PROSPECT: SAMPLING TOOL APPROACHES FOR LUNAR ICY REGOLITH

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ABSTRACT

Leonardo's development of a robotic package aimed at prospecting lunar resources is going on. The collaboration between ESA and ROSCOSMOS gave birth to the European PROSPECT package to be installed on board of Luna-27 spacecraft. PROSPECT is consisting of two main elements: ProSEED and ProSPA. ProSEED is the drilling robot designed to reach a maximum depth of 1.2 m and capable of collecting lunar soil samples for both the Russian and European instrument suites. ProSPA, developed by Open University, is the instrument suite capable of receiving solid samples from ProSEED, extract volatiles, identify and quantify the extracted volatiles. The Russian ST&H will be served by ProSEED as well: a robotic arm will bring the specimen to the instruments. To cope with both European and Russian needs in terms of quantity and characteristics of the sampled material, Leonardo is developing and testing two alternative concepts of Sampling Tools.

1. INTRODUCTION

Leonardo is developing the ProSEED drilling system as part of the PROSPECT package with the aim of drilling the Moon south Pole region down to a target depth of 1.2m. The architecture of the drill is consisting in a single-rod drill housed inside a carbon fiber drill box, which can be positioned along an arc of a circumference in order to be able to perform vertical surveys in 5 different locations. One of the most crucial sub-systems of ProSEED is represented by the Sampling Tool. This can be seen as the end-effector of the drill; it is the tool in direct contact with the Lunar soil, demanded to perform the cutting and the sampling of the material we want to analyze to achieve the scientific goals. In the past years several approaches were developed and tested by Leonardo for interplanetary sampling. Heritage came from comet and Martian sampling technologies developed in the frame of Rosetta and ExoMars programs.

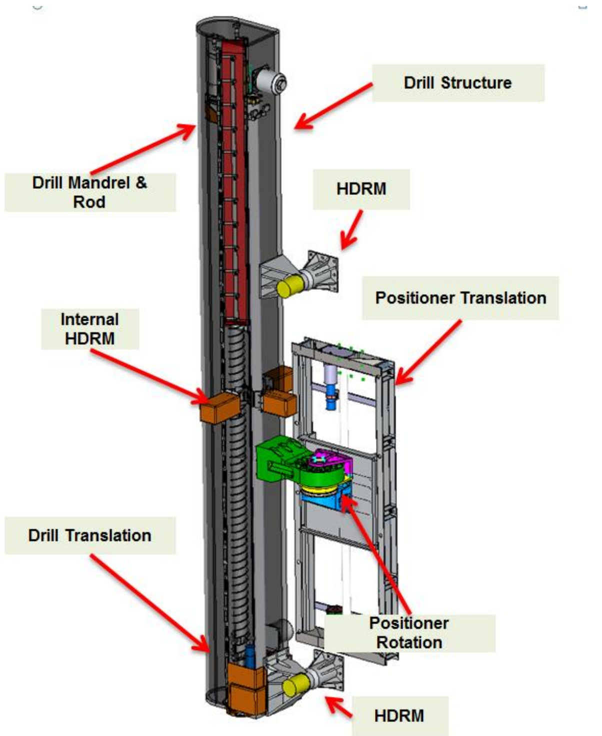

Figure 1-1 – Overview of ProSEED Mechanisms

Also, a different approach was attempted in the precursor phase of PROSPECT, the Lunar Drill Development (Phase A). In that frame, the L-GRASP sampling tool was tested in lunar representative

temperature conditions.
To give a picture of the starting point for the PROSPECT Phase B, here are summarized the major previously developed technologies for interplanetary sampling.

1.1. SD2 Push-tube sampler (Rosetta mission)

This small sampling mechanism was developed to collect soil samples on a comet at very low temperature. It has no positive retention mechanisms, and relies on cohesive properties of the sample material that had to be punt in a small oven. Diameter of the tube is about 3 mm. The push tube mechanism was spring-loaded.

Figure 1-2 . SD2 Push-tube

1.2. ExoMars Drill Tool with shutter

This ExoMars Drill Tool was designed to cope with sand and rocky materials that can be found in the Mars geology. It has the capability to create cores of material with a diameter of about 10 mm. In order to be able to collect sandy materials, a specific semi-spherical shuttering mechanism was designed.
It is not requested any particular processing of the material by the Drill Tool; in principle, when drilling solid rocks, it can create a solid cylindrical core that will be delivered to a specific mechanism demanded to the crashing necessary to prepare the material for the scintific instruments.

Figure 1-3 - ExoMars Drill Tool

The internal piston and shuttering mechanism are linked by a single degree of freedom that is actuated by a brushed DC motor of size 13 mm.

1.3. L-GRASP (Lunar Drill Phase A)

The L-GRASP sampling tool was specifically developed for applications in icy environment expected to be found at Moon south pole. It has the same corer-approach of the ExoMars Drill Tool with a slightly increased diameter of about 12 mm. The two main differences object of this specific development were:

1. implementation of a different approach for the retention mechanism in order to overcome the weaknesses of a delicate shuttering mechanism of ExoMars type.

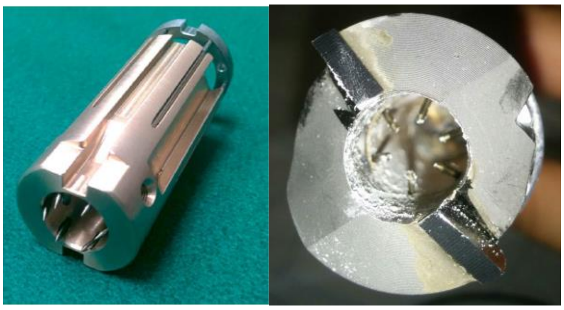

Figure 1-4 - L-GRASP internal spike-retention mechanism

2. development of an optimized cutting bit geometry to be utilized in icy regolith, and to be compatible with possible co-operation of an hammering actuator.

Figure 1-5 - L-GRASP in Coring (left), Drilling (center) and Delivering (right) configurations

Further information on this development and testing of this sampling tool can be found in [1].

Figure 1-6 - LDD Test Campaign at low temperatures

2. THE NEW REQUIREMENTS

With the beginning of the PROSPECT Phase B and the advancement in the definition of the Luna-27 Mission, it became clearer that the ProSPA instrument and the Russian instrumet suite could not share the same sample material. The list of requirements put on the sampling tool can be summarized by the following considerations:

- ProSPA has a strong heritage on the Rosetta mission; it needs a small quantity of sample material (in the order of few decigrams) and the consistency of such sample is not a driver. Once the sample material is put inside a ProSPA oven, the two main aspects will be the sealing process of the oven, and the heating power needed for the sampled material to reach the expected temperature to sublimate the volatiles for the scientific analysis.

- On the other hand, the Russian instrument suite needs a larger quantity of sampled material to be delivered, in the order of 5 cm^3. It is a driver the the delivered material is unconsilidated because the Luna-27 platform does not foresee any device or mechanism devoted to the crashing of the collected material. As a consequence, the unconsolidation of the sampled material should be addressed by the sampling tool itself.

- Additionally, in order to maximize the scientific outcome by comparing results of two independent instrument suites, it was requested that both ProSPA and Russian samples are taken from approximately the same depth and within two subsequent events (avoiding the possibility to collect one sample, deliver to one instrument and then re-enter the hole to collect a sample for the other instrument suite).

3. PROPOSED APPROACHES

One of the first activities of LEONARDO, in the Phase B, was to perform a trade-off in order to identify the best strategy to approach the development of a new solution capable of satisfying the highest number of requirements for the scientific end-users.
As an output of the activity, two alternative designs were selected to become breadboard models in the Phase B:

- ProSEED Sampling Tool Concept AA
- ProSEED Sampling Tool Concept AC

Both of the concepts implement two independent degrees of freedom (actuated by independent motoreducers) .

3.1. The Concept AA

In the Concept AA the Russian sample is stored inside an helicoidal chamber formed by protruding the sampling tool head. A deep groove helix (or auger) exits from the drill tube. In this configuration the material is processed (unconsolidated) by the cutting bits, and then it is captured by the deep helix groove instead of getting to the tube auger that would bring the material to the surface. With this concept the Russian sample has to be taken as first. After filling the helix chamber, the drill bit can be replaced in the drilling configuration in order to secure the sample inside the augered-tube. Retention of the Russian sample is hence guaranteed up to delivery point.
As a second step, the sampling tool is now ready to acquire the ProSPA sample. In the center of the cutting bit it will be implemented another mechanism based on SD2 sampling tube concept. The main difference is that this one is not spring-loaded but actually actuated by its own EC13 motoreducer. The ProSPA sampling operation is performed by raising the drill string by some millimetres (slightly more than the length of the push-tube) and the protruding the sampling-tube. Sample is then acquired by by roto-translation of the drill.
We are now in a condition with the helix grove filled with unconsolidated material and the push-tube filled with consolidated or unconsolidated (depending on the soil properties) sample, compatible with the ProSPA ovens design.
For the sample discharge operations, the ProSPA sample will be delivered first, then the unconsolidated material will be discharged in the Russian robotic arm receptacle. This architecture needs a discharging device for delivering the Russian sample.

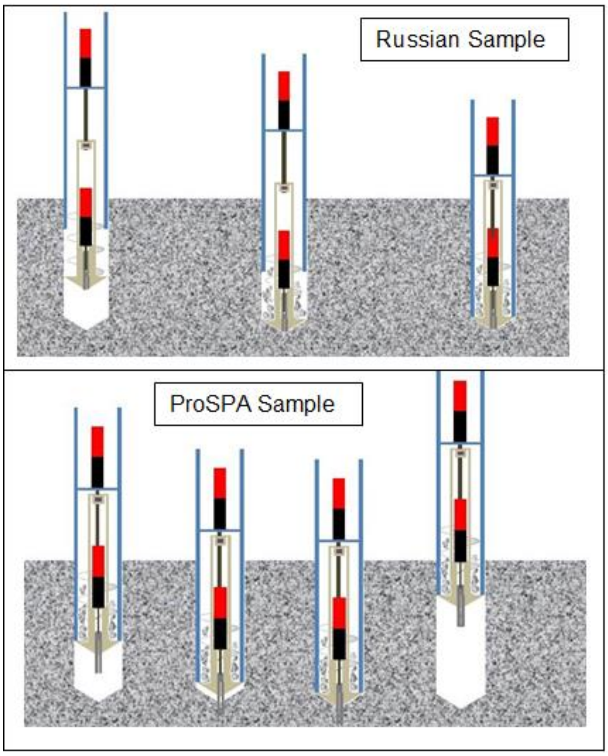

Figure 3-1 - Concept AA sampling sequence

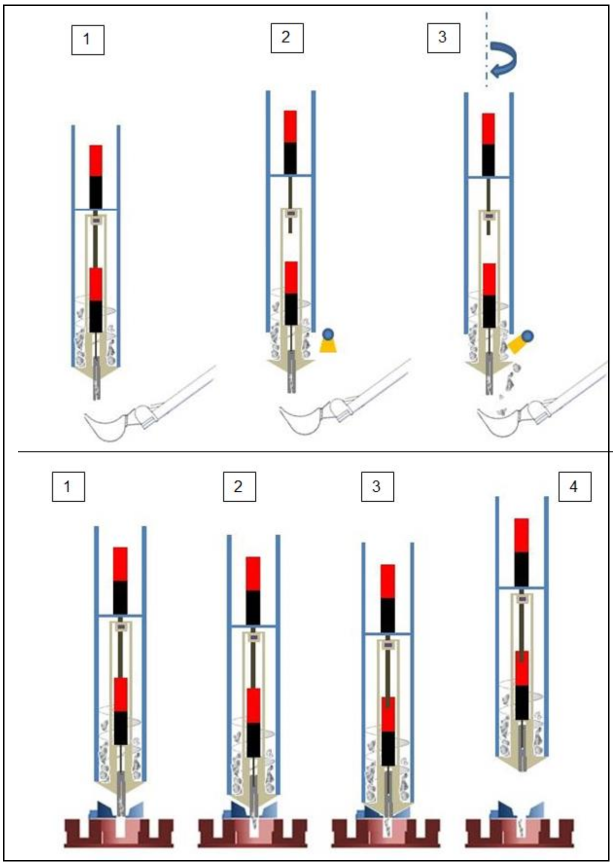

Figure 3-2 - Concept AA discharging sequence

3.2. The Concept AC

Also Concept AC has the capability to acquire the two subsequent samples. It is strongly based on the ExoMars Drill Tool technology with the shuttering mechanism, which is again merged with the SD2 push-tube approach for the ProSPA sample acquisition. The main advantage of this architecture is that the small ProSPA sample is thermally shielded by the material of the Russian sample inside the chamber.

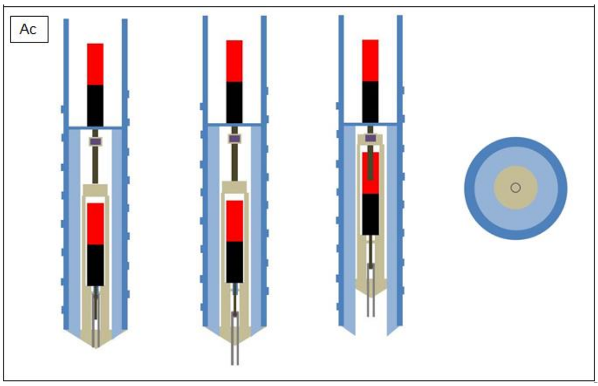

Figure 3-3 - Concept AC

In this concept the ProSPA sample is acquired first, then the piston assembly (including the push-tube) will be retracted creating the sampling chamber for the Russian sample in asimilar manner to the ExoMars and L-GRASP coring tools. At this point the shuttering mechanism can be activated to guarantee retention for both samples.

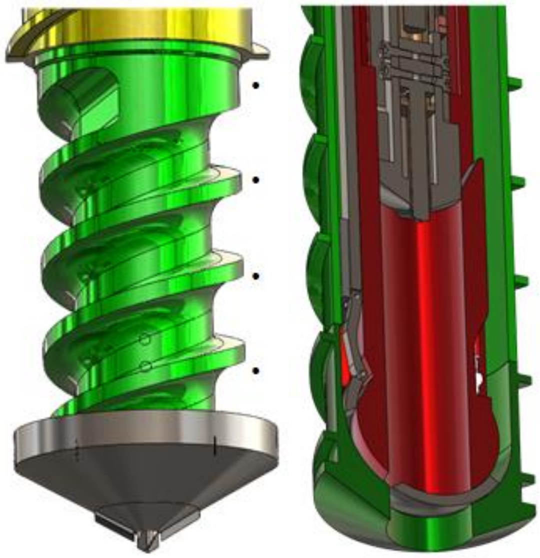

Figure 3-4 – Concept AA (left) and Concept AC (right) CAD view

4. THE CONCEPT AA PRELIMINARY BREADBOARD

The Concept AA presents a new methodology for Russian sample acquisition that was never developed at Leonardo. For this reason it was decided to advance the assessment of this sampling principle, by building a preliminary model of this tool with the capability to collect the Russian sample only (no push-tube implemented. Together with the tool, a preliminary version of the discharging device was 3D printed.

Figure 4-1 - Preliminary Concept AA during integration

The manufacturing and testing of this preliminary breadboard were completed in April 2017. The tool was tested in know materials and with lunar highland simulant (NU-LHT-2M) with water inclusion up to saturation and preconditined at -180°C.

5. TEST RESULTS

In this chapter, a brief summary of the testing results obtained on the preliminary breadboard is presented. The detailed list of test sessions performed is reported in Table 5-1. For each session the most important performance of the tool will be reported in a summary table.

Table 5-1- Test sessions

Test #	Test label	Material	Temperature
1	Bench Testing	-	-
2	SAA-TA-01	Gas concrete	Ambient
3	SAA-TA-02	Red brick	Ambient
4	SAA-TA-03	Dry Simulant	Ambient
5	SAA-TA-06	Dry Simulant (with pebbles)	Ambient
6	SAA-TC-04	5.9% Wet Simulant	-180 °C
7	SAA-TC-05	11.9% Wet Simulant	-180 °C
8	SAA-TC-07	5.9% Wet Simulant (with pebbles)	-180 °C
9	SAA-TC-08	11.9% Wet Simulant (with pebbles)	-180 °C

7.1. Gas Concrete (SAA-TA-01)

Gas concrete is the softest and less dense of the solid reference materials we typically use to evaluate the perfomances of a new sampling tool. It was specifically used to learn how to perform sampling operations with this new concept.

Table 5-2 - SAA-TA-01 Performance Summary

SAA-TA-01	DRILLING	CORING
05/04/2017	D100	C100
TU speed [mm/min]	14,51	14,54
TU force [N]	23,21	28,57
TU power [W]	0,01	0,01
DU speed [rpm]	52,71	60,00
DU torque [Nm]	0,30	0,43
DU power [W]	1,84	2,69
DeltaT bit [K]	~1	~1
Power; total [W]	1,84	2,69
Specific Energy [J/cm]	76,15	111,22
Volumetric Energy [J/cm^3]	6,71	9,81

Figure 5-1 - SAA-TA-01 Collected Sample

Sample acquisition was successful.

7.2. Red Bricks (SAA-TA-02)

A series of red brick was then put on top of the previously drilled gas-concrete block.

Table 5-3 – SAA-TA-02 Performance Summary

SAA-TA-02	DRILLING		CORING	
06/04/2017	D300_1	D300_2	C300_1	C300_2'
TU speed [mm/min]	14,94	16,42	15,13	17,75
TU force [N]	280,17	317,64	324,06	36,23
TU power [W]	0,07	0,09	0,08	0,01
DU speed [rpm]	59,94	60,03	59,97	59,99
DU torque [Nm]	2,17	2,26	2,52	0,58
DU power [W]	13,61	14,21	15,83	3,61
DeltaT bit [K]	~15	~15	~15	negligible
Power; total [W]	13,68	14,30	15,91	3,62
Specific Energy [J/cm]	549,55	522,42	630,90	122,48
Volumetric Energy [J/cm^3]	48,46	46,06	55,63	10,80

Figure 5-2 - SAA-TA-02 Collected Sample

Stratigraphy can be seen by different colors deposition. Sampling was done still in gas.concrete.

7.3. Dry Simulant (SAA-TA-03)

This test was ment to assess the performance in the most critical conditions for the tool retention capability.

Table 5-4 - SAA-TA-03 Performance Summary

SAA-TA-03 #1	DRILLING	CORING
05/04/2017	D150	C150
TU speed [mm/min]	14,29	17,63
TU force [N]	1,32	1,20
TU power [W]	0,00	0,00
DU speed [rpm]	35,25	58,39
DU torque [Nm]	0,04	0,06
DU power [W]	0,17	0,38
DeltaT bit [K]	negligible	negligible
Power; total [W]	0,17	0,38
Specific Energy [J/cm]	7,09	13,00
Volumetric Energy [J/cm^3]	0.63	1.15

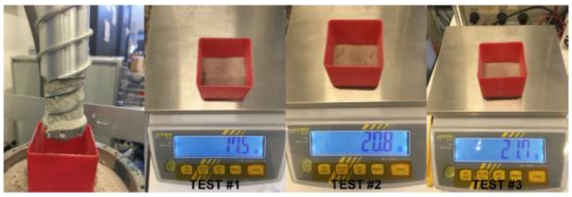

Figure 5-3 - SAA-TA-03 Collected Samples

7.4. Dry simulant + Pebbles (SAA-TA-06)

Table 5-5- SAA-TA-06 Performance Summary

SAA-TA-06	DRILLING	CORING
11/04/2017	D150	C150
TU speed [mm/min]	17,82	17,92
TU force [N]	0,11	-0,16
TU power [W]	0,00	0,00
DU speed [rpm]	47,61	59,95
DU torque [Nm]	0,06	0,07
DU power [W]	0,27	0,41
DeltaT bit [K]	negligible	negligible
Power; total [W]	0,27	0,41
Specific Energy [J/cm]	9,07	13,80
Volumetric Energy [J/cm^3]	0,80	1,22

Figure 5-4 - SAA-TA-06 Collected Samples

Inclusion of pebbels is tested to understand if hard rock inclusion may damage the mechanism during closure of the sampling chamber. The test was completely successfull.

7.5. 5.9% Wet Simulant (SAA-TC-04)

This was the first of the test at low temperature, useful to understand the behaviour with ice-regolith mixture.

Table 5-6 - SAA-TC-04 Performance Summary

SAA-TC-04	DRILLING	CORING
18/04/2017	D300	C300
TU speed [mm/min]	17,90	13,35
TU force [N]	91,04	111,27
TU power [W]	0,03	0,03
DU speed [rpm]	59,98	50,27
DU torque [Nm]	0,83	0,78
DU power [W]	5,20	4,83
DeltaT bit [K]	-	-
Power; total [W]	5,23	4,86
Specific Energy [J/cm]	175,30	218,18
Volumetric Energy [J/cm^3]	15,46	19,24

Figure 5-5 - SAA-TC-04 Collected Sample

The test was successful with good drilling performances.

7.6. 5.9% Wet Simulant + Pebbles (SAA-TC-07)

Inclusion of pebbles within a medium hardness matrix. Likely to be the most representative Moon scenario.

Table 5-7 - SAA-TC-07 Performance Summary

SAA-TC-07	DRILLING	CORING
18/04/2017	D300	C300
TU speed [mm/min]	12,49	12,72
TU force [N]	161,56	103,57
TU power [W]	0,03	0,02
DU speed [rpm]	51,29	53,73
DU torque [Nm]	1,24	0,96
DU power [W]	7,68	5,95
DeltaT bit [K]	-	-
Power; total [W]	7,71	5,97
Specific Energy [J/cm]	370,65	281,91
Volumetric Energy [J/cm^3]	32,68	24,86

Figure 5-6 - SAA-TC-07 Collected Sample

7.7. 11.9% Wet Simulant + Pebbles (SAA-TC-08)

Table 5-8 - SAA-TC-08 Performance Summary

SAA-TC-08	DRILLING		CORING
21/04/2017	D500	D400	C400
TU speed [mm/min]	3,98	4,36	7,54
TU force [N]	396,43	352,56	377,50
TU power [W]	0,03	0,03	0,05
DU speed [rpm]	52,65	56,40	59,98
DU torque [Nm]	3,55	4,48	2,90
DU power [W]	21,95	28,15	18,22
DeltaT bit [K]	-	-	-
Power; total [W]	21,98	28,17	18,26
Specific Energy [J/cm]	3315,12	3880,28	1454,21
Volumetric Energy [J/cm^3]	292,31	342,14	128,22

Figure 5-7 - SAA-TC-08 Collected Sample

6. CONCLUSIONS

With the exception of test run SAA-TC-05, all the tests were successful, proving the good architecture of Concept AA. The only failure was anyway due to non representative conditions (liquefaction and re freezing of water at ambient pressure) that lead the formation of an icy cap on the sampling tool head, preventing the correct drilling and evacuation of the material.

Figure 6-1 - Issue

In any case Leonardo is working to address this issue by improving the design of the cutting bits to cope with this non representative conditions for imminent full breadboard models testing activities.

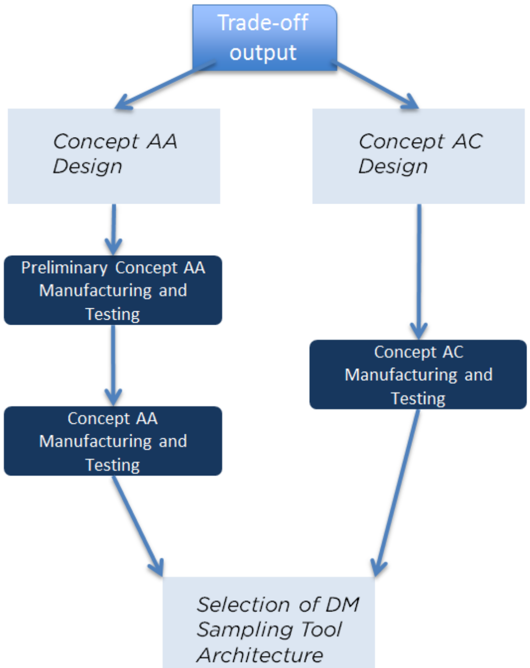

Figure 6-2 - Activity workflow

7. REFERENCES

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