Final Report

Team 2 - C.P.F. (Constellation Providers for the Future)

ROSPIN ACADEMY

LEVEL THREE

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1. Introduction

1.1. Purpose

This document is created in the frame of the Intelligent Lunar Orbiting Navigation Access (I.L.O.N.A) project compiled by Team 2 of ROSPIN Academy Level 3 programme to be reviewed by the evaluation committee within the ROSPIN Academy Level 3.

The purpose of this document is to provide a set of considerations and results based on the mission design developed within the team.

- Section 1 provides an introduction of the mission, the project purpose and the tables with acronyms and abbreviations
- Section 2 provides the tables containing the related documents and the nomenclature used to define the name of the requirements
- Section 3 contains a synthesis of the mission concept and architecture focusing on the mission statement, mission objectives, mission requirements, mission timeline and CONOPS
- Section 4 describes the mission feasibility in terms of constellation and subsystems design definition and systems budgets
- Section 5 contains the business model canvas

1.2. Scope

This document aims to consolidate a mission which enables satellites in the cislunar environment to navigate autonomously and provide a telecommunication and GNSS lunar system. This document is structured as follows:

1.3. Acronyms and abbreviations

Tabel 1-1: Acronyms and abbreviations table

Acronym	Description
ADCS	Attitude Determination and Control System
BOL	Best of Life
B2B	Business to Business
B2C	Business to Consumer
B2G	Business to Government
COMMS	Communications
CONOPS	Concept of operations
COTS	Commercially off-the-shelf

Acronym	Description
EPS	Electrical Power Supply
GNSS	Global navigation satellite system
LEO	Low Earth Orbit
LLO	Low Lunar Orbit
OBC	On Board Computer
PNT	Position, Navigation and Timing
ROSPIN	Romanian Space Initiative
ST&TH	Structure, Mechanisms and Thermal Control
SZM	Shielded Zone of the Moon
UHF	Ultra High Frequency

2. Related documents

2.1. Reference Documents

Tabel 2-1: Reference Documents

Ref	Document Title	Document number	Date
[REF001]	Presentation hand-out		02/09/2022
[REF000]	Project Poster		02/09/2022

2.2. Standard Documents

Tabel 2-2: Standard Documents

Ref	Document Title	Document number	Date
[STD001]	Technical Requirements Specification	ECSS-E-ST-10-06C	06/03/2009
[STD002]	Statement of Work	Version 1.1	28/08/2022

2.3. Nomenclature

The following conventions will be used for the mission requirements naming.

All requirements will follow the following naming:

ILONA-XXXX-NNN

Tabel 2-3: Nomenclature

<table>
<tr><th>Acronym</th><th colspan="2">Description</th></tr>
<tr><td rowspan="2">ILONA</td><td colspan="2">Is the constellation’s name.</td></tr>
<tr><td>ILONA</td><td>Intelligent Lunar Orbiting Navigation Access</td></tr>
<tr><td rowspan="8">XXXX</td><td colspan="2">Is the type of requirement based on subsystem naming.</td></tr>
<tr><td>MR</td><td>Mission Requirements</td></tr>
<tr><td>LR</td><td>Link Requirements</td></tr>
<tr><td>CR</td><td>Constellation Requirements</td></tr>
<tr><td>PR</td><td>Power Requirements</td></tr>
<tr><td>MS</td><td>Mass Requirements</td></tr>
<tr><td>TH</td><td>Thermal Requirements</td></tr>
<tr><td>ADCS</td><td>Attitude Determination and Control Requirements</td></tr>
<tr><td>NNN</td><td colspan="2">Is a number which provides the order of each requirement.</td></tr>
</table>

3. Mission Concept and Architecture

3.1. Mission Statement

As the space industry continues to develop vigorously, a need for navigation and telecommunications started to arise. A GNSS and communications system on the moon represents a huge opportunity for the development of the human race and for businesses. By creating a constellation that can provide these services, it will not only represent an innovation, but it will also open the deep space for future missions.

3.2. Mission Objectives

3.3. Primary Mission Objectives

Providing GNSS and Telecommunication modules for the Lunar environment.

Achieving a stable lunar constellation**

3.4. Secondary Mission Objectives

Providing support for the future Lunar Base

3.5. Mission Requirements

This section presents a set of consolidated requirements based on the needs and activities which will be executed.

Tabel 3-1: Mission Requirements

ID	Title of the requirement	Text of the requirement
MISSION REQUIREMENTS		
ILONA-MR-0010	**Size**	**Satellite shall not exceed a 12-U structure.**
ILONA-MR-0020	**Mass**	**The mass of one Satellite shall not exceed 25 kg.**
ILONA-MR-0030	**Objective**	**Ilona shall provide GNSS and Communications infrastructure**

LINK BUDGET REQUIREMENTS		
ILONA-LB-0010	Com Satellites	The frequency used for satellite to satellite communication shall be Ka-band
ILONA-LB-0020	Com Gateway	The frequency used for satellite to Gateway communication shall be Ka-band
ILONA-LB-0030	Diameter antenna	
CONSTELLATION REQUIREMENTS		
ILONA-CO-0010	Satellite number	The total number of satellites for the Ilona Constellation shall not be less than 28.
ILONA-CO-0020	Number of Orbits	Ilona Constellation shall have a total number of 4 orbits.
ILONA-CO-0030	Number of satellites on orbit	Ilona Constellation shall not have less than 7 satellites per orbit
ILONA-CO-0030	Orbit Angle	Ilona Constellation shall be based on Andromeda Constellation inclinations assumptions.
POWER REQUIREMENTS		
ILONA-PB-0010	CubeSat Power	Satellites shall use x W at any time.
ILONA-PB-0020	Mass of the battery	Battery shall have a mass of 5 kg.
ILONA-PB-0030	Solar Arrays Area	The satellite shall use a solar array area of 0.36 m^2.

MASS REQUIREMENTS		
ILONA-MS-0010	**Total Mass**	**Satellite shall have a weight of 22.5 kg.**
ILONA-MS-0020	**Launcher**	**Ilona Constellation shall use an Ariane 62 launcher.**
THERMAL REQUIREMENTS		
ILONA-TH-0010	**Maximum Temperature**	**The satellite shall be kept at a temperature which does not exceed 353 K.**
ILONA-TH-0020	**Minimum Temperature**	**The satellite shall be kept at a temperature of at least 233 K.**
ILONA-TH-0030	**Coating**	**The coating of the satellite shall be MLI**
ADCS REQUIREMENTS		
ILONA-ADCS-0010	**Sensors**	**The satellite shall use a nadir sensor, a star-tracker and three gyroscopes.**
ILONA-ADCS-0020	**Actuators**	**Satellites shall use reaction wheels compatible with 12U structure.**

3.6. Mission Timeline and Concept of Operations

3.6.1. Mission Analysis

In developing a mission that should constitute the base for a new GNSS and telecommunication lunar system, various problems were encountered. The number of needs and constraints could be potentially increased if a secondary mission objective is added. A potential lunar base could influence the lunar constellation.

Multiple configurations were added for the mission steps. The most important steps in the Mission Design are: launch, orbit transfer, constellation design. These elements will dictate the course of the mission and the concept of operations.

The new space era requires every mission to have a commercial component, hence the missions that are to come are greatly influenced by cost.

The next step is to analyze means of orbital transfer. Chemical and electrical propulsion are the used ways of reaching desired celestial bodies or specific orbits. If cost is an important factor, the mission will be designed to integrate a propulsion system which can place the satellite on the Moon's orbit in the most cost efficient way.

On the Moon's Orbit, multiple decisions have to be made. In terms of orbital maneuvering, constellation, and coverage, the most affordable decision has to be determined.

3.6.2. Mission Timeline

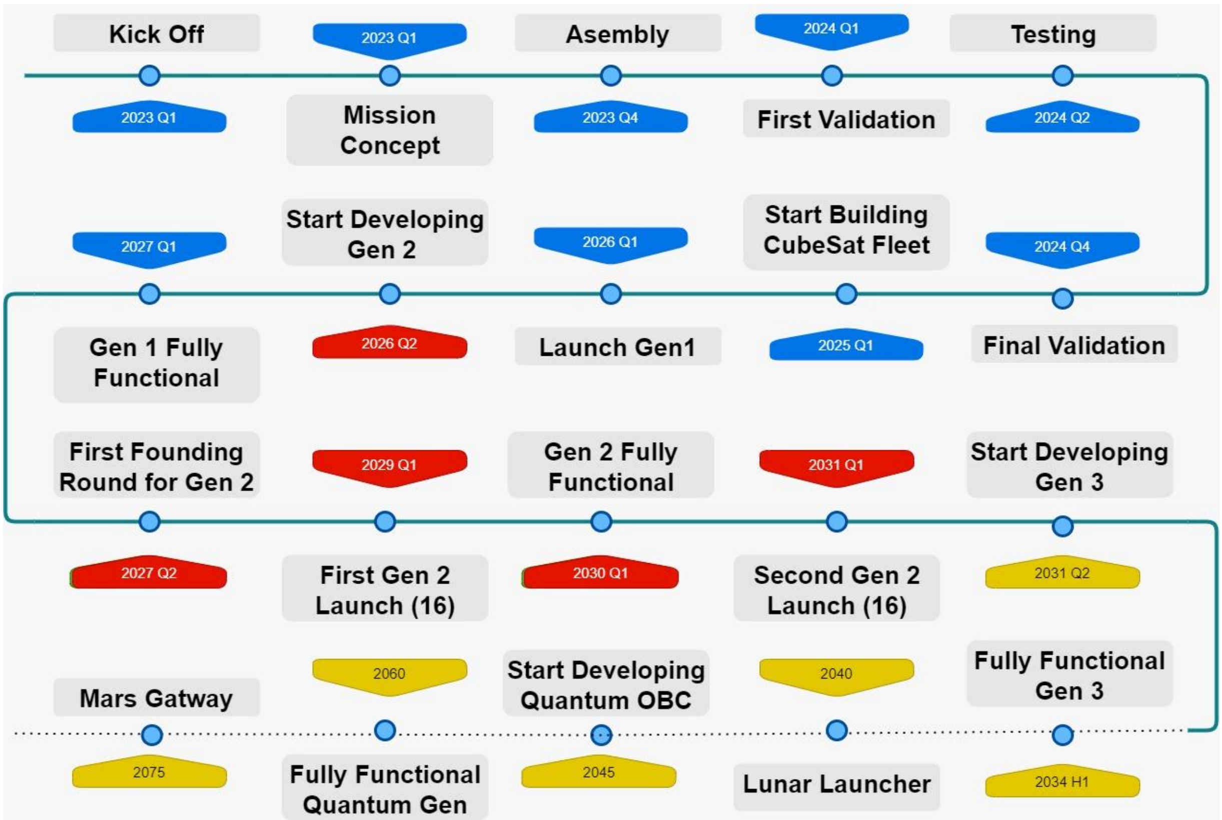

Figure 3-1: Mission Timeline

3.6.3. Concept of Operations

This mission requires numerous criteria: cost, wet mass, dry mass, risk, time, TRL, power budget. With these characteristics we constructed multiple concepts which were subjected to a trade-off analysis.

Tabel 3-2: Mission Concepts

Mission Concept 1	Mission Concept 2	Mission Concept 3	Mission Concept 4
Individual Launch	Individual Launch	Shared Launch	Shared Launch
Chemical Propulsion to orbit	Chemical Propulsion to orbit	Electrical Propulsion to orbit	Electrical Propulsion to orbit
Gateway	Gateway	Gateway	Gateway
Capsule orbit release with phasing	Multiple capsule orbit release	Capsule orbit release & CubeSAT does its own maneuvers	Individual CubeSat from LEO Transfer with phasing

Tabel 3-3: Concept of operations

		Mission Concept 1		Mission Concept 2		Mission Concept 3		Mission Concep t4	
Criteria	Weight	Rank	Score	Rank	Score	Rank	Score	Rank	Score
Cost	0.3	2	0.6	1	0.3	3	0.9	4	1.2
Wet Mass	0.1	2	0.2	1	0.1	3	0.3	4	0.4
Dry Mass	0.1	2	0.2	1	0.1	3	0.3	4	0.4
Risk	0.15	1	0.15	4	0.6	2	0.3	3	0.45
Time (Launch - Final Constellation)	0.1	3	0.3	4	0.4	2	0.2	1	0.1
TRL	0.1	2	0.2	1	0.1	3	0.3	2	0.2
Power Budget - CubeSAT	0.15	4	0.6	4	0.6	2	0.3	1	0.15
TOTAL	1		2.25		2.2		2.6		2.9

As it can be seen in the trade-off analysis, it can be observed that the best option for this mission is Mission Concept 4:

Tabel 3-4: Concept of operations

Mission Concept 4: masa ~ 1t
Ariane 6/ Falcon 9
Transfer from LEO
Electrical Orbital Transfer (CubeSat)
Phasing and change of inclination (CubeSat)
Propulsion Aliena 4U

4. Mission Feasibility

4.1. Constellation

4.1.1. Constellation Design

The constellation design is based on the Andromeda constellation which is already theoretically proven.

The constellation will be composed of 24 satellites equally divided among 4 elliptical orbits that are placed on the so-called frozen orbits of the moon, at specific inclinations: 27, 50, 76, 86 degrees reported to the equatorial plane of the moon.

These frozen orbits have the ability to keep the satellites on their orbits without often effectuating special maneuvers for station keeping.

The Molniya orbits are defined by their elliptical characteristics and their prolonged time spent in a certain area, which gives us more coverage in that zone, but less coverage in the others.

Any satellite will travel slowest at the farthest point of its orbit—called the apoapsis—and fastest when it is closest to the moon. Therefore, we want any orbit to have its apoapsis approximately above a potential hot spot in order to provide long periods of communications. With the selected orbits, the lunar poles are covered by three satellites simultaneously 94 percent of the time, with at least one satellite overhead at any given time. The equator, meanwhile, has at least one satellite overhead 89 percent of the time, and simultaneous coverage by three satellites 79 percent of the time.

4.1.2. Interplanetary transfer and constellation maneuvers

The constellation will be put in LEO by the Ariane 62 launcher from Kourou, French Guineea launch site because it's the closest to the equatorial plane of the Earth.

From LEO, our cubesats will perform an individual low-thrust orbit transfer in more than a year, using the MUSIC Electric Propulsion System, using an delta-V of 8 km/s to get to an equatorial LLO.

Earth-Moon space low-thrust

From	To	Delta-V (km/s)
Low Earth orbit (LEO)	Earth-Moon Lagrangian 1 (EML-1)	7.0
Low Earth orbit (LEO)	Geostationary Earth orbit (GEO)	6.0
Low Earth orbit (LEO)	Low Lunar orbit (LLO)	8.0
Low Earth orbit (LEO)	Sun-Earth Lagrangian 1 (SEL-1)	7.4
Low Earth orbit (LEO)	Sun-Earth Lagrangian 2 (SEL-2)	7.4
Earth-Moon Lagrangian 1 (EML-1)	Low Lunar orbit (LLO)	0.60-0.80
Earth-Moon Lagrangian 1 (EML-1)	Geostationary Earth orbit (GEO)	1.4-1.75
Earth-Moon Lagrangian 1 (EML-1)	Sun-Earth Lagrangian 2 (SEL-2)	0.30-0.40

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Figure 4-1: Earth-Moon space low-thrust

From LLO to the final position, there are two orbital maneuvers. One inclination change and one orbital raise maneuver to make it to the elliptical frozen orbits.

These maneuvers have a total delta-V budget of 6,816 km/s calculated based on the following formulas:

$$\Delta v_i = v_0 \sqrt{2 - 2\cos\frac{\pi}{2} i_0}$$

$$T_2 = \frac{1}{X} \frac{\Delta\Lambda + X \cdot 2\pi}{v/a_1}$$

$$a_2 = \left(\frac{T_2\sqrt{\mu}}{2\pi}\right)^{2/3}$$

$$e_2 = \frac{a_2 - a_1}{a_2}$$

$$v_{P,2} = \frac{\sqrt{\mu a_1 (1 + e_2)}}{a_1}$$

$$\Delta v_{ph} = |\Delta v_{start}| + |\Delta v_{end}| = |v_{P,2} - v| + |v - v_{P,2}|$$

4.2. Subsystem design definition

4.2.1. Attitude Determination and Control System

The ADCS strives with its complexity to fulfill multiple functions. The ADCS software contains algorithms and control schemes which are utilized to:

- perform a data acquisition procedure through sensors to ensure a consistent understanding of the manner in which the satellites are oriented in orbit
- implement an actuation system in charge of stabilizing the satellite through different maneuvers and orienting the satellites in the desired directions.

Its main purpose is to precisely determine the attitude through sensors and to get information about the satellite's position. The collected data from sensors will be processed by the ADCS controller to get reliable positioning information. This information will be vital for the antennas to be precisely pointed to the Moon and to the Gateway.

Based on rigorous research and comparing multiple space-graded ADCS solutions, it was chosen as an ADCS module which accomplishes the mission needs' and the mission requirements.

One of the main encountered problems when searching for an integrated ADCS is avoiding unneeded functions and components (magnetometer and magnetic-torquers), considering the lack of a magnetic field on the moon.

As such, the chosen COTS integrated ADCS will be an integrated stack of CubeSpace components (photodiodes for Sun sensing, thermopiles for Earth horizon sensing, Gyroscope for angular rate sensing, camera for photos, videos and star tracking) compatible with the integrated reaction wheels and power bus.

Figure 4-1: D-SENSE MULTI-SENSOR ADCS MODULE

The integrated actuators are a set of four reaction wheels redundant 3-axis control system, used to increase the attitude control and precision pointing capabilities of the satellites. The reaction wheels include DC brushless motors assembled in sealed housing.

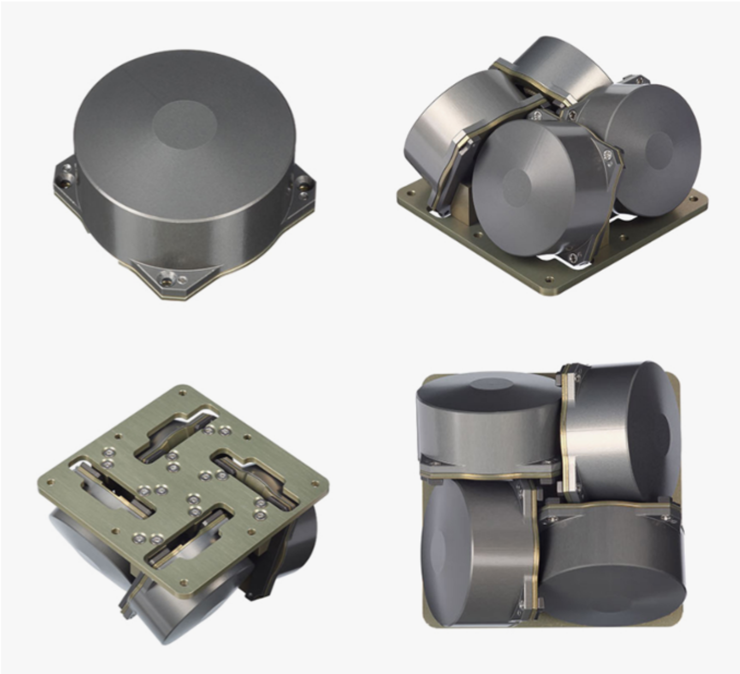

Figure 4-2: CubeSat Reaction Wheels Control System SatBus 4RW0

4.2.2. Communications

Communications will be done with the help of the Cross Link between the CubeSat constellation and the Lunar Gateway which is going to be the link between the Moon and Earth.

For Cross Link, Ka-Band frequencies (22 – 26 GHz) are being used because of their compatibility with the Lunar Gateway and, eventually, in the case of Mars orbiters with relay capabilities using the Lunar Gateway as a staging point for crew transportation.

For Proximity Link, restricted S-Band frequencies (3 – 4 GHz) are being used because of the regulations protecting the SZM where the usage of UHF is forbidden (the constellation strives for full coverage). This means L-band links for PNT are not recommended. As such, the adoption of S-band for proximity link by multiple relay orbiters would enable the in-situ tracking service and the in-situ navigation (GPS-light or Galileo-light capability). Optical links are not being used, primarily, to avoid any extra implementation costs due to multiple approaches. Furthermore, the laser needs extreme precision, which ultimately is not yet provided.

The implementation of a mesh constellation is made possible by the high speed of the Ka-band transceiver. The satellites eventually need to communicate with the Lunar Gateway, however if the change of attitude and position is too demanding or the Lunar Gateway is blocked by the moon, a longer transmission path, through other satellites of the constellation, is to be chosen.

A 45 W 4U Transceiver is being used to transmit and receive the Ka-Band (compatible with the Lunar Gateway) with data-rates of approximately 130 Mbps. The S-Band patch antenna used for transmission in the restricted S-band frequencies of GNSS data will have a transmit antenna gain of 24 dB and a transmit antenna power of 34 dB.

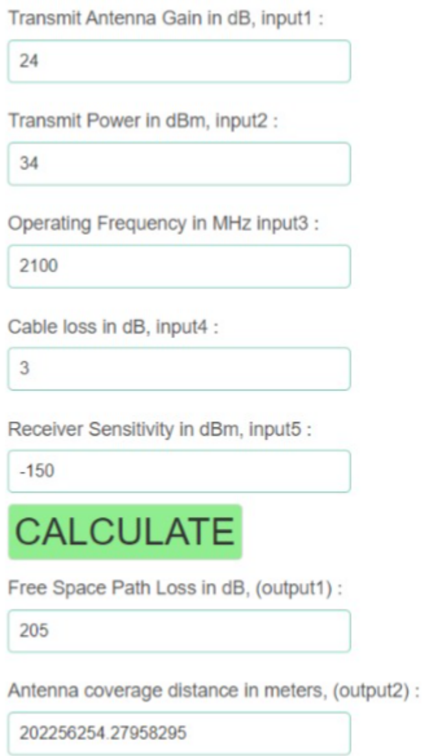

Fig. 4-3

In view of our orbits and altitude, the chosen specifications for the S-Band patch antenna are more than sufficient. The range of such antennas considering the needed receiving power for GNSS (-150 dB on ground) is 200 000 km, considerably more than the apogee of 8090 km of the orbit.

4.2.3. Electrical Power Supply

A 4 wing solar array and a 1U battery (2S6P) constitute the basis of the EPS. Considering the high power demand from the Ka-Band antenna and the MUSIC electric propulsion, although not simultaneous, the battery needs high specific energy. In this case, to maintain the battery life (above 75% but below 95% charge) and to easily power all subsystems we chose a 138Wh battery (max unregulated output power of 150W, max charging power of 60W and nominal energy capacity of 138 Wh). As backup for one time failure, two such batteries will be used. The size of the solar array is 0.36 m^2, weighing 1.41

kg. With the stowed footprint of 2 x 3 U and its stowed height of 12mm, the solar array has only one deployment axis. Its BOL is 191 W, in full light conditions. During the in-orbit lifetime, less than half of the solar array is needed to charge the battery and the rest of the subsystems. The system's lifetime is imposed by the charge, discharge cycles of the batteries and can vary greatly.

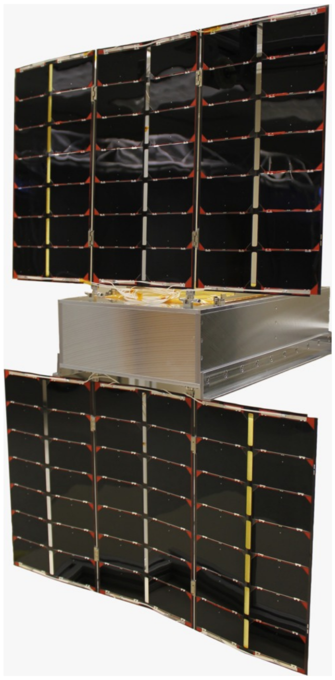

Fig. 4-4: Solar arrays

4.2.4. On Board Computer

The purpose of the OBC is to control the communication process and to make possible the transfer of data. Taking in consideration the algorithms used to facilitate the communication process, the internal RAM of 640 Kb used is enough to run one process at a time for uplink or downlink from the CubeSat.

The external RAM is 8 Mb which is enough to avoid the deadlock effect of the processes, ordering the processes and pointing to the code to be ran in the internal ram when is needed. There should be a parent algorithm that will have the rest of the algorithms which will be considered as child processes and for that the processes do not need to run simultaneously and will ran as single child processes that will be sent from external ram to internal ram. The complexity of the algorithms used to facilitate the process is good enough taking in consideration the processor clock that is up to 280 MHz. Also the operating temperature scale is large enough for different cases and different processes that the OBC do for downlink or uplink.

In case of major failure, the OBC is responsible for the decommissioning of the satellite (sending it into deep space).

4.2.5. Payload

The mission's payload consists of the communication system and the OBC used for data transfer. Future developments of the hardware and software might include multi-threading and smaller and better transreceivers to increase the overall performance of the mesh constellation. The software is essential in prolonging the lifetime of the mission. Monitoring thecubeSats' health of the battery greatly influences the rate with which satellites are being decommissioned and replaced.

4.2.6. Propulsion

Every CubeSAT in the I.L.O.N.A Constellation will use an low-power electrical propulsion system both for the interplanetary transfer from the LEO to LLO and for positioning on the chosen orbits around the Moon.

The MUSIC-DM Electric Propulsion System will ensure the necessary maneuvers within a 4U form factor. The hollow cathode technology will provide a specific impulse from 100 s to 1000 s at 100W and a wide range of thrust from 0.25 mN to 5mN and a total impulse of 15 kNs using Kr/Xe gas as fuel.

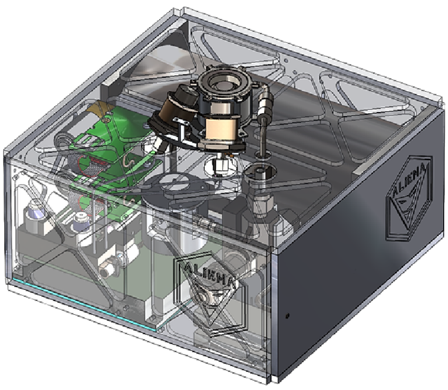

Fig. 4-5 MUSIC Electric Propulsion System

4.2.7. Structure Mechanism and Thermal Control

The structure of our satellite is defined by a 12U format cubesat. In this volume we have integrated all our subsystems in a well optimized adjustment.

Regarding the most voluminous subsystems on our satellite, the propulsion, by choosing Aliena's product, the design of every aspect of this subsystem in a very finite space was possible, using only 4U.

The other voluminous subsystem is the communication subsystem, which also utilizes 4U of our cubesat. The antennas are separated from the other subsystems by the fact that they do not have the same thermal insulation applied.

The On Board Computer and the Comms utilize exactly 1U, subsystems that manage all the signals and computational power to function properly.

The reaction wheels, which are used to solve the movement situations, are utilizing half of 1U of our cubesat.

And, not lastly, the energy subsystem which powers all the other subsystems, one of the most important ones, are as big as 2U, enough to leave around 0.5U for cable management and space optimization.

The energy subsystem also functions on a foldable solar panel system. The panels are side mounted on the cubesat and they lift and unfold with small integrated actuators. This movement is constantly adjusted by the ADCS for the best optimisation of power production, making our cubesat lifetime longer.

Thermal wise, the problems raised by this design were minimal and the multi-layer insulation for the cubesat is performing well enough to keep the components safe from temperatures and radiation.

4.2.8. One time Failure risk

A real concern for any space mission is the possibility of a subsystem failing. In our case for the vital subsystems of our mission with the highest risk of failure a backup has been added. As such, with our limited space (12U) another smaller battery is needed (without taking into consideration the propulsion) and the on board computer has been separated by role. The ADCS integrated system has its own OBC, while the management of the payload is done by a separate OBC.

4.3. System Budgets

4.3.1. Mass Budget

Tabel 4-1: Mass Budget

Component/Integrated Subsystem	Weight Datasheet	Error Margin	Approximate weight [kg]
Propulsion	5	5	5.25
Solar Arrays	1.5	15	1.73
Battery	5	15	5.75
S-Band Patch Antenna	0.1	10	0.11

Ka-Band Transceiver	1.5	10	1.65
Structure and MLI	2.5	10	2.75
Reaction Wheels	1	10	1.10
ADCS	0.2	15	0.23
OBC	0.2	15	0.23
Atomic Clocks	0.1	12	0.12
Total	18.91		
Total with 20% error margin	**22.7**		

4.3.2. Cost Budget

We have Two Phases for the whole mission. The first Phase is set to send up to 28 12U CubeSats on the desired orbit and the second phase will send up to 32 CubeSats. One Phase will have multiple large steps: First CubeSat, first generation of CubeSat fleet construction, Launch of the 28 CubeSats, Orbital Transfer from LEO to Moon's Orbit. Every step is represented in huge amounts of costs.

4.3.2.1. Phase One

In the first phase we will construct the first CubeSat that will orbit the moon and will represent the prototype for the rest 27 CubeSats to make the Constellation. One CubeSat will be around 2.5 million euros. From the design of the CubeSat were selected the more expensive parts and all the little ones will be considered in the margin error.

Tabel 4-2: Cost Budget ph.1 - CubeSat

	CubeSat - non recurring		
	Component	Price LEO[€]	FInal Value[€]

	S-Band	9400	47000
	Ka-Band	21000	105000
	OBC	40000	200000
	Structure	20000	100000
	Solar Panels	35000	175000
	RW4	8000	40000
	ADCS&Gyro	37000	185000
	Atomic Clock x 2	4000	20000
	Propulsion		1200000
	Error Margin		0.2
Total[€]			2486400

In the cost of the first Phase we also had to consider human and non-human resources for development. Considering the human resources, we choose 70 employees, considering that every subsystem will need up to 9 employees and the rest minimum of 10 will be in the other departments from our company. Considering the laboratories needed, we did research about the cost of a construction and testing of a CubeSat and the result was around 200.000 euros and considering the budget for the components we need to replace we raised to 340.000(considering the components on the laboratories that present high risk of breaking.

Tabel 4-3: Cost Budget ph.1 - Human and Infrastructure

	Human and Infrastructure - non recurring					
	Component	Number	Price/unit/year[€]	Years	Price/unit[€]	Price[€]
	Employees	70	150000	4	600000	42000000
	Salaries error	0	0		0	8400000
	Laboratories	2			340000	680000
Total[€]						51080000

The next step is to construct the fleet of the 27 CubeSats and in total will be sent 28 CubeSats(even if 24 is enough, it's good to have 4 more satellites for redundancy). Considering that the components are COTS, we can achieve a total discount up to 12%.

Tabel 4-4: Cost Budget ph.1 - Human and Infrastructure

	CubeSats Constellation - recurring		
	Components	Number	Value[€]
	Number of satellites	27	67618800
	Discount		0.12
Total[€]			59504544

The last step considered in the budget needed is the launch process. The rocket used will be Ariane 62 which costs about 77.000.000 euros, but the price per kg is not yet defined. The single information in this way is about Falcon 9 which has a price per kg of 3250 euros. The calculations of the cost for the Ariane 62 ride to LEO are presented in the table below:

Tabel 4-5: Cost Budget ph.1 - Launch

	Launch - non-recurring				
	Component	CubeSat[kg]	Number	Total kg	Price[€]
	Ariane 62	23	28	644	2254000
	Ariane 62				77000000
Total[€]					79254000

After all these steps priced individually the total cost of the First Phase is as follows: 2.486.400+51.080.000+59.504.544+79.254.000=192.342.944 euros.

4.3.2.2. Phase Two

In 2026 the launch of the first 28 CubeSats is done and the team will now go for the next generation of CubeSats. The steps for the Phase Two are the same as in the Phase One so the development of the CubeSat will be almost the same in pricing(it can depend on the prices of components in 2026, but for that reason in the final price an inflation percentage).

Tabel 4-6: Cost Budget ph.2 - Cubesat

	CubeSat - non recurring		
	Component	Price LEO[€]	FInal Value[€]
	S-Band	9400	47000
	Ka-Band	21000	105000
	OBC	40000	200000
	Structure	20000	100000
	Solar Panels	35000	175000
	RW4	8000	40000
	ADCS&Gyro	37000	185000
	Atomic Clock x 2	4000	20000
	Propulsion		1200000
	Error Margin		0.2
Total[€]			2486400

The second part of pricing is to verify the laboratories and to use the most recent equipment. Also the Salaries will be the same at this point, but again there is a factor of inflation or salaries fluctuation.

Tabel 4-7: Cost Budget ph.2 - Human and Infrastructure

	Human and Infrastructure - non-recurring					
	Component	Number	Price/unit/year [€]	Years	Price/unit [€]	Price[€]
	Employees	70	150000	4	600000	42000000
	Salaries error	-	-	-	-	8400000

	Refactoring Laboratories	2	-		100000	200000
Total[€]						50600000

The next step after innovating the CubeSat is to make another fleet of 16 CubeSats to send on the orbit and to replace and supply the existing constellation.

Tabel 4-8: Cost Budget ph.2 - Cubesats Constellation

	CubeSats Constellation - recurring		
	Components	Number	Value[€]
	Number of satellites	16	39782400
	Discount		0.1
Total[€]			35804160

The next step after the fleet is done is to launch. This time we will not launch individually, but we will search for a partner in 2029 to make this launch possibile with Ariane 62 to LEO. In this way the calculations of the cost for ride sharing are as shown in the next table:

Tabel 4-9: Cost Budget ph.2 - Launch

	Launch - non-recurring						
	Component	CubeSat kg	Number	Total[kg]	Rocket Cost[€]	percentage	Price[€]
	Shared Ariane 62	23	16	368			1288000
	Rocket Contribution				77000000	0.0368	2833600

Total[€]							4121600

The total cost for the phase will be drastically reduced because almost a half of the number of satellites sent in the first phase and the launch will not be individually but by a sharing ride. The total cost will be calculated as follows: 2486400+50600000+35804160+4121600 = 93.012.160 euros.

4.3.2.3. Final Mission cost

After the two phases are done the business model is made to have our profit and to be capable of launching the other 16 satellites in order to replace after 5 year all constellations and to have in the end a constellation of 32 CubeSats. In the final cost are included percentages for possible inflation until 2030, error margin percentage and advertising budget. The calculations are made in the below table:

Tabel 4-10: Final Mission cost

Parts	Price[€]	Total[€]
Phase 1	192342944	192342944
Phase 2	93012160	285355104
percentage of possible inflation	0.2	342426124.8
error percentage of total	0.15	393790043.5
Advertising	6000000	399790043.5
ROM Cost		400000000

The ROM Cost can also be variable with a percentage up to 20%(more or less than the Final Cost). In the end the budget for the mission that we need is 400.000.000 euros.

4.3.3. Power Budget

Tabel 4-11: Power Budget

Component/Integrated Subsystem	Power Datasheet [W]
Propulsion	-100

Solar Arrays BOL	191
Battery	138
S-Band Patch Antenna	-2.5
Ka-Band Transceiver	-45
Reaction Wheels	-6
ADCS	-0.5
OBC	-0.6
Atomic Clocks	-0.25

The power budget has been calculated in regards to the surplus of electrical power. The case where both propulsion and high frequency transmission are needed has not been taken into account as they should not concur.

Tabel 4-12: Operating modes

In case of			
Propulsion	**Strong light conditions [W]**	**81.15**	**Enough for charging the batteries**
	Eclipse [W]	**28.15**	
High frequency transmission-8770	**Strong light conditions [W]**	**136.15**	**Enough for charging the batteries**
	Eclipse [W]	**83.15**	

4.3.4. Link Budget

Tabel 4-13: Link Budget

Coverage	Type of link	Data rate	Frequency
Long Range	S-Band	10 Mbps	3-4 GHz
	Ka-Band	130 Mbps	22-26 GHz

5. Business Model Canvas

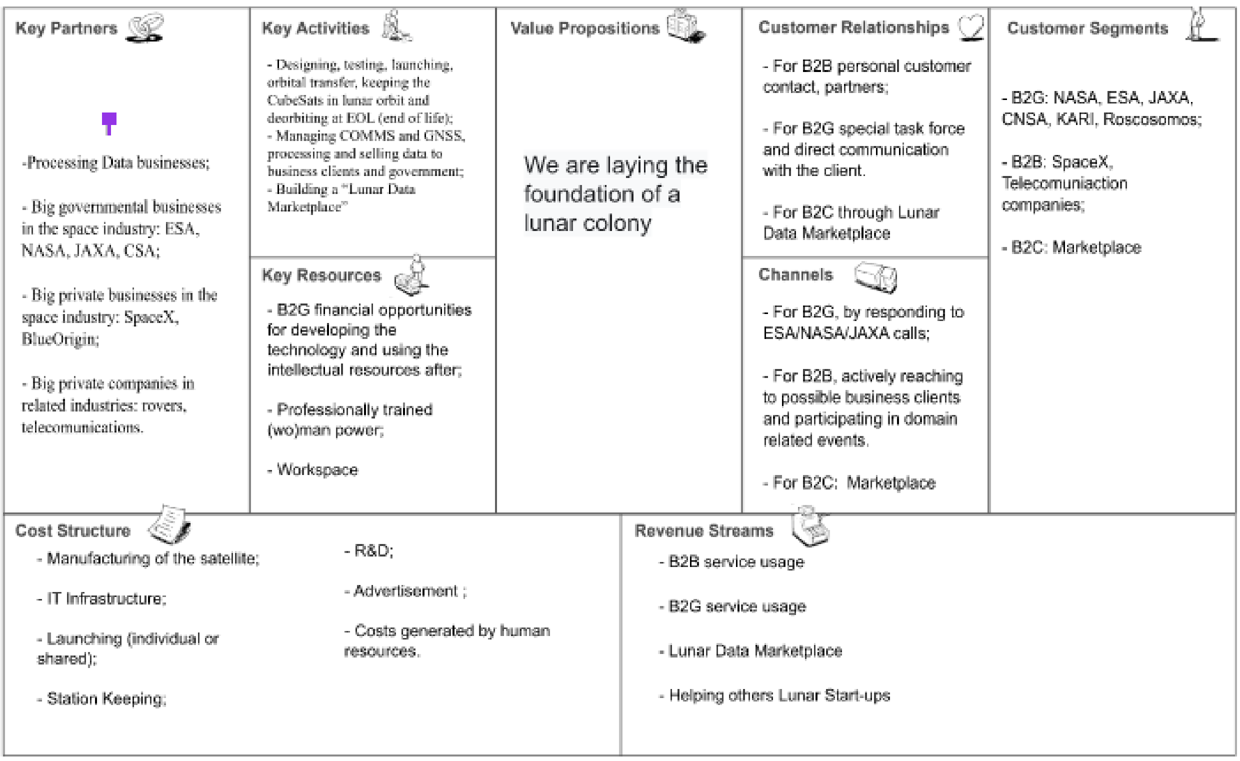

Fig. 5-1 Business Model Canvas

5.1.1. BMC Explanation

Our value proposition is "We are laying the foundation of a lunar colony" which demonstrates that we could easily develop billions of euros of health for the entire society. Being one of the first companies that provides GNSS and Communication on the Moon, puts us in a very advantageous position.

The key activities that we are going to do are collecting lunar data with ILONA Constellation, processing it with the help of an external company (A Start-up that we will help develop), and providing the process data into a Lunar Data Marketplace.

Analyzing the key activities we could easily anticipate that the customers segments are 3 big classes: B2G, B2B and B2C. For the B2G segment the principal agencies are the agencies that are involved in the Lunar Gateway Project (ESA, NASA, JAXA, CSA). For the B2B segment we will communicate mainly with a Start-Up focused in Processing Lunar Data and on a secondary plan, basically every company that it's interested in the space sector (more details in 5.4.2 chapter). For the B2C segment we will build a Marketplace which will satisfy a lot of customers' needs (Gaming, Entertaining, Real Time Moon Data etc).

5.1.2. Market Analysis

Our ideas are based on a lunar market analysis from now till 2040. It's estimated that in the next 20 years, more than 100B € will be invested by the private and public space agencies, with more than 45B € on landers and more than 30B € on rovers. Non-space agencies will also invest a lot of money in this sector and some big companies that have already announced their interest are: Audi, Toyota, GM (rovers, robotics), Caterpillar, Rio Tinto (mining), Foster + Partners (building), Skyre (energy).

Following an optimistic roadmap on the Moon Race from “Lunar market assessment: market trends and challenges in the development of a lunar economy” from September 2021, if a series of factors are satisfied, in 2035 more than 200 people are going to live on the moon, and more than 1000 in 2040, with a budget of 1205B €. Even if this kind of scenario is difficult to achieve, it shows us that a lunar market is a potential place for even bigger business than here on Earth.

5.1.3. Business Model Schema

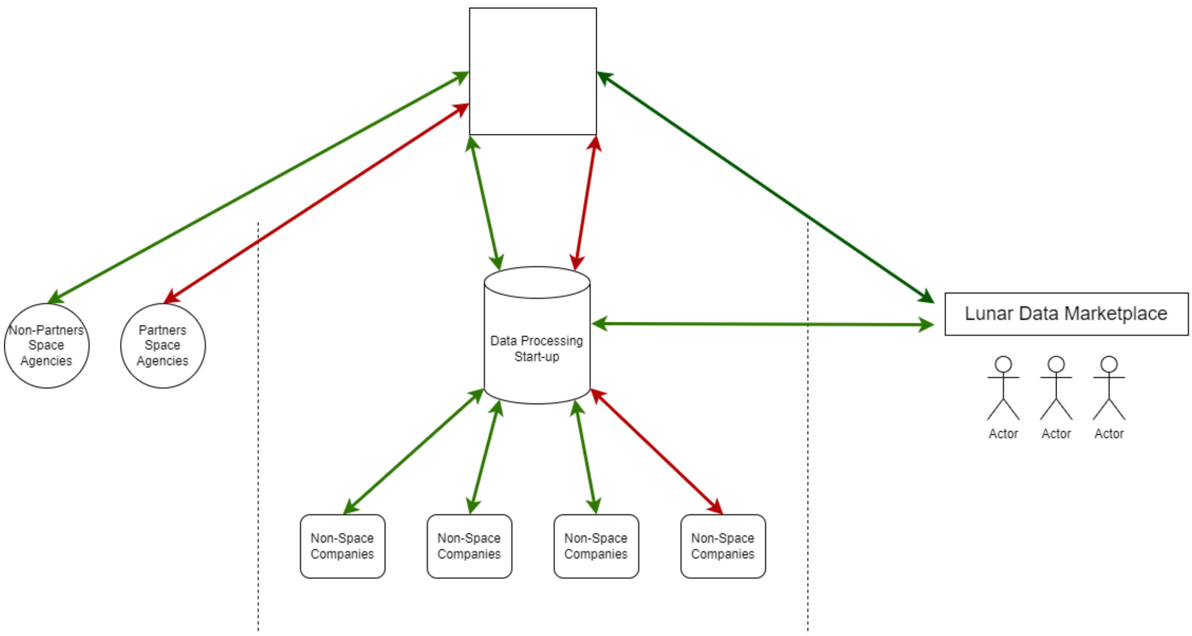

Fig. 5-2 Business Model Schema

For a more clear vision on our business model, we build a business model schema. In the left you could see our B2G segment, in the middle B2C and in the right B2C. The green arrows mean that we provide data and we get back money, and red arrows mean that we provide data and we get back other data.

B2G segment is a classical type of collaboration (espacilay barters with companies as NASA, ESA etc), but we also build an infrastructure for private companies such as SpaceX and Blue Origin which are willing to land on the moon after we will have the first generation fully functional.

B2B it's our main segment, and we have an idea based on the fact that the moon will be the next Gold Rush. Providing the raw data to data processing Start-up (that we will help develop) will put us in a very advantageous position compared with competition. The idea is very easy: after the start-up process and sale of the data, we get a fee from every transaction that they will do. Also, for our long term vision we will negotiate a barter type partnership every time is needed and possible. For example Foster + Partners which presented their intention in the lunar construction market will get access to the data provided by the data processing start-up but will help us with our ideas on the moon surface constructions.

B2C is a secondary source of income, via Lunar Data Marketplace. This will be a platform in which everyone could access lunar data related projects in entertaining scopes such as Gaming or Movies. This Marketplace will be developed after our first generations of CubeSats in collaboration with the start-up. Another advantage for building a Lunar Data Marketplace is the fact that we will easily get a community interested in the moon economy, which doesn't have a lot of laws right now. We will surely support developing these laws, providing the communication infrastructure for any kind of lunar-lunar transaction.

5.1.4. Funding Opportunities

In terms of money and founding we will approach perspectives. One is a classical way to do business, with calls from ESA and other Space Agencies and the other it's focused on the New Space Methods.

After the first generation it's fully functional, we are planning to open a first funding round for the second generation, which means it will be a hybrid public-private project, and we will think of a system in which any company that funds has access to our processed data in a different way than others.

Talking about profit, we estimate that in the year 2027, after the first constellation is functional, we will start getting money , in the first phases by space agencies, and till 2030 we will surely be a self-sustainable business.

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