PARABOLIC FLIGHT TEST CAMPAIGN OF A BREADBOARD OF A SAMPLING TOOL MECHANISMFOR LOW GRAVITY BODIES

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ABSTRACT

A parabolic flight test campaign was performed in the scope of the ESA activity "Sampling tool mechanism for low gravity bodies", under the Mars Robotic Exploration Preparation -2 program. The study is part of a set of studies to reinforce Europe's position in Mars robotic exploration and prepare for a European contribution to a future international Mars Sample Return (MSR) mission.

The purpose of the overall activity was to conceive, develop and test on ground and in a microgravity environment a novel concept of a sampling tool mechanism capable of collecting at least 100 g of regolith from a low gravity body. This paper focuses on the hardware tests performed during the parabolic flight test campaign and summarizes the achieved results and lessons learnt.

The resulting technology can be applied to several future ESA missions in which collecting and returning regolith samples back to Earth for scientific analysis is envisaged.

1. INTRODUCTION

1.1. Background

Sample return missions to asteroids, moons and planets of our solar system are the next logical step of robotic exploration beyond Earth. The recent success of missions like Rosetta (ESA, comet Churyumov-Gerasimenko), Dawn (NASA, asteroids Vesta and Ceres) and Hayabusa (JAXA, sample return of asteroid Itokawa) show the large variety of different objects that are accessible by modern spaceships.

The asteroid population of the solar system yields an excessive but largely unexplored amount of scientific information on the evolution of the solar system. Increasing attention is paid to the economic value of certain asteroid types but also their potential thread to Earth has been recently raised during public discussions. The level of knowledge on the interior structure, composition and especially surface properties of these bodies is still rather limited. Direct access to the surface and sample collection would remedy the situation considerably. The asteroid surface while very different in composition typically shows an unconsolidated top layer of soil – the so-called regolith.

The objective of the activity was to carry out a rigorous engineering assessment in order to perform a trade-off of several sampling mechanism concepts and select the most adequate design to collect at least 100 g of regolith from a low gravity body (e. g. a Mars moon or a Near - Earth asteroid). A prototype for test under laboratory and micro-g conditions on a parabolic flight was designed, manufactured and assembled [1].

The sampling strategy and hardware system must be robust and compatible with potentially unexpected environmental conditions.

During the second phase of the activity, the experiment was updated for the parabolic flight campaign requirements and tested in low g conditions. The goal of this experiment has been to demonstrate a successful sample collection of representative surface material in excess of a mass of 100 g in a micro gravity environment.

Figure 1. Operators conducting parabolic flight test

1.2. System overview

A trade-off between candidate technologies was made taking into account the state of the art in sampling technologies and the requirements applicable [1]

As a result of the trade-off done, the brush sampling technology was identified as the most promising technology to collect samples in a low gravity body.

1.3. Sampling Tool

The sampling tool consists of a brush-wheel mechanism with 3 rollers forming an angle of 120º between each other and actuated by one motor each. When the bristles of the brushes touch the terrain the regolith particles are dragged, lifted and driven into the sample canister, which is placed in the upper-central side of the main structure. The internal geometry of the sample canister and a closing door mechanism prevent the regolith particles to escape the canister.

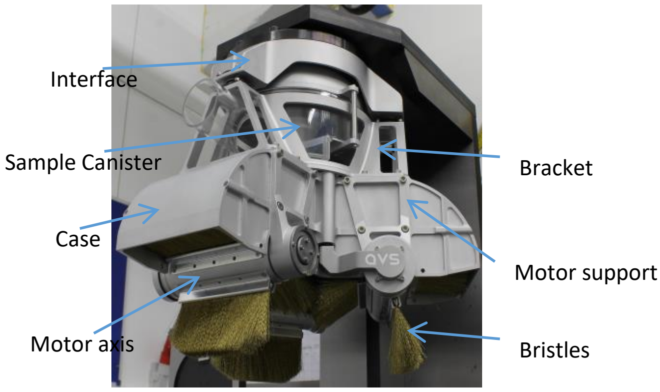

Figure 2. AVS Sampling Tool Mechanism Breadboard

The brush optimisation was of essential importance for a successful design of the mechanism. One of the advantages of this solution is its versatility, as it can be designed with different type of bristles (different materials, stiffness and number). The distribution of them can be optimised to reach the best performance.

2. TEST CAMPAIGN

In particular, the goal of this experiment was to demonstrate a successful sample collection of representative surface material in excess of a mass of 100 g in a micro gravity environment. The sampling tool functionality and requirements compliances had been previously validated during a ground test campaign [1]. More than 300 representative test cases from where the parameters related to the actual sampling sequence were identified and reproduced.

The sampling tool and the experiment set-up were adapted from ground to parabolic flight conditions. The test item was a novel design of a rotary brush sampling tool mechanism capable of collecting a sample from a soil reservoir and transfer it into a sample canister for safe storage

2.1. Parabolic Flight test Campaign

The experiment qualified to participate the 64th ESA Parabolic Flight Campaign at Novespace premises in Bordeaux-Merignac (Bordeaux airport) in 2016. The hardware was installed inside the airbus A310 Zero-G owned by Novespace.

Figure 3. Flight trayectory example

The experiment test set up consisted of three individual racks: (1) the motorized sampling tool and the regolith simulant container, (2) command and control station, and (3) storage container for sample canisters. The experiment required 4 operators to conduct the test sequences during the flight campaign.

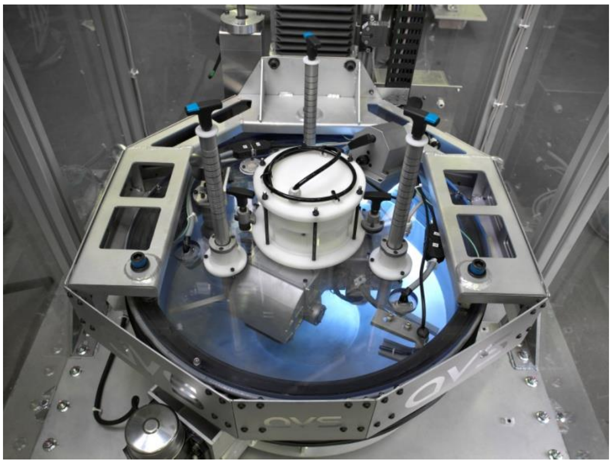

Figure 4. Experiment rack 1: Motorized sampling tool and regolith simulant container

Figure 5. Experiment rack 2: Commend and control station

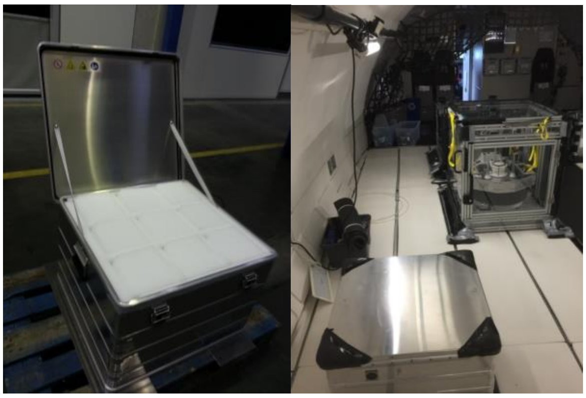

Figure 6. Experiment rack 3: Storage container for sample canisters.

The campaign consisted of three flight days, with a total of 93 flown parabolas. Typically the microgravity phase during each parabola lasts 22 seconds. In total 54 sampling sequences were executed. It was the first time that this kind of mechanism has been tested in a micro-g environment in Europe.

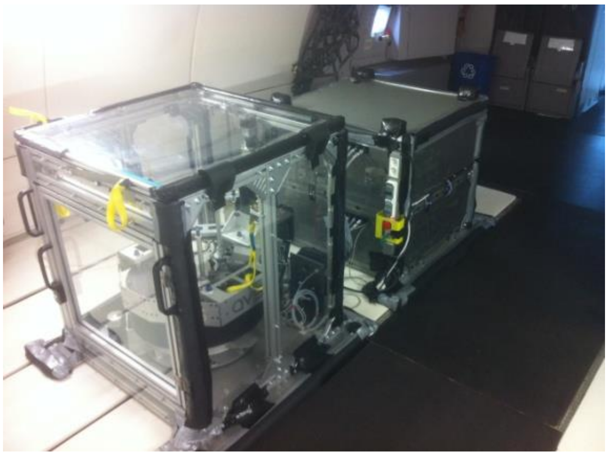

Figure 7. Experiment on board.

The most critical functions of the mechanism were characterized and operations successfully demonstrated in an environment relevant to a real sample acquisition mission to a small moon or asteroid type of body. Emphasis was given to optimise the sampling efficiency by varying key control parameter like brush velocity, sampling depth and forward motion. The interaction of the mechanism with the soil was analysed to achieve a better understanding of the particle dynamics in a micro-gravity environment.

3. RESULTS

The hardware worked flawless as well as the software control. All planned tests were executed.

The tests show that the flight conditions that can be realised on such a campaign are at the edge of the requirements needed (residual g-forces) thus describing the end of testability.

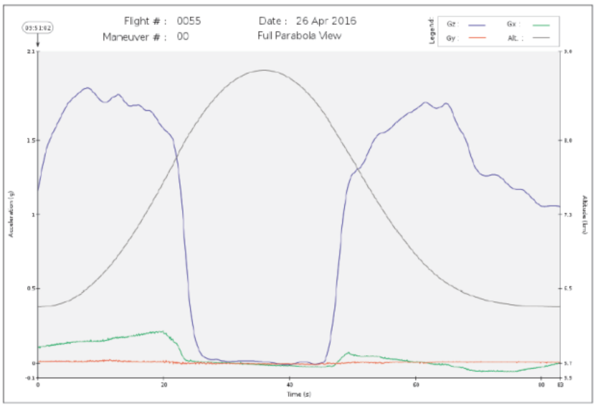

Figure 8. Example of flight parabola

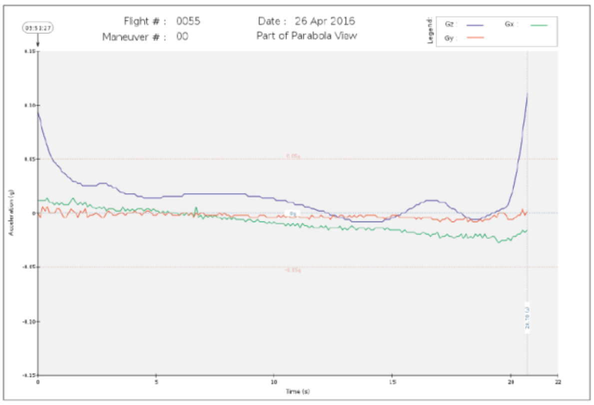

Figure 9. Example of flight microgravity phase profile

Software design, time reference, soil levelling, load cell measurements, bellow stiffness, control operator manual operation and mainly flight profile fluctuations lead to variability in the experiment execution and a complex data interpretation.

Successful sampling could be demonstrated. Variable flight conditions compromise a fair number of tests but trends of the tool performances are visible. High sampling velocities (>500 rpm) seem counterproductive (clogging of material). On the contrary, slow brush velocities (<250 rpm) seem advisable.

The filling of the sample containment is a complex process not comparable to tests under 1 g conditions.

Figure 9. Sample canister full with sampled soil.

3.1. Future work

A repetition of the campaign is only advisable if a small gravity is still existent eg lunar conditions. A dedicated parabolic flight campaign with Lunar and Martian gravity profiles is recommended in order to establish representative stable soil conditions during sampling operations, by avoiding soil turbulences due to negative accelerations in x and z axes. Modelling will take a major role since realistic conditions are not testable

3.2. Lesons learnt

Based on lessons learnt, the following points should be improved in a potential next parabolic flight campaign:

- Establish a time reference
- Avoid operator actions during 2G and 0G
- Consider for all force data recording the same gravity reference level
- Try to reduce amount of soil onboard

4. CONCLUSIONS

As a result of the parabolic flight test campaign, a TRL 4-5 level has been reached with for this technology. This test campaign is irreplaceable for the design optimization of the tool and preparation of a successful future sample return space mission. The envisaged destination is any asteroid within the solar system and specifically the Martian moon Phobos, target of an ongoing ESA study supported by industrial partners.

The demonstration and qualification of this sampling tool in a relevant environment serves the development of mission enabling technologies for preparation of future space missions by showing a robust mechanism design and achieving successful results in a wide range of operating conditions.

The resulting technology can be applied to several future ESA missions in which collecting and returning regolith samples back to Earth for scientific analysis is envisaged. The potential destination is any asteroid within the solar system and specifically the Martian moon Phobos, target of an ongoing ESA study supported by industrial partners

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