SAMPLE CANISTER CAPTURE MECHANISM FOR MARS SAMPLE RETURN: FROM CONCEPT TO TRL 6 (INCLUDING 0-G ENVIRONMENT)

F. Mailland[(1)], E. Piersanti[(1)], A. Bursi[(1)], L. Montemurro[(1)]
R. Carta[(2)], D. Filippetto[(2)], M. Lavagna[(2)],
S. Debei[(3)], M. Zaccariotto[(3)], C. Bettanini[(3)]
J. Larranaga[(4)],
P. Falkner[(5)]

[(1)] *CGS S.p.A., Compagnia Generale per lo Spazio, an OHB Company, via Gallarate 150, 20151, Milano, Italy,* fmailland@cgspace.it, epiersanti@cgspace.it, abursi@cgspace.it, lmontemurro@cgspace.it
[(2)] *Politecnico di Milano, Dept. Of Aerospace Science and Technologies, Via La Masa 34, 20156, Milano, Italy,* riccardo.carta@polimi.it, daniele.filippetto@.polimi.it, michelle.lavagna@polimi.it
[(3)] *CISAS - "G. Colombo" Center of Studies and Activities for Space - University of Padova, Via Venezia 15, 34131, Padova, Italy,* mirco.zaccariotto@unipd.it, stefano.debei@unipd.it, carlo.bettanini@unipd.it
[(4)] *Aurora Technology B.V. for ESA, Heereweg 345, 2161CA Lisse, The Netherlands,* jonan.larranaga@esa.int
[(5)] *ESA-ESTEC, Keplerlaan 1, 2201AZ Noordwijk, The Netherlands,* peter.falkner@esa.int

ABSTRACT

The ESA Study "Sample Canister Capture Mechanism (SCCM) Design and Breadboard" has been conducted under the Mars Robotic Exploration Preparation (MREP) program. The Study is part of a set of feasibility studies aimed at identifying, analysing and developing technology concepts enabling the future international Mars Sample Return (MSR) mission.

The activity focuses on the design of a mechanism that shall enable the Orbiter of the Mars Sample Return mission to recover a spherical Orbiting Sample (OS) coming from Mars surface that contains a set of soil samples. The design concept of such mechanism has been then demonstrated performing a set of Functional, Micro-gravity and Environmental tests on an Elegant Breadboard Model implemented during the Study.

The paper focuses on design solutions implemented and lesson learnt raised during the mechanism development; starting from the design concept, the validation through the test activities including the parabolic flight, and the future possible improvements.

1 OVERVIEW

The Sample Canister Capture Mechanism (SCCM) is a technology development activity in the framework of the ESA MREP program. The MSR is a challenging mission with the purpose to send a Lander to Mars, acquire samples from its surface/subsurface and bring them back to Earth for further more in depth analyses. In particular, the technology object of the Study is relevant to the Capture Mechanism that, mounted on the Orbiter, is in charge to capture and secure the Sample Canister or Orbiting Sample accommodating the Martian soil samples, previously delivered in Martian orbit by the Mars Ascent Vehicle. Such a technology has been investigated in several past studies, where different concepts based on partial (with rigid frame) or fully inflatable mechanisms have been considered, demonstrating several unsolved criticalities.

A new robust concept based on simplicity, lightness and compactness has been developed, able to meet an updated set of demanding requirements and stringent performance, coming from the past experimental activity results. The concept is based on a single degree of freedom mechanism that performs three main operations required during the capture manoeuvre in Mars orbit: OS retention, OS transfer and OS securing inside the Orbiter. The SCCM is composed by a rotational arm that moves inside a CFRP funnel which accommodates two optical detection sensor lines, a soft impact surface to damp the OS motion and an Hold-Down and Release Mechanism which holds in position the Arm during the launch phase. The SCCM design turned out to be quite challenging in fulfilling the requirements. Several architectural solutions have been traded-off; parts geometry and kinematics were designed in order to avoid OS jamming between the arm and the funnel, to guarantee that sensors could detect the incoming OS, and to prevent the OS escaping before the arm closure. The implemented actuation chain (composed by the motor, gearbox, bearings, coupler and arm) ensures a motorization factor sized according to a set of demanding requirements, compliant with the ECCS standards even under the worst environmental conditions, for example the arm shall keep the moving OS inside the funnel during the capture, preserving its nominal functionality, while the OS is bouncing against the arm itself, moreover the arm shall ensure the adequate stiffness when locked at the manoeuvre end. The optical sensors positioning is optimized to guarantee reliability against failures, maximize simplicity and lightness, and minimize their triggering time lag. Multi-body modelling has been used to analyse the capture dynamics and to produce a design robust to failures, followed by an extensive sensitivity analyses which investigate the SCCM scalability. At the end of the design process, an elegant breadboard model

Proc. '16th European Space Mechanisms and Tribology Symposium 2015',
Bilbao, Spain, 23–25 September 2015 (ESA SP-737, September 2015)

(EBM) was built and tested in relevant environment, under collaboration between CGS SpA, CISAS and Politecnico di Milano, verifying the design performances and bringing the mechanism Technology Readiness Level (TRL) to level 6. In particular the successfully performed test campaign includes the mechanical properties characterization tests, the on ground functional tests, the environmental thermal-vacuum and vibration tests. The EBM has been then tested in the relevant environment (0-g parabolic flight) to investigate the capture dynamics and the mechanism performance under microgravity. All tests have been successfully completed, demonstrating very good performance, even beyond those nominally expected.

2 DESIGN

2.1 Capture Operation

Once the orbiter will have reached the final operative orbit around Mars, the SCCM will be set in stand-by mode waiting the start of its nominal mission, and during the rendezvous it will be in a ready for capture configuration. In this last phase, the SCCM will have to fulfil three different main tasks, the first is to ensnare the OS, the second is to transfer it into a trap, and the third is to secure the OS inside the trap. This SCCM is designed to entrap an OS with spherical or quasi spherical shape having a diameter of 230 mm.

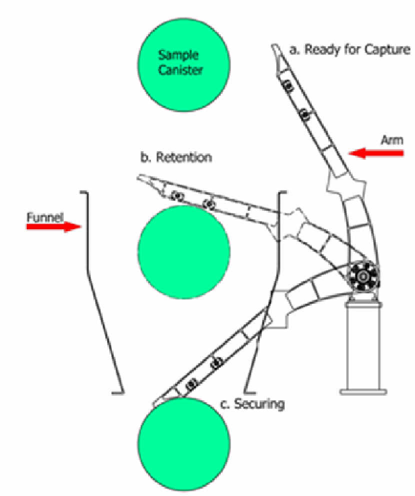

Figure 1. SCCM Operative modes: a. Ready for capture, b. Retention, c. Securing.

The current operations envisage that the when the OS is approaching the orbiter, the arm is opened and fully out from the funnel, which is a container equipped with two row of optical sensors. Once these detectors are triggered by the passage of the OS, the arm is suddenly rotate to a "retention" position, closing the funnel entrance, preventing the OS to escape. The OS therefore it is able to bounce on the funnel wall and on the arm. In order to reduce the kinetic energy of the OS during these bounces, the internal wall of the funnel is covered with a damping material. After that some of the residual energy of the OS has been reduced by the impacts with the wall, the arm will be slowly closed in order to drive the OS towards the trap. At the end of this "transfer phase" the OS will be pushed entirely inside the trap.

2.2 Flight Model Design

The SCCM has an overall volume of 800 x 800 x 500 mm^3 when in stowed configuration, and foresees four main elements: a funnel, an arm, an actuation chain and an arm support tower.

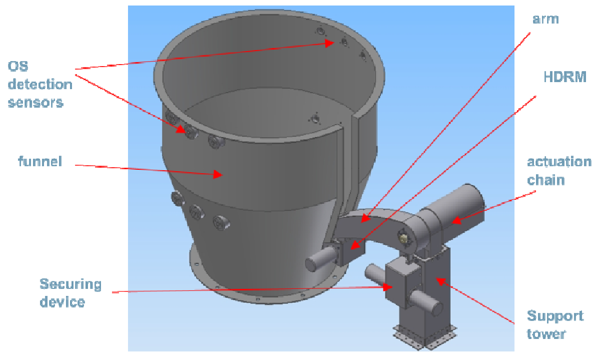

Figure 2. SCCM flight model concept.

The funnel is represented by a container made in Composite Fibre Reinforced Polymer (CFRP), aimed at providing the artificial envelope where to "capture" the Sample Canister before its retention and securing inside the trap. Such a funnel has been shaped in order to prevent any jamming of the OS during all arm operations. On its lateral sides, it accommodates two rows of optical sensors which are instead aimed at detecting the OS transit during the capture manoeuvre.

The arm is made in aluminium alloy and is accommodated on a lateral side with respect to the funnel. Its main task is to perform a set of operations enabling retention, transfer and securing of the OS once this latter has entered the funnel envelope.

In order to provide the required movement to the arm, an actuation chain has been also designed, composed by: a hinge, a shaft, an electric stepper motor and a gearbox. Inside the hinge, two back-to-back bearings allow the rotation of the shaft on which arm is mounted.

Moreover, during launch the arm is foreseen to be locked on the funnel structure trough a Hold Down and Release Mechanism (HDRM) which is located on a flange just below the slot needed to allow the arm passage. Finally, for arm accommodation, a Support Tower in aluminium alloy has been envisaged.

All mechanisms (HDRM, Motor and Securing Device) have been covered with a micrometeoroid and thermal shield, in order to prevent them to be damaged by small debris and help the thermal control system to keep them at the right operational temperatures.

2.3 Performance

The system has been designed in order to be able to satisfy the requirements related to a variable incoming trajectory, leading to the following improved capabilities:

	Min.	Max.
Incoming speed	5 cm/s	15 cm/s
Radial offset from the geometrical centre of the funnel	0 cm	100 cm
Angular misalignment from the nominal direction	0 °	5 °
Radial offset of centre of mass with respect to the geometrical centre	0 mm	5 mm
OS mass	4 kg	6 kg
OS diameter	15 cm	30 cm

Table 1. SCCM design performance.

Each sensing and actuating devices (HDRM, motor, optical barrier) are fault tolerant. Moreover the redundant optical barrier, made of 6 optical lines, allows roughly estimating the direction and velocity of the incoming OS.

When the arm is brought from the stowed configuration to the ready for capture position, no high acceleration levels are expected and a torque slightly higher than the resistive one shall be produced by the motor. As the OS triggers the sensors, the arm is moved of 45° avoiding any impact with the OS itself (retention operation), and even in this case the torque that the motor must develop has to be slightly higher than the resistive torque. Once retention has been performed, the arm is then kept in that position for up to 30 seconds. During this short time interval, the OS could impact back on the arm, introducing a further torque due to the maximum impact force at the tip of the arm. In order to reduce such a torque, two approaches have been implemented: reduce the actuation chain stiffness by modifying the shape of the shaft, and allow the occurrence of some slippage. During transfer, the provided torque has to be greater than the resistive torque, at which it has to be added the one required for moving the OS towards the trap. Since the maximum torque occurs during the transfer operation, this then results as the sizing case, as reported in Tab. 2.

Operation	Torque
Opening the arm / Closing to retention	57.3 Nmm
Retention	100.0 Nmm
Transfer	108.5 Nmm

Table 2. Motor required torque.

The total mass of the SCCM was required to be less than 16 kg, with a goal of 10 kg. The current FM design foresees a total mass of about 12 kg.

The peak power occurs during the activation of the HDRM (33W), whereas the maximum power during the capture phase is of about 27W.

3 MANUFACTURING AND INTEGRATION

The Elegant Breadboard Model (EBM) was assembled and integrated at PoliMi-DSTA, in particular the Funnel is made of CFRP, the Support Tower, the Arm and the Baseplate are Aluminium parts and the Actuation Chain is composed of Aluminium and Steel parts. The optical instruments were provided by CISAS together with their own electronics while the DC motor was purchased from Phytron. With respect to the previous EBM design the motor changed therefore some modifications were implemented to cope with the new mechanical test requirements; in particular the Support Tower and the Motor Interface Flange were extensively reshaped in order to improve the frequency response while reducing the acceleration levels of the Breadboard under qualification vibrational solicitation. Moreover a different HDRM (from TiNi Aerospace) has been selected in order to ease the mechanism testability.

Figure 3. Elegant Breadboard Model, as built.

Tab. 3 reports the EBM weighted mass budget.

Description	Mass [g]
Funnel Assembly	5915
Arm Assembly	1764
Drive Mechanism Assembly	2103
Tower Assembly	2578
Baseplate Assembly	57972
Total	70333

Table 3. EBM Mass Budget.

The mass of the EBM solely (without the baseplate assembly) is 12361 g.

In the following figures more details of the model are shown.

Figure 4. from top-left: HDRM, arm latching, arm hinge, arm and support tower.

4 TEST

The on-ground SCCM Test Campaign had the objective to raise the current Capture Mechanism technology and to validate the developed SCCM design concept by means of environmental testing. Furthermore, a Parabolic Flight Test Campaign has been conducted in order to test the system in representative 0-g conditions, bringing it up to TRL 6 (demonstrating the critical functions of the element in a relevant environment).
The considered system is the Elegant Breadboard Model (EBM), which is representative as much as possible of the designed Flight SCCM concept. This representativeness is important in order to guarantee the applicability of the test results also to the designed concept.
The on-ground Test Campaign foresees two main sets of tests: Functional Tests, in Earth gravity environment making use of a simulated 0-g Ground Support Equipment, and Environmental Tests, including both vibrations and thermal-vacuum tests.

4.1 Functional tests

Functional Tests (FTs) was aimed at demonstrating the functionalities and performances of the critical components of the EBM, as well as of the overall system. Such an objective has been achieved by performing the foreseen SCCM operations (arm release, deployment, closure, reset, and retention) and comparing the obtained results (in terms of arm speed, arm position, OS detection capability, etc.) to the defined requirements. In order to simulate the Mars Orbit 0-g environment, an ad-hoc test set-up was implemented, foreseeing the use of simulated 0-g Ground Support Equipment designed and assembled at PoliMi-DAST, see Fig.5. The EBM was accommodated and fixed in “reversed” position (with the funnel entrance facing the ground), and by mean of a motorized pulley, it was possible to simulate the OS (hanged to a thread) approach at different speeds.

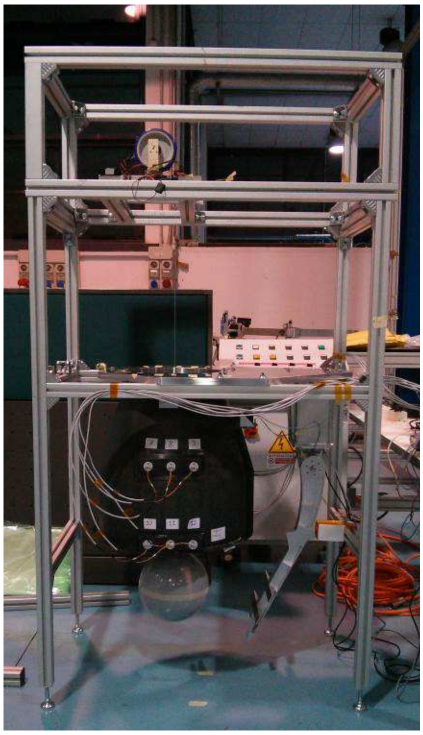

Figure 5. 0-g Ground Support Equipment (GSE).

Moreover, this equipment allowed the EBM position to be modified with respect to the OS position in order to simulate different OS entrance conditions (trajectory angular and radial misalignments w.r.t. the nominal trajectory coincident with the funnel longitudinal axis):

OS initial angle [deg]	OS initial offset [cm]	OS initial speed [cm/s]
0	0	10
5	10	15

Table 4. OS initial conditions.

The GSE also allowed the EBM to be positioned in a horizontal configuration in order to reduce the effects of the gravity on some of the measurements. This particular test configuration was used to measure the motor maximum torque, minimizing the effect of gravity acting on the arm own mass. A strain gauge half bridge was installed on the EBM motor shaft to measure the torque delivered by the motor while its internal temperature was monitored by means of the motor embedded temperature sensor.

Figure 6. Functional Test (OS approach).

The functional on-ground test campaign was overall successful demonstrating:

- all components (e.g. motor, actuation chain, HDRM, latching device, optical barrier, micro-switches) performed as expected
- OS motion sensing and arm actuation
- optical barriers multiple failures tolerance
- mechanism performance (Tab.5)

Performance tests	Results
Arm closure/deployment duration	<20s
Retention duration	6,60 – 7,60 s
Motor maximum torque	11 Nm
Motorization factor	~60
Failure mode	>2 failure tolerant

Table 5. Functional tests results - performances.

4.2 Environmental Tests

Environmental Tests had the objective to demonstrate the capability of the EBM to withstand to launch and thermal-vacuum environments. Such an objective has been achieved by testing the EBM under environmental conditions simulating the real ones that would be faced by the SCCM during its mission. Proper existing facilities for environmental tests have been used. First, the Thermal Vacuum Test (TVT) was performed, followed by a full set of functional tests in order to verify that no functional degradation has occurred on the EBM. After that the Vibration Tests (VTs) were performed followed by an additional set of functional tests to verify the EBM status.

The TVT foresaw accommodating the EBM inside a Thermal-Vacuum chamber in a horizontal configuration, which was required for the operations execution and the motor torque measurements during the thermal cycles. However, this affected the duration of the thermal stabilization period that relied only on radiation, because the experiment size which prevented the installation of the EBM directly in contact with the chamber cold plate.

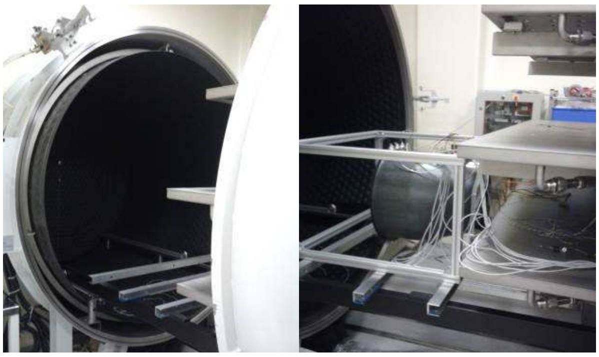

Figure 7. T-V test setup.

The test consisted in operating the EBM along a predefined temperature profile simulating the thermal environment faced by the SCCM during its mission. The temperature profile foresaw a set of complete thermal cycles (1 cycle at non operative conditions, 7 cycles at operative conditions):

Temperatures	Values
Minimum Non-Operational/Survival Temp.	248 K
Minimum Operational Temperature	252 K
Maximum Operational Temperature	322 K
Maximum Non-Operational/Survival Temp.	335K

Table 6. T-V test temperatures.

During the first cycle, the SCCM was not operated. After this, the remaining 7 cycles simulated the temperature profile associated with the minimum and maximum operative temperatures. During each of these cycles, the arm movement was tested to verify its proper functioning and the motorization factors were measured. Moreover, at the minimum temperature of the first of these seven cycles, the release of the HDRM was also performed. At the end, the EBM functionalities were verified by performing a full functional test assessment.

The test campaign was overall successful demonstrating (in both cold and hot environments):

- all components (e.g. motor, actuation chain, HDRM, latching device, optical barrier, micro-switches) performed as expected
- arm actuation
- mechanism performance (Tab.7)

Performance tests	Results
Arm closure/deployment duration	13.5 – 14.2 s
Motor maximum torque	8.91 – 10.75 Nm
Motorization factor	~14

Table 7. T-V test performances.

The Vibration Tests (VTs) were performed with the objective to verify the capability of the EBM to withstand the expected launch conditions. The VTs foresaw to accommodate the EBM on a vibrating slip table for the tests along the funnel entrance plane (X and

Y axis), and on the top of a shaker with a head expander for the tests along the longitudinal axis of the funnel (Z axis). During the tests, the arm was in stowed configuration (the foreseen launch configuration) with the HDRM engaged. Once completed the campaign, the functionalities of the EBM were further demonstrated by performing functional tests of the Arm Assembly (actuations with/without load) and of the HDRM (release) in order to verify that no damages occurred on its structural integrity.

Figure 8. VT setup shaker (left) and slip table (right).

More in detail, the Vibration Tests performed on each axis foresaw the following cases:

- Low level sine vibration test for resonance search;
- Sine vibration test with levels typical of a large launch system;
- Random vibration test with levels typical of a large launch system.

The levels applied were selected to be consistent with those of a typical large launch system (e.g. Ariane5) and are the same already used in a reference study case:

Test type	Description
Resonance search test	10 – 2000 Hz, 0.2 g
	5 – 21 Hz →±5.7 mm
Sine X-axis	21 – 60 Hz → 10 g
	60 – 100 Hz → 6 g
	5 – 21 Hz →±5.7 mm
Sine Y-axis	21 – 60 Hz → 10 g
	60 – 100 Hz → 6 g
	5 – 21 Hz →±11 mm
Sine Z-axis	21 – 60 Hz → 20 g
	60 – 100 Hz → 6 g
Random X-axis	9.03 gRMS
Random Y-axis	9.03 gRMS
Random Z-axis	14.00 gRMS

Table 8. VT levels.

The VT campaign was overall successful, demonstrating the EBM capability of withstanding the input levels without degrading the system performances. Especially, the first frequency is >100Hz. Frequencies of the first modes of the EBM are reported in Tab. 9. The columns represent the frequencies resulting respectively from the FEM analysis, the resonance search before the VTs and the resonance search after the VT campaign. The percentage of reduction of the frequencies between the vibration test and the FEM analysis is always below 15%.

Mode ID	FEM [Hz]	Before VT [Hz]	After VT [Hz]
1	123.75	107	107
2	134.24	117	117
3	141.56	125	125
4	150.17	138	136
5	151.22	145	144
6	223.21	200	201

Table 9. Resonance search results.

4.3 Parabolic flight

The in-flight Test Campaign was aimed at demonstrating the capability of the designed and manufactured EBM to perform the required capture operations in a relevant environment, here represented by the zero-g/microgravity condition provided by the Parabolic Flight, which allows testing the system with a realistic OS dynamics.
The test took place during the 61st ESA Parabolic Flight Campaign at Novespace premises in Bordeaux-Merignac: it foresaw three days of tests and in each day 31 parabolas were performed, with a 22 seconds of microgravity phase for each parabola. In the first day of flight the tests were performed without taking into account OS misalignments and operating at fixed OS speed. This enabled verifying that all functionalities were correctly provided, calibrating the launcher and assessing the acceleration perturbation effects on the launcher performances. These tests provided inputs to choose the launching strategy for the following days in which the complete tests were performed. The following two test days were used to perform the complete test: each one was divided into two parabolas using the first one for launch and retention operation and the second for transfer and securing. The results of the first day, in particular of the transfer and the retention operations, were used to optimize the test sequence for the complete tests, which at the end resulted in a complete capture operation within a single parabola. Both in test days 2 and 3 the launch was performed considering different configuration of launcher offsets (0-10cm), angles (0-5 deg) and initial speeds (16-21cm/s).
The EBM was included within a Flight Experiment Rack, in order to cope with the special conditions of a parabolic flight. In particular the free-floating OS was subjected up to 2g of accelerations during the hyper-gravity phases at the beginning and at the end of each parabola: an impact of the OS onto the arm, in this condition, could generate a torque that the motor was not design to withstand. To take care of this issue, the solution adopted was the use of a brake (Mayr® ROBA-stop-M 16/891.100/28) mounted on the arm shaft, which decoupled the motor from the arm during hyper-gravity phases thus blocking the arm. Furthermore it was necessary to design a device able to provide the OS with an initial trajectory and velocity suitable to test and

verify the EBM capture capability. The OS launcher was therefore designed for variable initial velocity (10-25cm/s), trajectory inclination (0-5 deg) and displacement (0-10cm), OS retention under an acceleration of 2g in all directions, simple reset and quick launch. The OS launcher is shown in Fig. 9; the spring is responsible of imparting the linear velocity to the OS and the actuation system is commanded by a manual release mechanism. The velocities required for the tests were selected by changing the initial compression of the spring in the actuation system while the orientation and misalignment of the OS trajectory are set moving the entire launcher with respect to the funnel.

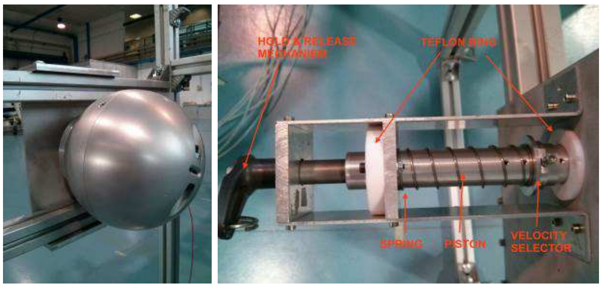

Figure 9. OS Launcher.

A cylindrical container was also added at the bottom of the funnel to store the OS after the completion of the transfer tests. The final design challenge was building a dedicated housing for the experiment compliant both with the test and the safety requirements for the parabolic flight.

Figure 10. Experiment ready for parabolic flight.

The parabolic flight test campaign has proven successful in every aspect allowing the validation of the design of the capture mechanism in microgravity environment. In particular the detection sensors triggered the arm closure in every tested condition and the actuation chain demonstrated the capability of the EBM to capture the OS once it entered the funnel and to transfer it into the trap afterwards, without OS pinching between the arm and the funnel, withstanding also the impacts of the OS with the arm. However, the launches was affected by microgravity perturbations (up to 0.05g) and in some cases lead to failed tests, because the not-nominal OS trajectory that prevents the triggering of the optical barrier or makes it bump against the funnel edge.

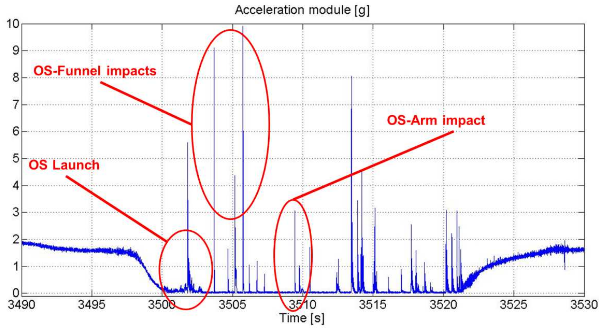

Figure 11. OS acceleration along a parabola.

Fig. 11 shows the record of OS acceleration during a typical parabola. It is possible to identify the microgravity phase, the initial launch and several bumps against the funnel or the arm (discernible only by the video-check of the test). Tab. 10 reports the measured impacts characteristics. It has to be noted that no damaged to funnel protective layer occurred and that no motor synchronization loss has been recorded during impacts.

OS impacts on	Durations [ms]	Forces [N]
Funnel	15.6-16.1 mean 6-26 min/max	257-327 mean 139-734 min/max
Arm	20	216-219 mean 72-431 min/max

Table 10. Impacts results.

4.4 Tests Results

The functional test campaign was successfully completed: the EBM performances were evaluated during the functional tests; the breadboard design proved effective both at system and component level in laboratory environment.

The environmental test campaign was successfully completed demonstrating EBM ability to withstand mechanical and thermal loads induced during all mission phases. Moreover the breadboard performances were not affected from these environmental loads.

The parabolic flight test campaign was successfully performed demonstrating the EBM full functionality in relevant 0-g environment. The expected number of test cases were almost doubled since the arm actuation proved able to complete a full transfer within one single parabola, these enabled to extract a better statistics of successful/failed complete tests. No major remarks needs to be reported on the hardware itself, the major issue to cope with was the strong perturbation experienced by the OS during its free floating phase within the EBM rack. The failed tests were due to the

OS perturbation rather than EMB malfunctioning. In particular the early seconds of microgravity are crucial for the positive outcome of the test case since the OS was released by hand at the very beginning of the parabola, thus the OS launch was really sensitive to the microgravity quality, which was completely random and unpredictable.

The presence of strong perturbation forces the EBM to be tested under conditions worse than the one foreseen during the design phase proving the robustness of the concept implemented. The OS trajectory was not rectilinear, thus the definition of its angle and offset with respect to the funnel mouth was not possible, and the speed also was not constant: for this reason the test conditions are considered non nominal, in particular worse than the ones the breadboard was designed for. Thus:

- the perturbations caused the OS to enter the funnel with speed, offset and angle limits randomly inside or outside the one specified in the design requirements: the EBM performances were not reduced;
- the higher speed the OS was launched with (21 cm/s) increased the impact forces on the funnel walls and on the protective layer, but no damage on both components occurred;
- the OS speed caused also higher impact forces on the arm with respect to the expected one, consequently, the torque the motor had to withstand was higher than the one foreseen during the design phase; however, this effect did not resulted in sync loss in the motor.

5 LESSON LEARNT

At the end of the Study, it has been possible to identify some criticalities and some other minor points of the current design, which could be reviewed in future, in order to overcome the related implementation issues:

- Usage of an Encoder for a reliable measurement of the arm angular position could be of interest, because at each impact the motor can lose the steps synchronization;
- Usage of a mechanical end-stop to prevent the opening of the arm beyond the micro-switch activation point, which is a quite delicate item that could prevent the mechanism functioning if damaged;
- The lug to tower interfaces geometry could be modified taking advantage of the available tower upper surface , in order to ease the drive chain installation;
- Verify the internal layer needing and study of different (softer) material, including the real stiffness and damping capability of the funnel wall without any layer.

As a result of the manufacturing and integration of the Elegant Breadboard Model, the weighted mass has been 12.6 kg (not considering electronics, baseplate and interfaces with the test facilities). Therefore an optimization of the design it is required in order to move toward the mass goal of an overall mechanism weighting about 10Kg. The following design modifications have been noted to be studied in future:

- Current design foresees a motor drive chain with a straight shaft. Due to the sizes of the motor and the gearbox, their mass acts with a force at a certain distance from the tower, generating a not-negligible momentum. In order to reduce the mass of the tower that has to support the motor weight, it is possible to substitute the nominal gearbox with a one equipped with a 90 degree shaft, directly connected to the side of the tower.
- Another possibility, in order to make the tower lighter, could be to design it like a beam-structure or in composite material.
- Another component to be refined is the securing device. In order to perform assessment, it is necessary to know better in detail how the trap works and its interfaces with the funnel/arm of the Capture Mechanism.
- The usage of TiNi Aerospace HDRM, tested on the EBM also on the Flight Model
- Additional lightening on funnel and arm structures are possible.

6 CONCLUSION

The original Study objectives foresaw to develop a new robust Capture Mechanism concept and to implement an Elegant Breadboard Model to be intensively tested in order to demonstrate its functionality, its survivability to the space representative environment and its capabilities. During the Study, it has been decided to add more tests in microgravity, in order to verify also the capture manoeuvre dynamics and impact forces. All the test objectives have been met.

At the end, the new technological concept has successfully completed all the tests campaigns, demonstrating to be more robust, reliable and performing than originally expected by the requirements. In fact, the mechanism has been proven under several conditions (of initial trajectory, speed, temperatures, air, vacuum, accelerations), even in largely not-nominal conditions, and for a large number of times (>150 actuations). Moreover, it demonstrates high motorization factors (>10) along all the tests and at different temperatures. The success of the Study is even more worth, due to the fact that all these performances have been achieved designing an advanced but compact, light and very simple concept, which is next to the 10 kg goal of overall mass.