/SAP) of HY-2 is located (Fig. 1 and 2).

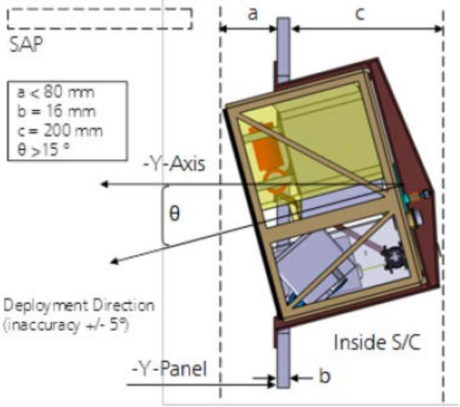


Figure 2. MASCOT/MESS system mounted on HY-2 -Y-Plane. In the upper part the E-Box compartment and in the lower one the P/L compartment.

Furthermore the MASCOT system needs to be installed on the mother S/C from the outer -*Y*-Panel side (Fig. 2) and being late accessible.

Having a closer look to the above mentioned requirements they could be an interesting feature for other exploration missions. Actually, the MASCOT/MESS system can be described as an extremely lightweight multi-purpose lander platform with a mobility mechanism. It can be used as an add-on experiment/exploration platform in various scenarios on low gravity bodies. Though, in the following the (structural) concept will be described as custom-designed for the HY-2 mission.

2. STRUCTURAL CONCEPT

In order to adapt the MASCOT system's structural design to the HY-2 requirements a system of two structural main parts was developed (Fig. 3). The MESS is used to provide for MASCOT an I/F to the HY-2 -Y-Panel. It transmits the mechanical loads in between both structures and serves at the same time as electrical I/F carrier (umbilical connector). Additionally a calibration target, which isn't needed on the lander during operation on the asteroids surface, is mounted on the support structure. In general the principal design is based on a framework structure, which has various advantages to pure solid structure:

- Good capability to "bridge" the cut-out by the mechanical I/F (MESS) and to realise highly efficient open geometries.
- Optimal structural shape (struts) to make use of the inherent strong orthotropic properties of unidirectional (UD) CFRP.
- Very good stiffness to weight ratio possible.

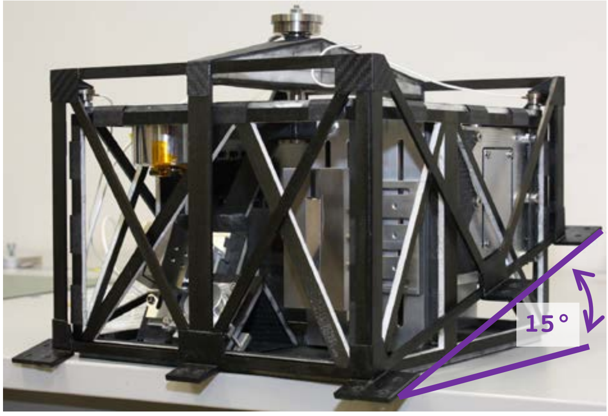


Figure 3. MASCOT, 1st structural model (inner cubic structure) connected to the mechanical I/F structure (MESS) by an structural model of the push-off mechanism.

Due to its "bridging"-function the MESS was directly constructed with an inclination of 15° with respect to the -Y-Panel (Fig. 2 and 3). Consequently MASCOT is tilted as well and a nominal straight release will avoid any collision with the mother S/C's SA.

2.1 Mechanical-Electrical Support System (MESS)

According to the framework principal nearly the complete MESS is made up of solid UD-CFRP (M40J) struts. Only the main truss is made up of a CFRP-foam sandwich. This truss includes the physical connection device between MESS and MASCOT – a non-explosive actuator (NEA). The actuator pulls MASCOT with 2500 N against 4 bearing points in the locally reinforced top corners of the support structure (Fig. 4). This load is derived as being high enough to avoid any lift-off of MASCOT at its bearing points during launch phase. Since the NEA keeps MASCOT only in position also a push-off mechanism is needed. This is basically a spring pushing against a plate, which is guided in the direction of separation. The plate is necessary since the excentric spring of the push-off mechanism doesn't push directly through the lander's centre of gravity (CoG). Consequently the push-off plate design is determined by the diameter necessary to push through MASCOT's CoG. By giving the energy contained in the spring the approach speed can be controlled. A first test of the push-off mechanism was performed in the 19th DLR parabolic flight campaign (see Chap. 4.1).
Considering only the MESS structure w/o the separation and push off-mechanism it has a weight of only 550 g.

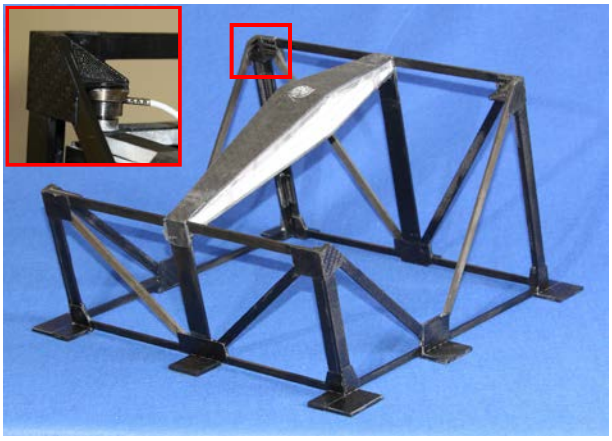


Figure 4. MESS, 1st structural model and detail of one corner's bearing point with a 5kN load cell for measuring the reaction forces during shaker tests.

2.2 Lander (MASCOT)

For the lander a framework design was selected as well. It has the outer dimensions of 295 x 275 x 195 mm³ and contains two by a middle wall separated compartments. One for the P/L and another one dedicated for the E-Box including the power supply and a mobility mechanism (Fig. 5, top). This one is located on the side of the E-Box pointing into the direction of the middle wall. It works with an excentric mass being accelerated for the hopping manoeuvres. All together the lander is in its current design able to support 3 instruments with an overall mass of 3 kg. The on board power supply is designed to supply the lander for 16 hrs, which corresponds to 2 asteroid days on 1999JU3.

In contrast to the MESS the lander structure is completely made of sandwich components. Most of the struts consist of not more than one UD-CFRP facesheet ply (LTM123/M55J) on each side and a foam core (Rohacell IG-F 31). Only shear loaded parts are additionally reinforced with ±45° CFRP plies

(Epoxy/M40J). This relates especially to the upper middle wall at the region around the structural I/F between MASCOT and MESS. In Fig. 5 (left) it can be seen how the load introduced by the NEA is lead through the diagonal struts of the middle wall. From there ± 45° CFRP straps connecting the middle and side wall transmit the loads to the side wall by shear. Also the other wall parts are connected amongst each other by ± 45° CFRP straps. Once introduced into the sidewall the load is subdivided again and lead through the side wall struts to the bearings in the 4 corners of MASCOT (Fig. 5, right). These conical shaped bearings allow a force transmission in axial and in radial direction. All moment axes at the 4 bearing points are free. Where the bottom of MASCOT has a framework the counterpart side is closed radiator surface. Currently the radiator is a CFRP-foam sandwich construction. It is connected via screws drilled into resin threads with the side walls. Partially the resin threads are substituted by Helicoils® (Fig. 6).

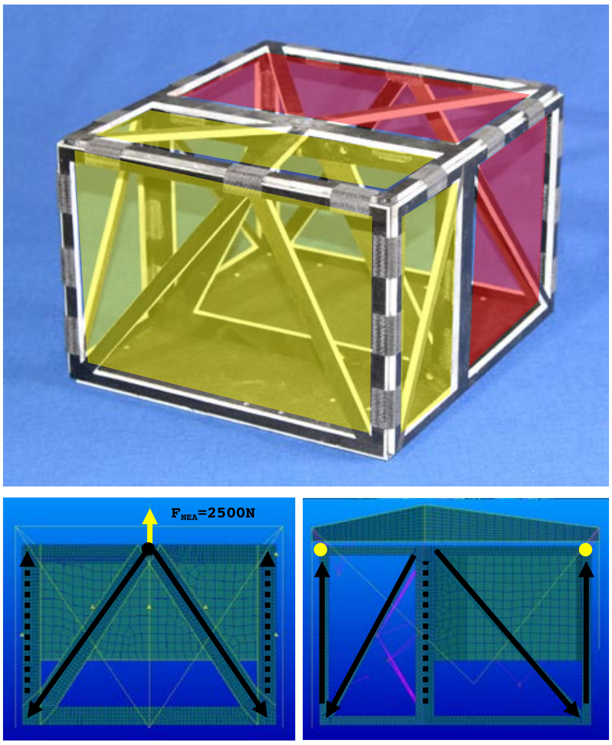


Figure 5. MASCOT, subdivided into a P/L compartment (yellow) and the E-Box compartment (red). Below the load path within the middle wall framework is shown. The load is introduced by the NEA with preload of 2500 N (left). By shear into the sidewall transmitted load is further lead to the 4 bearing points at MASCOT's corners (right).

In comparison to an earlier fully aluminium design of the lander structure with similar design approach the CFRP structure is about 75% lighter. Though, the stiffness of both structures is in a similar range, which clearly demonstrates the advantage of UD-CFRP used in framework structures like this. The total structural mass of the MASCOT system is 950 g, which equates an overall structural mass ratio of ~9%. The complete system's mass is ~9 kg.

3. DESIGN FEATURES

The MASCOT system is characterised by various design features. Some still need to be tested or detailed designed:

- Framework design for an optimal use of the orthotropic material properties of UD-CFRP, which results in a very stiff and lightweight structure. The total structural mass of the MASCOT system is 950 g (450 g MASCOT lander + 500 g structural I/F). This equates an overall structural mass ratio of ~ 9%.
- Completely insertless designs, i.e. the screws are drilled into pure resin threads (Fig. 6, left). These are done by removing locally the foam and potting the whole with resin. Some threads are reinforced by Helicoil® substitutions (Fig. 6, right). Both designs worked well, but were not yet tested with full load level. According pull out tests will be performed soon.
- Function integrated design. For example the middle wall as main loaded I/F and central load distributing structure supports also two instruments. The same is valid for the sidewalls, which support in the latest design iteration the E-Box. So no additional brackets are needed.
- Mobility mechanism, which allows hopping manoeuvers on the asteroid's surface. The mechanism is embedded into the E-Box structure.
- Excellent field of view due to the framework structure.
- Multi-purpose usage. By shifting the middle wall along the main truss axis of the MESS the P/L and E-Box compartment respectively can be varied in volume. Accordingly also the MESS I/F is shifted. The push-off plate allows a push vector offset to the lander's CoG as already realised in the current design. In general the way of providing its own adaptable I/F structure the MASCOT system can be mounted in various positions on its mother S/C.

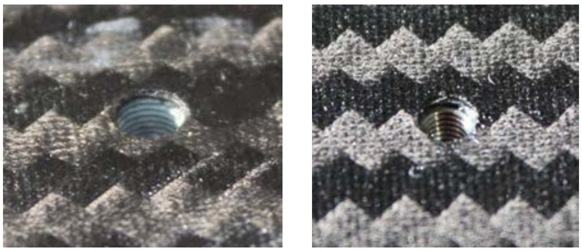


Figure 6. Resin thread (left) and resin potting with Helicoil® (right).

4. SIMULATION & TESTING

The structural MASCOT/MESS system has been simulated by a finite element model (FEM). The MESS is mostly represented by BAR elements (except of the main truss) whereas all sandwich structures are represented by 2D shell elements (compare for example to Fig. 5). Fig. 7 shows the results of a frequency response (FR) calculation to an excitation in X-direction. The X-direction can be consider as worst case regarding FR and clearly the first eigenfrequency of 120 Hz can be recognized.
The first shaker test with the structural model (STM) was performed with maximal 5 g instead of 25 g as required. Furthermore the STM was made of high tension fibres that won’t be used for the qualification and flight model. These will be made of high modulus fibres as described in Chap. 2.2. However, the behaviour of the STM was as expected regarding the FEM calculations. Of course, the first eigenfrequency was lower. According to the lower excitation of 5 g also the preload of the NEA was with 500 N five times lower. During shaker test the resulting reaction forces at the 4 bearing points were positive, so no lift-off could be recognised.

The next shaker test campaign with full loads will follow in April. Also outgassing tests have to be performed.

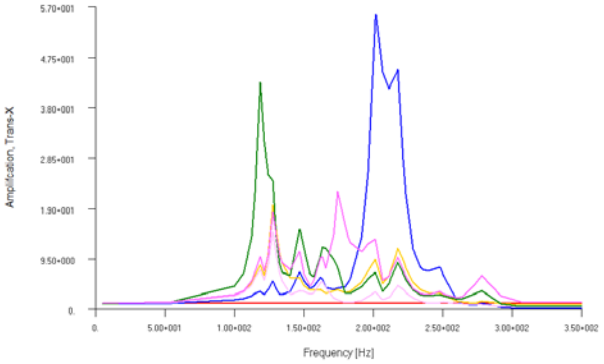


Figure 7. Frequency Response to an excitation in X-direction.

4.1 Parabolic Flight Campaign

Additionally to the laboratory tests MASCOT was successfully tested within DLR’s 19th parabolic flight campaign (Fig 8). Here especially the mission critical separation phase of MASCOT from the mother S/C and the MESS respectively was demonstrated. The aim was to test the push-off mechanism and to verify an according multi body simulation. Furthermore there is energy stored in the MASCOT structure due to the preloading induced by the NEA. The aim was to get a better understanding of the influence of the so stored energy on the lander’s dynamic behaviour during and after separation.

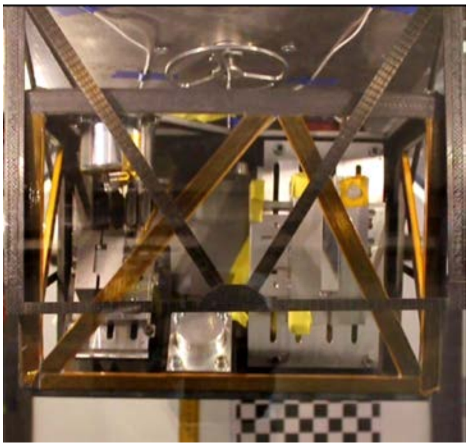


Figure 8. MASCOT after separation within the MESS dummy during parabolic flight test. At the top the plate of the push-off mechanism.

5. CONCLUSION

Developed for the HY-2 mission with launch date in December 2014, the MASCOT system shows a good performance. The lander is much lighter (>75%) than a comparable aluminium structure while having nearly the same stiffness. As the first shaker campaign with reduced loads (5 g), the parabolic flight campaign and according simulations have successfully proofed the MASCOT/MESS design it will be on board of the HY-2 S/C and can enter Phase C soon.

Several solutions as the insertless design and strap connections, the use of a highly orthotropic “1 ply UD layup” for most of the sandwich facesheets as well as the functional integration will be further followed.

The structural flexibility regarding accommodation and nearly no structure around the P/L compartment due to the framework design offer a lot of variations. In addition MASCOT has its own mobility unit and provides an adaptable I/F structure (MESS). Due to this it may be used also for other missions heading to low gravity bodies.

5.1 Outlook

Although the design is already sophisticated, some further tests and detailed design have to be performed, i.e. for example outgassing test of the foam core and pull out tests for the resin threads. Next, a shaker test campaign with full levels will be performed before the detailed design activities are started. The QM (qualification model) will be manufactured right after by the middle of 2012. Due to thermal reasons also optional sandwich designs for the radiator plate (aluminium honeycomb core, different face sheet materials) will be investigated.