M04

In-Situ Resource Utilisation

Executive Summary

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Version	Date	Page and/or paragraph affected
01.00	09.11.2018	Initial Version
02.00	14.12.2018	Deleted the copyrights at the footer because ESA requested that so partially or in total publishing is possible. Erased the prices also a demand from ESA. Included the newest picture of the 3 possible landings coordinates at Shackleton Connecting Ridge

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1. Introduction

The main aspect of this study is the feasibility of the mission concept and the demonstration of the economic viability of a commercial payload delivery service to the Moon as well as the demonstration to produce water/or oxygen with materials from the Moon. This payload delivery service should be an end-to end service from Earth to a targeted location on the Moon, launched not later than 2025.

1.1. Scope

The scope of the proposed study is to establish a baseline mission definition and an initial comprehensive offer for the end- to end commercial provision with a ceiling price.

The economic service viability should be demonstrated without ESA funding for the development of the associated space and ground segment within the frame of the commercial service procurement contract. The study shall provide the inputs to the Council of Ministers in December 2019.

2. Work Package Description

The feasibility of a commercial mission to perform a surface technology demonstration as well as a feedstock characterization on a dedicated site of the Moon shall be shown and is scheduled not later than 2025. ESA would only procure the service not the development of the transport or communication-system needed to fulfill such a mission. Payloads, to produce a minimum of 100g of contained water and/ or 90g of contained oxygen with locally sourced materials from the Moon, are under development and will be provided by OHB or Space Application Services. The Overall total industrial procurement budget for the service and payload is set and should be met. The mission implementation is constraint to that budget and shall be enabled through commercial services.

The mission study consists of three segments and their services: Payload, Transport and Communication. Additionally, a parallel line ran with also 3 segments.

The ISRU demonstration study was split into the following work packages depicted in figure 1.

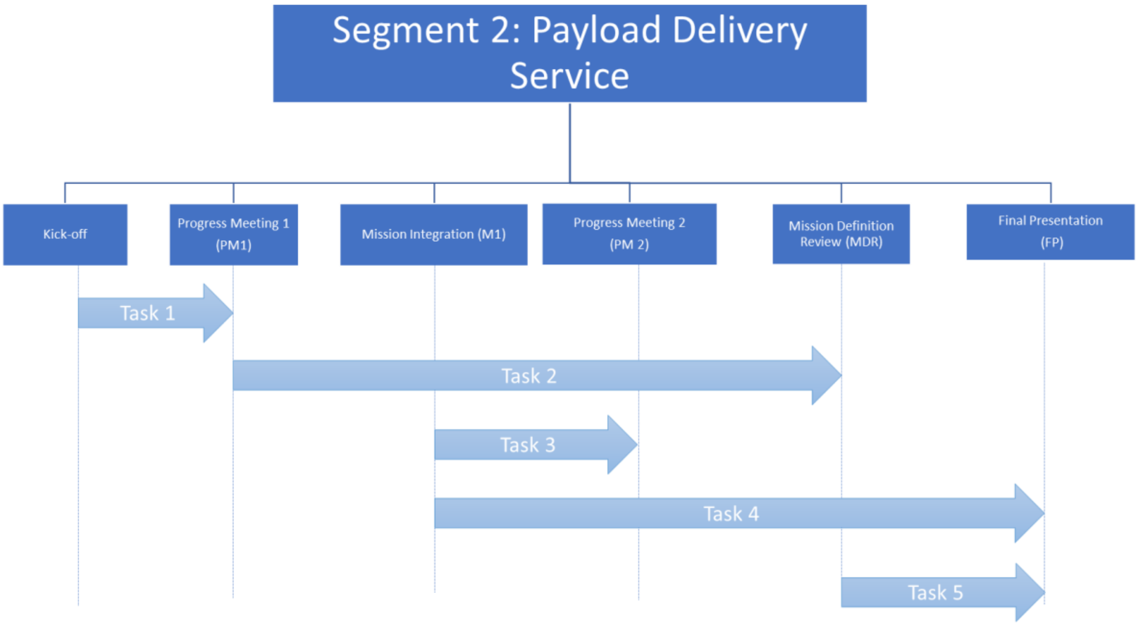

Figure 1.: Overview of the Work Packages

2.1. Work that was performed

At the beginning of the phase zero study PTScientists performed a preliminary analysis for each of ESAs pre-selected landing sites (Shackleton Plateau, Shackleton connecting ridge, Mare Orientale, Shoemaker Faustini and Schrödinger Basin) and identified potential risks for such a mission. The Landing site assessment is one of the most important key points for ISRU mission because the payload demonstration is depending on that.

Referring to those risks PTScientists investigates, if we can fulfill the requirements due to the sun illumination conditions, desired slope of the terrain and topography related to dangerous boulders and rocks as well as communication availability during the whole mission phases especially while safe landing. In the end a subset of 5 risks were selected which reflecting the most significant risks existing.

Table 1.: landing site risk matrix

Landing Site	Risk 1 Absolute navigation not available	Risk 2 Slope of landing site is to high	Risk 3 Power/Thermal Issues on the landed lander because of low Sun elevation angle	Risk 4 Loss of telemetry link during Landing	Risk 5 Dangerous Rocks & Boulders For the landing
Shackleton Connecting ridge #1	**HIGH** Rationale: low sun elevation angle	**MEDIUM** Rationale: there are few large areas with slope below 5°	**HIGH** Rationale: almost at the South pole, very low Sun elevation angle	**MEDIUM** Rationale: a relay satellite is needed, more risks involved	To be analyzed when the exact coordinates are known
Schrödinger Pyroclastic Flow far side #2	**LOW** Rationale: Sun elevation angle reasonably high	**LOW** Rationale: Very flat area	**LOW** Rationale: Sun elevation angle reasonably high	**MEDIUM** Rationale: a relay satellite is needed, more risks involved	To be analyzed when the exact coordinates are known
Shoemaker Faustini connecting peak #3	**HIGH** Rationale: low sun elevation angle	**MEDIUM** Rationale: there are few large areas with slope below 5°	**HIGH** Rationale: almost at the South pole, very	**MEDIUM** Rationale: a relay satellite is needed, more risks involved	To be analyzed when the exact coordinates are known

			low Sun elevation angle		
Near side site, Orientale #4	**LOW** Rationale: near-equatorial site, high Sun elevation angle	**LOW** Rationale: Enough large flat areas (TBC when exact coordinates are known)	**LOW** Rationale: High Sun elevation angle	**LOW** Rationale: direct communication with Earth is possible	To be analyzed when the exact coordinates are known
Malapert (proposed by PTS) #5	**HIGH** Rationale: low sun elevation angle	**MEDIUM** Rationale: there are few large areas with slope below 5°	**HIGH** Rationale: almost at the South pole, very low Sun elevation angle	**LOW** Rationale: direct communication with Earth is possible	To be analyzed when the exact coordinates are known

The sensors and their accommodation possibilities on the S/C were deeply looked into with a sensor suite analysis. This includes the performances of all the sensors on Alina-2 like Star Trackers, Laser Altimeter, Radar (Doppler) and Crater Navigation and the cameras. It was elicited what happens if some sensors fail or can´t perform properly during the descent maneuver. Also, the possibility of a hover- phase and a landing abort was investigated. Every landing site has different requirements, opportunities but also risks. The outcome of the landing site assessment was Shackleton Connecting ridge. Special on this landing site is the peak of eternal light, the good conditions for science (payload investigations) but on the south pole is more difficult to land than on the equatorial plane. Whereas landing on the far site of the Moon requires a relay satellite.

Then all participants in the study had to agree on a maximum time period for the mission. This was related to the needed time of operating the payload but also not to exceed the monetary framework. For example, the operating times and availability of ground stations as well as the relay satellite. It was discussed if the payloads can work in parallel or better in serial.

The Alina-2 spacecraft will be designed with solar power as well as additional batteries to provide enough power to the payload. Since the two payloads are not the same weight, additional counterbalances masses must be planned. This can be scientific payloads provided by ESA or PTScientists will sell the available free mass to other customers (universities) or companies. Since at least 4 production cycles will be planned to run through, to produce the required 100g water, one batch needs approximately 65 hours. After landing all systems will do a health check before the surface excavation and mapping (handling) will take place. This long production cycle leads to the investigations to ensure survival of the lunar night, if the experiment can´t fulfil its task in time, it should be reactivated after the next lunar day begins. So, PTScientists does a sensitive analysis of the Alina-2 lander regarding to survive a 14 days/14 nights cycle on the Moon.

Thereafter, PTScientists discussed with segment 3 how our own developed communication system on ALINA-2 spacecraft can communicate with the relay satellite of SSTL/Goonhilly. The baseline communication architecture with our current modems seems feasible to do so, but further investigations are still necessary.

Further, PTS has been assigned to specify the tolerances for the damping elements on the S/C- landing legs because the payload Segment was requesting a dedicated landing height what is really difficult to say. The 4 landing legs will pull- actuated shock absorbers and a novel terrain adaptability mechanism can be compressed 300mm. But nobody knows for sure therefore, PTScientists suggest on the construction of a payload height adjustment system which is self- sufficient and independent from the height of the lander.

The launcher possibilities including mass, fuel budgets and delta-V for Falcon 9 and Ariane 6 was determined to select a launch date. Follower the eliciting of larger areas offering sun greater than 14 days at Shackleton Connecting Ridge as well as a better feasible GNC landing ellipse.

The last thing PTScientists probe was the view factor of the hot waste which should be unload out between the S/C and what it means for the lander and the thermal interferences.

3. Results

The maximal payload capacity on the spacecraft is 300kg with respect to the x-axis of Alina-2, all payloads must be mounted symmetrically. A uniform distribution is preferred, which means 150kg around all four sides of ALINA-2. Since the primary payload has 100.8 kg and the secondary only 56.2kg, we will sell the free payload capacity to other agencies or customers.

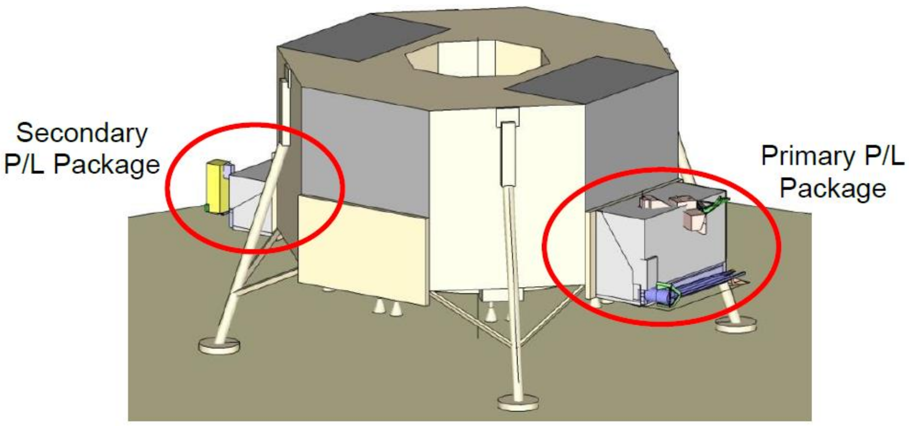

Figure 2.: ISRU payload accommodation

The Trade-off between the landings sites lead to Shackleton Connecting Ridge because of the mission requirements and needs of payload. Polar Regions are riskier to land but at the same time have a better environment for the ISRU experiments. That´s why the decision was made to go to the South Pole.

The geographical parameters of Shackleton Connecting Ridge are the following Coordinates: -89.4745°N, -137.43358°E , -137.0049E,-89.4625N,-137.4208E,-89.42227N

It was decided on a nominal mission duration which was set to 14 days and that the working phases of the two experimental scientific payloads should perform one after the other (serial) because of the difficult power budgets especially addressing the needs of primary payload which needs over 10 hours more than 600W. The general power baseline is 300W but additional batteries are available.

The best launch date regarding the mission analysis is the 6th of August 2025 and the preferred launcher is Ariane 6. In this study a second landing possibility was examined. The first landing opportunity and powered descent will be the 8th of September 2025 and then the next chance of landing will be at the 18th of September. The largest landing ellipse, approximately 400 x 600m, which guarantees "good" illumination conditions with more than 90% of the area of this ellipse. The longest-quasi continuous illumination period is at least 50 days.

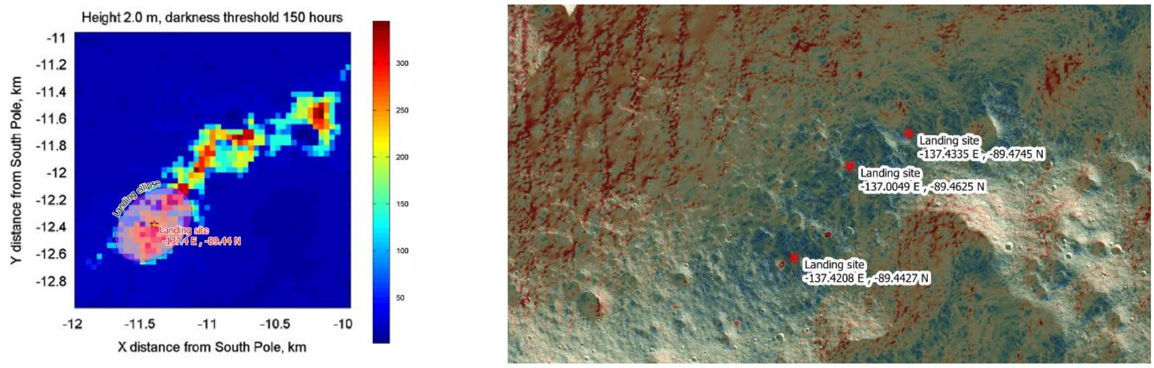

Figure 3.: first landing ellipse 400x600 at Shackleton Connecting Ridge and 2 other landing pots (coordinates)

Almost from the 7th of September till the 21st. of September there is continuously visibility with the Ground stations: Perth, Malibu and Goonhilly.

The view factor between the hot waste and the S/C-Alina-2 is 14% which means it is not dangerous for the lander but further investigations will show if this can be used and help to survive the lunar night.

Few minutes before landing a hover phase is possible to avoid rocks or greater boulders.

The damping effect on the landing legs was analysis and it can be compressed to 300 mm.

<u>Conclusions for phase zero:</u>

- Landing site at Shackleton Connecting Ridge-> Coordinates: -89.4745°N, -137.43358°E, -137.0049E,-89.4625N,-137.4208E,-89.42227N.
- A nominal mission duration of 14 days
- Payload capacity on the lander is 300kg
- Additionally, counterbalance masses are considered -> ESA can provide other scientific payloads or PTScientists will sell the other available space and mass to customers
- First Launch opportunity is: 6th August 2025 with Ariane 6 or Falcon 9 but Ariane 6 is preferred
- Two landing attempts are possible
- A hover-phase is possible
- First landing attempt 8th September 2025, afterwards the second landing attempt will be possible at the 18th September 2025
- Landing accuracy and greater landing ellipse will improve significantly by upgrading the IMU (currently used one for simulations is a COTS DMU30 IMU, which is a COTS MEMS IMU.)
- Power baseline provided by the lander is: 300W
- Additional Batteries are also available to cover the power consumption and operations of the payload
- Primary and secondary payload can operate partial in parallel because of the power requirements of the primary payload
- View factor is 14% of emitted radiation energy from the hot waste to the lander~ not dangerous but maybe can be used

- PTScientists currently used baseline communication architecture seems to fit to the relay satellite
- Damping effect on the damping elements of the landing legs: approx. 300mm
- Thermal interface between the lander and payload through: thermistors, heaters and MLI
- A radiator and a possible placement facing the space was presented from PTScientists
- The lunar night survival is still under investigation.

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