L’SPACE MCA
Spring 2022

Project S.C.R.A.M.
Southern Crater Resource Assessment Mission

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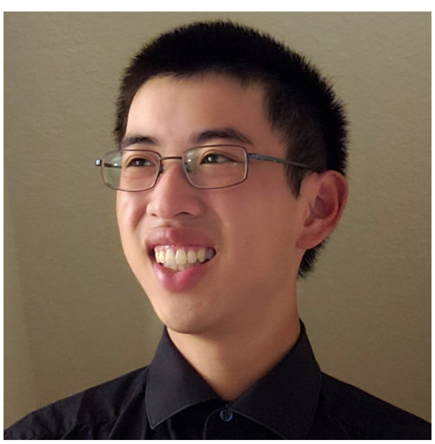
1. *Introduction and Summary*

1.1 Team Introduction

Team Caelum is a multinational team of space exploration enthusiasts spanning half the globe. The name Caelum was chosen because it means anything that is above the surface of the earth, or “The Heavens”. This is appropriate because Team Caelum’s mission is focused on advancing humanity into the heavens. Below is a short introduction to the team.

Name	Biography
Nate Dee 	Mechanical Engineering at Washington State University, Richland, WA Junior Nate is the Project Manager and admin team member of Team Caelum. He brings the leadership and maintenance experience of a 9-year US Navy avionics technician and emergency responder, and is an avid mechanical tinkerer.
Jordan Wong 	Biological Systems Engineering at University of California, Davis Davis, CA Junior Jordan is the Deputy Project Manager and science team member of Team Caelum. He also serves as the Project Manager for the UC Davis Space and Satellite Systems Club’s very own Cubesat mission. He hopes to take what he learns at L'SPACE towards building a new mission proposal for the club’s next CubeSat mission.

<table>
<tr><td>Madhavi Prakash
</td><td>Mathematics at Santa Monica Community College, Santa Monica, CA

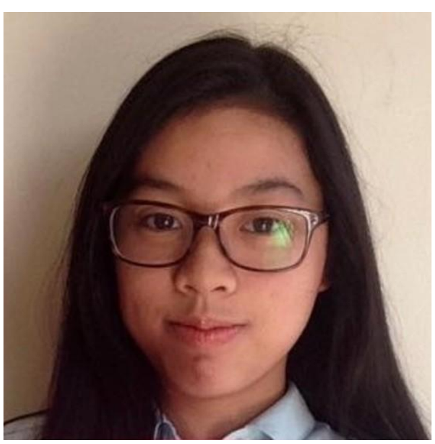
Freshman

Madhavi serves as the Science Lead of Team Caelum.

She hopes to apply her analytical and creative skills to this project. She performs Indian classical music and practices yoga in her free time.</td></tr>
<tr><td>Michael Francesconi
</td><td>Mechanical Engineering at University of California, Davis
Davis, CA

Freshman

Michael serves as the Engineering Lead of Team Caelum.

He hopes to apply and develop his experience in CAD modeling. In his free time, he enjoys reading and running.</td></tr>
<tr><td>Courtney Songco
</td><td>Computer Science at Mt. San Jacinto College
Menifee, CA

Sophomore

Courtney serves as the Admin Lead for Team Caelum,

She hopes to apply her experience in Computer Science. During her spare time, she enjoys doing product design and writing.</td></tr>
</table>

Shye Alyss 	Astronomy and Astrophysics at Deanza Community College, Cupertino, CA. Sophomore Shye is part of Caelum's Science team She contributes as a researcher and utilizes her critical thinking and problem solving abilities.
Leonel Hernandez 	Mechanical Engineering at California State University Northridge Los Angeles, CA Junior Leo is part of Caelum's engineering team. He contributes as an engineer by using his problem solving skills. In his free time he likes to make art.
Hulbert Zeng 	Philosophy and Computer Science at University of California, Riverside Riverside, CA Hulbert is a part of Caelum's engineering team. He also serves as the lead for the UCR Team Tech and the software lead for the UCR Robosub. He hopes to apply his software skills and project design experience.

<table>
<tr>
<td>Mahesh Acharya
</td>
<td>Computer science at Rio Hondo College, Whittier, CA

Sophomore

Mahesh is a part of Caelum’s Science team.</td>
</tr>
<tr>
<td>Miguel Garza
</td>
<td>Mechanical Engineering at Santa Rosa Junior College, Santa Rosa, CA

Miguel is a part of Caelum’s Engineering team.

He plans on transferring to a 4 year soon to complete his degree and graduate.</td>
</tr>
</table>

1.2 Mission Overview

Terminology clarification: Project SCRAM refers to the overall mission. This encompasses every aspect of the team, instruments, and research. When referring to the rover, the report will call it “the rover” with the exception of the name being revealed in the conclusion.

1.2.1 Mission Statement

The team’s primary goal is to understand the characteristics and origin of volatiles found within the permanently shadowed regions (PSRs) found on the lunar surface, as well as evaluate their potential for use by future human missions on the moon. These volatiles have the potential to include elements such as sulfur and water, which can potentially be utilized by future missions if their presence is known and in what quantities. The region of interest is Amundsen’s crater, and that as well as surrounding craters will be the main area of study for the duration of the mission. In combination with a mobile unit akin to a rover, an efficient method to sample these volatiles will be developed to determine the chemical and physical properties of any compounds and elements that are found volatiles present. The secondary goal of this analysis is to determine whether or not the presence of one compound is an indicator of another, related compound, reducing the need to search for many types of compounds at once.

1.2.2 Mission Requirements

The following requirements have been imposed by the L'SPACE Staff and Team Caelumn. These are the minimum standards by which mission effectiveness will be measured.

Mission Requirements:

1. L'SPACE requirements:
    - 1.1: No more than 125 kg
    - 1.2: No more than a 1.5 x 1.5 x 1.5 m footprint
    - 1.3: Budget capped at $150M USD
2. Team requirements:
    - 2.1 Science team requirements:
        - 2.1.1: Analyze 14 cm^2 of volatile samples per 5 m^2 of surface within the target region
        - 2.1.2: Analyze minimum 2 samples just outside PSR for comparison/ calibration
        - 2.1.3: Map subsurface boundaries to more accurately determine volatile concentrations
    - 2.2 Engineering team requirements
        - 2.2.1: Power system must be capable of simultaneously running all systems at x% for “y” time

2.2.2: Thermal control must be able to maintain stable internal temperature with fluctuations no more than +/- 29 degrees celsius

1.2.3 Mission Success Criteria

The criteria for mission success will be to gain a better understanding of the history and evolution of lunar volatiles, as well as analyzing the form, abundance, distribution, and composition of water on the moon. As such, the criteria has been broken down into four main goals required for a successful mission:

1. Successfully analyze at least 200 samples over the mission lifetime
2. Determine the approximate volume of available water per cubic meter of regolith
3. Identify chemical and/or physical relationships between lunar volatiles
4. Determine the ease of extraction/transportation of volatiles

1.2.4 Concept of Operations (COO)

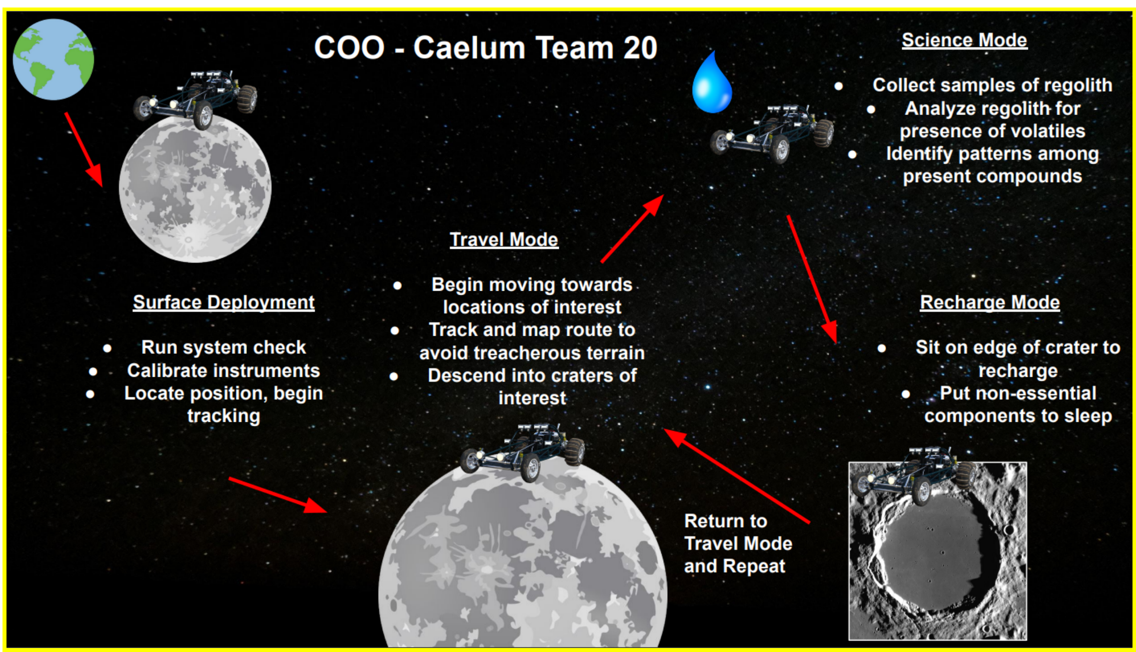


Figure 1: Concept of Operations

With two landing sites and over ten different potential science stations, Amundsen's crater is a prime target for the research proposed by this study. The rover's primary target will be site B3, located just north of landing site B. Site B's characteristics include temperatures from 23 to 239K, elevated Hydrogen levels (98-125 ppm), and slopes of less than 6 degrees. It is also near several other craters of interest, allowing for the rover to explore more areas without traversing very far.

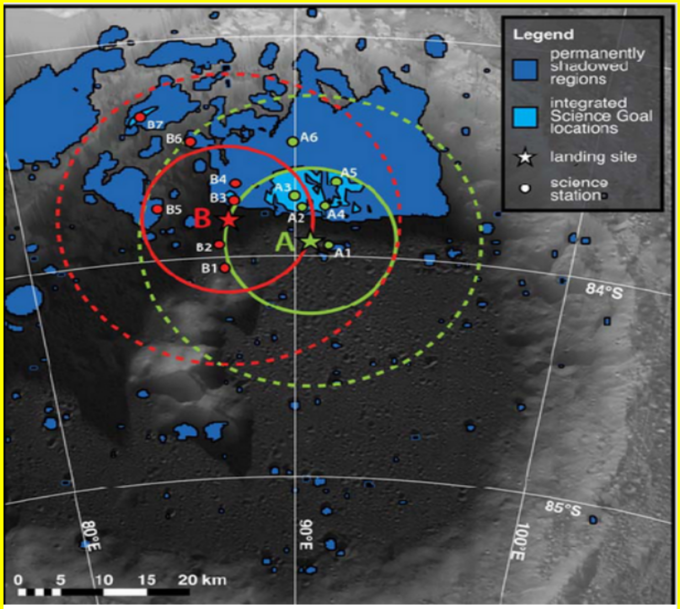


Image Source:
https://www.researchgate.net/publication/258674649_Volatiles_at_the_Lunar_South_Pole_A_Case_Study_for_a_Mission_to_Amundsen_Crater

Figure 2: Selected landing sites

1.2.5 Major Milestones Schedule

Table 1: Milestones schedule

Mission Phases	Major Milestone	Starting & Ending Date
Phase B: Preliminary Design and Technology Completion	This phase involves the completion of Team Caelum's Preliminary Design Review (PDR). The initial project baseline needs to be established which covers the technical, business, system requirements, design, schedule, management plans, and operation plans of the mission. The team will prototype the payload and rover for the mission to Earth's moon to research lunar regolith found on the Permanently Shadowed Regions (PSRs) of Earth's Moon. Several risk-mitigation and FMEA	2/15/22 - 4/11/22

	evaluations will be considered for the payload design, systems design, and instruments used for the mission. Another aspect that needs to be validated are the mission goals of the mission and the constraints provided by the client. The budget allowance will be broken down into a budget narrative for the whole mission which includes the testing facilities, manufacturers, outreach program, travel fees, hotel accommodations, the salary of each personnel, etc. The scheduling baseline is also overviewed from the conceptualizing of the PDR to the Operation Phase.	
Phase C: Final Design and Fabrication	This phase involves the Critical Design Review (CDR),The team shall go over the drafting, refining, and designing of the rover within the given constraints.	4/12/22 - 2/25/23
Phase D: System Assembly, Integration and Test, Launch	This phase involves the Test Readiness Review (TRR), (PLAR), (ORR). Appropriate testing requirements for each subsystem such as the thermal, structural, and communications will be determined, and then each subsystem will be tested to ensure successful operation for the mission duration. Additionally, the design will be evaluated to ensure it can be manufactured in cost and on schedule.	2/26/23 - 6/23/23
Phase E: Operations Phases MO & DA (Mission Ops & Data Analysis)	This phase includes the data analysis of the project. Once the spacecraft has landed within the chosen area of landing (surface of Amundsen). During the deployment, the spacecraft will utilize the scientific tools to collect the samples of regolith	6/24/23 - 5/14/27

	and shall be further analyzed to detect the presence of lunar volatiles. To ensure the spacecraft's flight path, the team will design a reference trajectory to map out the path. The examination of each instrumentation shall also be conducted and tested to lessen probable hazards that may disrupt this mission.	

1.3 Deployment Scheme and Rover Design Summary

Table 2: Rover design criteria

Criteria	Grade	Weight	Design 4	Design 2	Design 3	Design 1
Maneuverability: Ability of the rover to traverse lunar terrain	1:Cannot traverse terrain 5:Can easily traverse terrain	20%	4	3	4	2
Reliability: Ability to continue mission with unexpected issues	1:Too complex. Part failure makes rover inoperable 5: Redundant Systems make failure unlikely	30%	4	2	4	2
Cost: Ability to be built within budget	1: Cannot be built under budget 5: Can be built under budget	20%	4	4	1	4
Power Supply: Ability to stay powered	1:Can only stay for short periods in PSRs 5:Can make extended stays in PSRs	30%	3	5	4	5
	Total (%):	100	74	70	68	66

The rover is 590mm wide by 700mm long by 400mm tall. The main body is 500x300x170mm. The total mass of the rover is 32.46kg. The rover maneuvers using six wheels. The wheels are attached to a suspension system called the rocker-bogie system, which can rotate to compensate for uneven terrain. The rover has a solar panel on its side which will be oriented towards the sun when charging. When in the sun, the rover will use its radiators to maintain a stable internal temperature. The rover can maneuver into permanently shadowed regions when charged. There, the rover will use its heating system to keep a stable internal temperature. Once at a desired location, the volatile sampler will be lowered down to the regolith from the rover body. All data will be stored, and transmitted once outside of a permanently shadowed region.

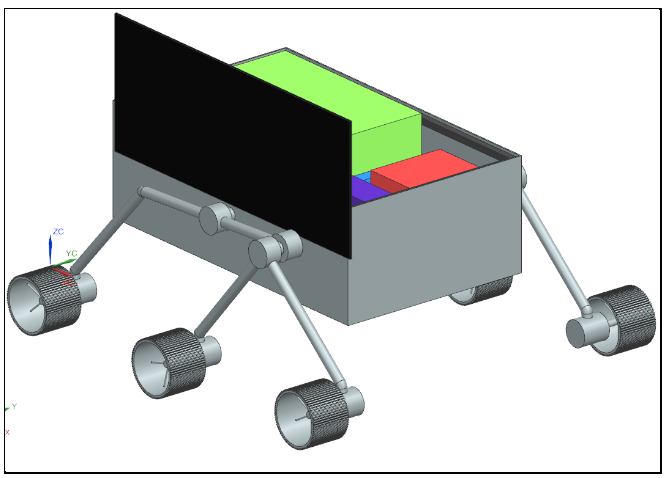


Figure 3: Rover Design

1.4 Payload and Science Instrumentation Summary

The integrated Volatiles Sampler(VS) and Volatiles Analyser (VA) instrument is a soil sampling, gas extraction and analysis instrument for the investigation of volatiles in lunar regolith, developed previously by the Lunar Volatiles Mobile Instrumentation (LUVMI) project. This device allows for a relatively straightforward path to collect information about volatiles in whichever reason is selected for analysis, as all that is required is the drill be inserted into the regolith. The system consists of a hollow drill shell, which is driven by a brushed DC motor for insertion into the ground. Once inserted, a heating element in the drill shell heats the regolith to extract volatiles in-situ in the ground. While some of the released gas escapes through the open bottom, the majority remains trapped inside the drill shell. Pirani pressure sensors monitor the gas pressure rise during heating, which can give some indication on the abundance of volatiles in the sample.

Directly above the drill shell sits the VA, which is a single unit consisting of an Ion Trap Mass Spectrometer (ITMS) and associated control electronics. This device will conduct mass spectroscopy on the gaseous volatiles, feeding information about the chemical composition of the compounds it detects.

In addition to the VS/VA integrated unit, there will also be several auxiliary science instrumentation to assist the main VS/VA unit. A navigation system consisting of a Ground Temperature Sensor (GTS), two cameras, and a Ground Penetrating Radar (GPR) will be used to identify ideal spots for driggin that will provide the most stable surface as well as ideal temperatures for drilling.

2. Evolution of the Project

2.1 Evolution of Mission Experiment Plan

2.1.1 First Iteration:

The first iteration of the mission experiment plan for the team was to initially explore through a wide area search of the polar regions of Earth's Moon so that the team could possibly collect more regolith and study upon more volatiles. Although this may have been a highly accurate and successful mission concept in terms of data collection and findings, this will have exceeded the required mission budget of $150M. Not only will the finances go beyond the required budget, but also the mass constraints for the payload would have been surpassed as well.

2.1.2 Second Iteration:

The second iteration was revised with the science objectives which narrowed to only certain areas of the permanently shadowed craters. However, there was a change in terms of the method for collecting the samples of regolith to examine the volatiles. The original objective was to collect these volatiles due to its possible benefits for human habitation; however, the team discussed the possible contamination of simply bringing up these volatiles out of the crater. Thus, there had to be another adjustment in the science objectives to allot more research and budget allocation for the excavation of the volatiles.

2.1.3 Third Iteration:

The third iteration for the mission experiment plan was the revision of the final science objective. The team decided to revise the science objectives regarding the presence of a particular compound that will be an indicator of another, related compound. With this, this helps in reducing the need to search for many types of compounds at once. This objective was added to the overall mission to make the mission experiment plan produce a better outcome.

2.2 Evolution of Deployment Scheme and Vehicle Design

2.2.1 Idea 1:

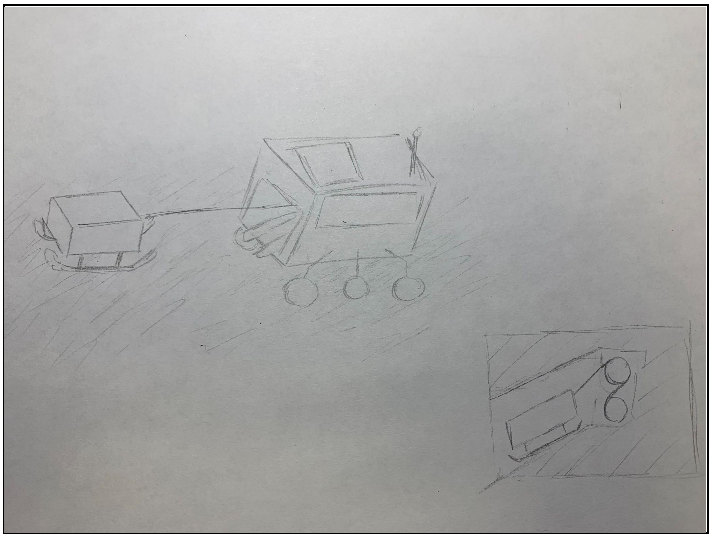


Figure 4: Design idea #1

This rover consists of two main bodies. The main body would house the smaller one, and would move from crater to crater. Once at the edge of a crater, the smaller body would be released but stay connected to the rover through a cable. This part of the rover would house the science equipment and perform experiments inside the PSRs. The smaller body would then slide down the side of the crater on sleds. The rover at the top of the crater would act as an anchor and be able to pull the smaller body out of the crater. It would also act as a power source for the smaller rover while it is in the dark.

This design was not chosen because the lack of wheels on the smaller body would make it unable to navigate the potentially rocky terrain on the moon. Additionally, its movement would be limited by the amount of cable the rover has. The cable would take up a lot of space and mass, and, if it failed, would make the rover inoperable.

2.2.2 Idea 2:

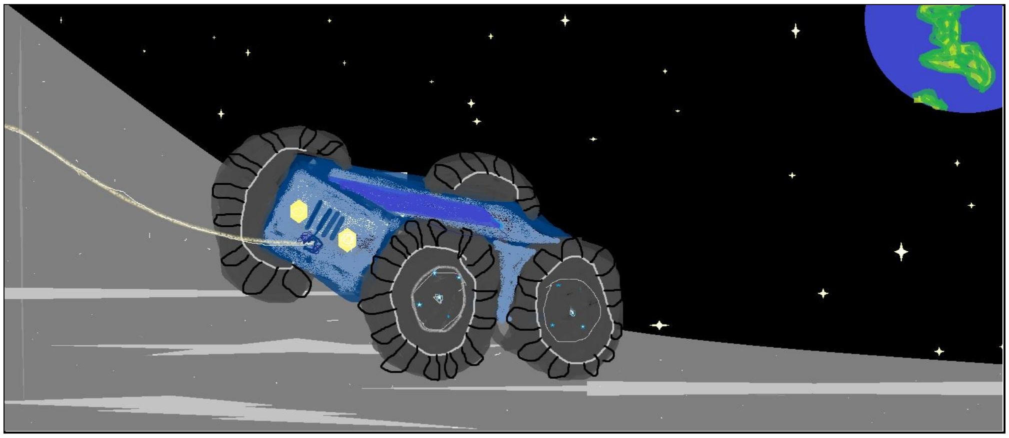


Figure 5: Design idea 2

This design consists of a retractable anchor that can be used to pull the rover when stuck. The wheels are also meant to expand in size in order to help the rover with break over angle. Second, all of the scientific equipment needed to analyze samples would be retractable and kept safe within the rovers body.

While this design is more mobile that the first design, its mobility is still limited by cable length. Similarly, it would also be rendered inoperable if the cable were to fail.

2.2.3 Idea 3:

Idea 3 is a single body rover with both RTG and solar panels acting as a power source. During the lunar days, the rover would drive in and out of the PSRs to charge its batteries. During the lunar nights the rover would park itself in a non PSR and rely on its RTG and batteries to keep the rover warm. The rover would have six wheels that would be able to move independently of each other.

This design was not chosen because RTGs of the necessary size do not exist for rovers. Development costs and production costs for a mission specific RTG would be beyond our budget. No visual created for this idea.

2.2.4 Idea 4:

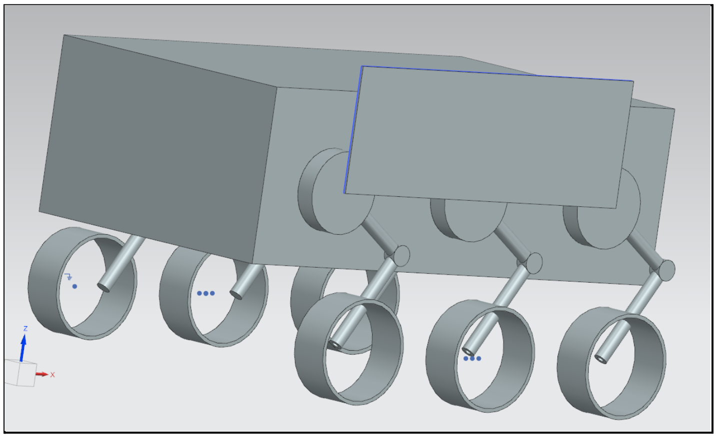


Figure 6: Design idea 4

This design is similar to idea 3, except it does not use an RTG. This design would have a solar panel on one side of the rover, which would then be oriented towards the sun when charging.

This design was chosen as it was the most reliable and within all defined physical constraints as well as within budget.

2.2.5 Idea 5:

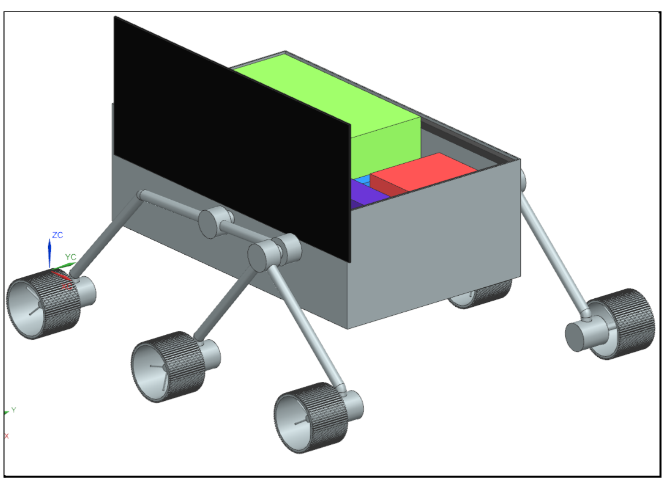


Figure 7: Design idea 5

This design is an evolution of the fourth design. The suspension has been redesigned to use a rocker-bogie system in order to provide increased stability over rough terrain and simplify the suspension system. The motors have been downsized in order to use less power, and planetary gearboxes have been added in between the motor and wheel shafts in order to better support the weight of the rover as well as decrease the size of motor needed to maintain mobility.

2.3 Evolution of Payload and Science Instrumentation

The evolution of science instrumentation took place through the following chronological iterations:

1. Planetary Ground Penetrating Radar: It was suggested that GPR could be used to locate the presence of ice water. After further discussion, it was concluded that, since it cannot directly measure composition and requires a fairly decent change in composition to see different layers, other methods would prove to be more efficient.
2. Neutron spectroscopy: There was a mention of using a neutron spectrometer to sense the amount of hydrogen in the subsurface. However, after discussion and more in-depth research, it was brought to attention that most neutron detector systems suffer from the disadvantage of the strong dependence of counting efficiency on the energy of the neutrons to be detected.
3. Possible Organic Volatile analysers like gas chromatography (GC), high-resolution gas chromatography (HRGC) and photo-ionization detectors were reviewed. After further discussion, it was concluded that given the payload constraints, other avenues were to be explored.
4. Ion Trap Mass Spectrometer: Finally, the ion trap mass spectrometer was researched and selected as the volatile analyser due to its optimal dimensions, feasibility and relevance to our mission’s science goals and overall objective.

3. Deployment Scheme

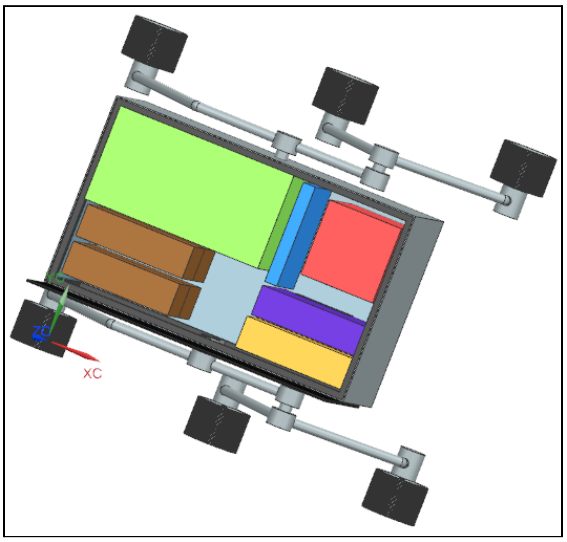
3.1 Selection, Design, and Verification

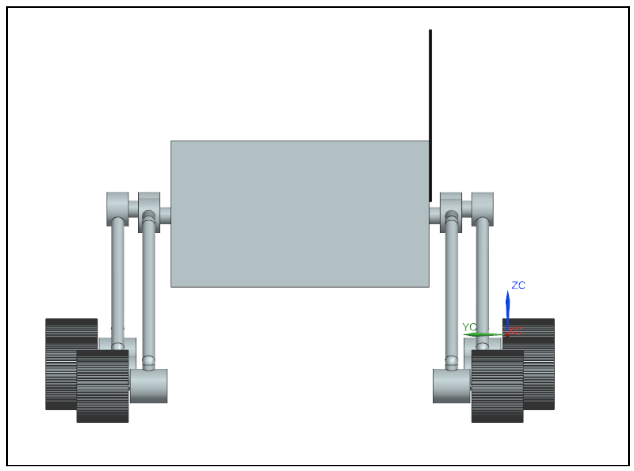
3.1.1 System Overview

The rover is 590mm wide by 700mm long by 400mm tall. The main body is 500x300x170mm. The total mass of the rover is 32.46kg.

Below, figure 8 shows the interior of the rover with all its parts (Red-Science, Brown-batteries, Green-thermal control system, yellow-cameras, blue-computer, purple-amplifiers, black-solar panels).

The rover is not expected to encounter terrain sloped more than six degrees. The rover will, however, encounter fields of rocks that can shift the balance of the rover. Additionally, the lunar soil can be loose and is expected to stick to the rover's wheels.





Figures 8 and 9: Overhead and front view of the rover

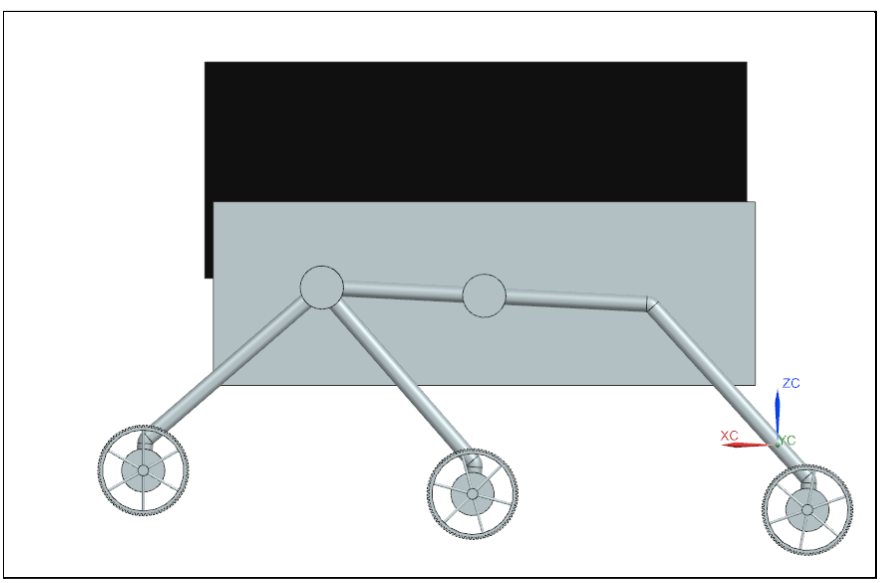


Figure 10 Side view of the rover

3.1.2 Mechanical System Overview

There are two main parts to the mechanical system, the first of which is the suspension system. The suspension for the rover uses a rocker-bogie system. The entire system is constructed out of aluminum. The pivots are 40mm in diameter and 25mm long. A 20mm diameter hole is drilled 20mm deep into the pivots in order for the axles to fit.

The legs of the rocker bogie system consist of 15mm diameter aluminum rods, which have had their middle sections hollowed out in order to allow wires to run to the motors. The bogie part of the suspension consists of two 212mm rods joined at 90 degrees at a pivot. This pivot attaches to the bogie system via a hollow 20mm axle.

The rocker part of the suspension has a 300mm long rod with a pivot at one end, which connects to the rocker, a pivot at the middle, which connects to the body of the rover, and another 150mm long rod at the other end tilted downwards at 45 degrees.This results in the wheels being 300mm apart.

The frame is made of 2mm thick sheets of aluminum, riveted to a frame made of 10x10mm aluminum blocks that have been welded together using friction stir welding. Two, 20mm holes are cut into the side of the frame. Here the suspension system is attached to the frame of the rover.

The rocker-bogie system will be manufactured in house using aluminum 2024 bars purchased from a vendor. The middle of the bars will be hollowed out using a lathe. In order to angle the bars, they will be cut with a band saw. The pieces will then be welded together to form the rocker-bogie system.

The second system is the wheel and axle system. The wheels will be cut from a solid aluminum disc using a lathe to hollow out the central portion and a 5 axis CNC machine to groove the sides. Grooved holes will be drilled where the aluminum axles will be inserted into place

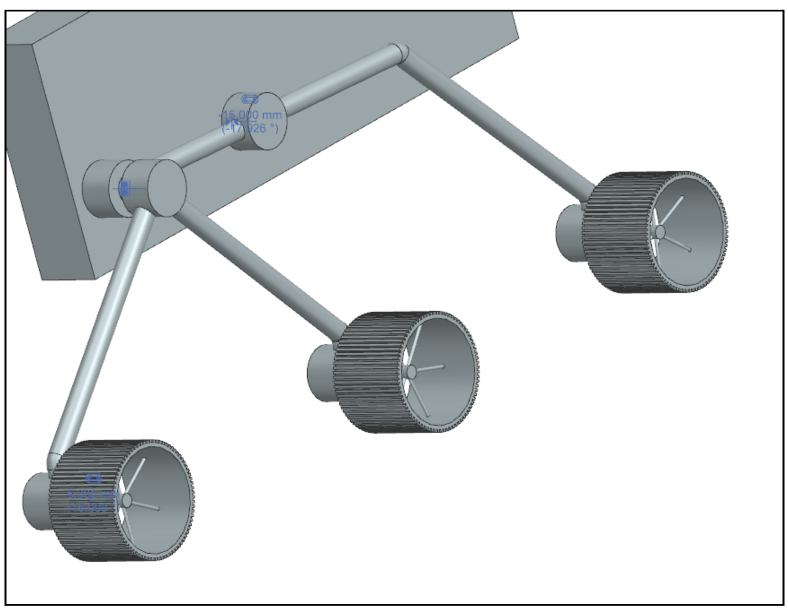


Figure 11: Rocker-Bogie suspension

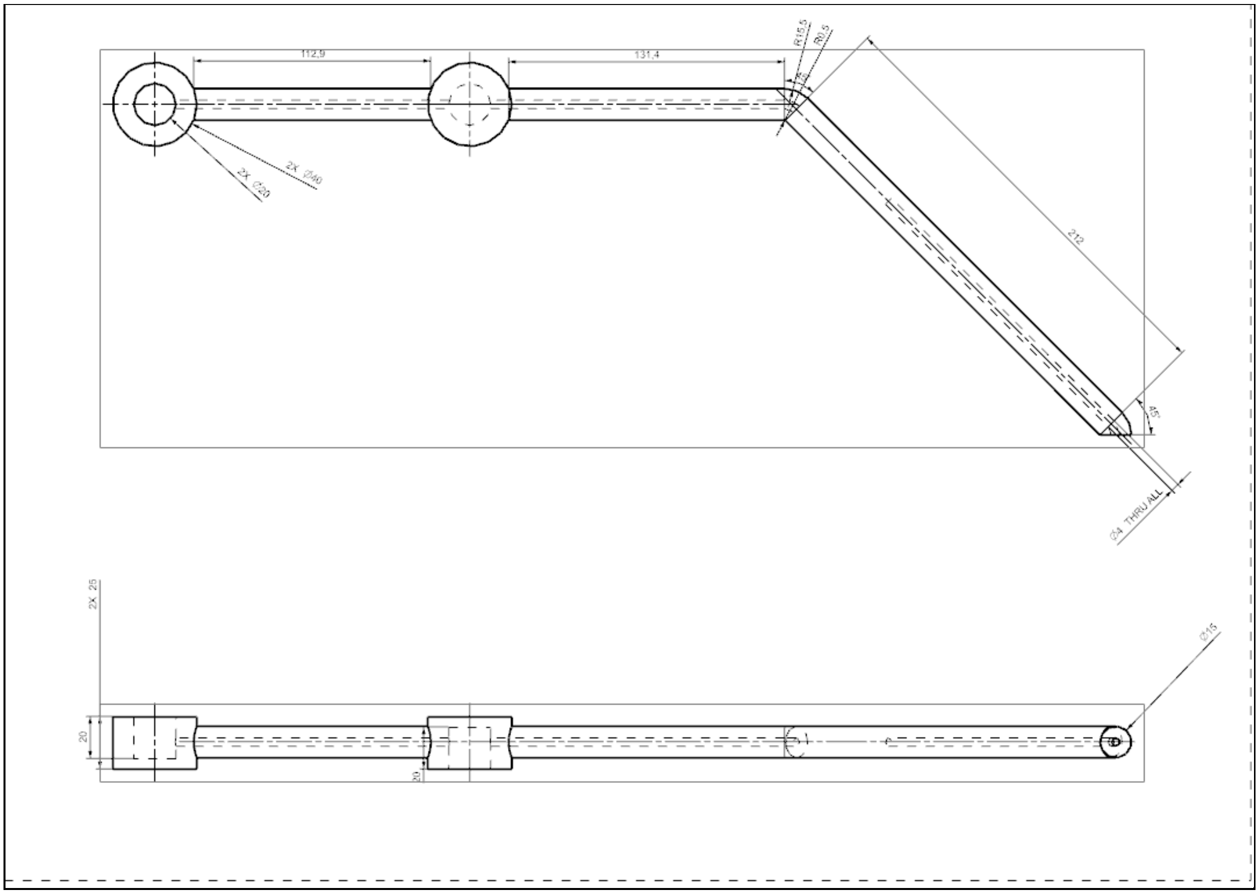


Figure 12: Rocker Arm

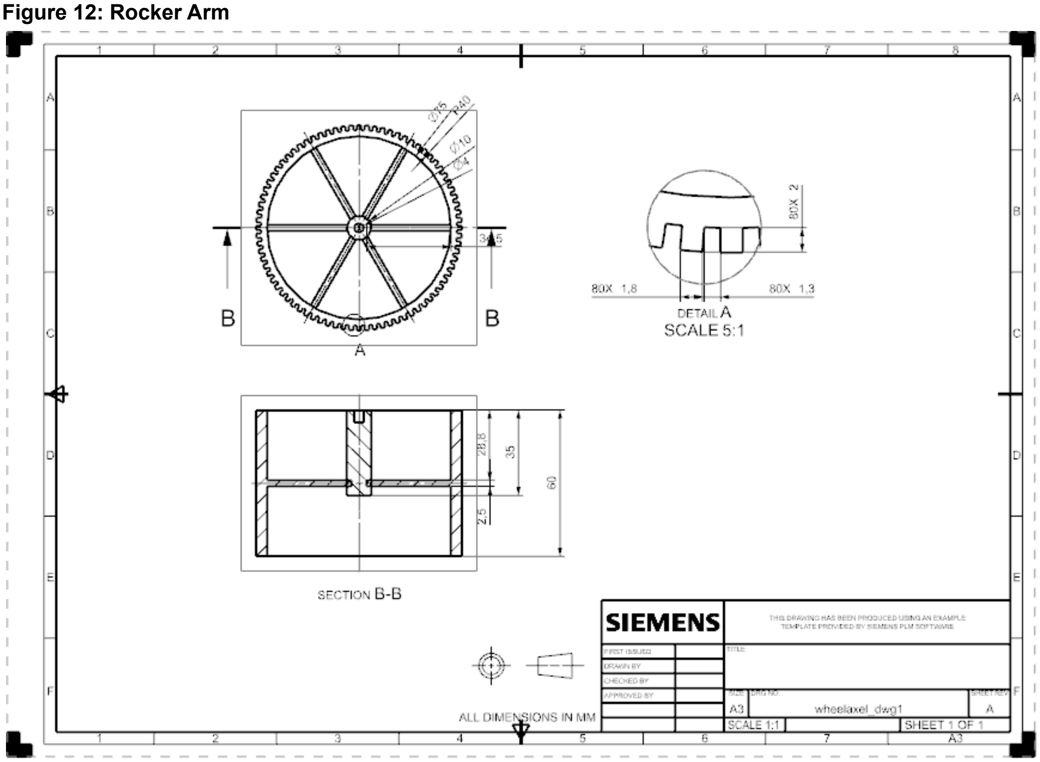


Figure 13: Wheel and axle

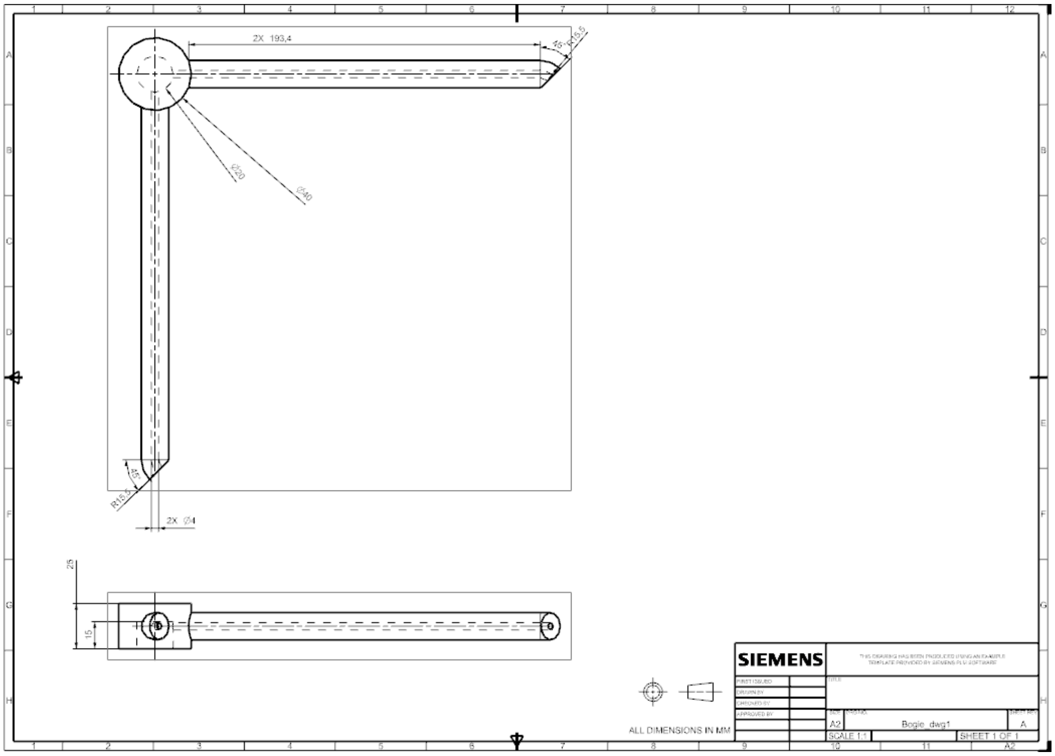


Figure 14: Bogie Arm

3.1.3 Power System Overview

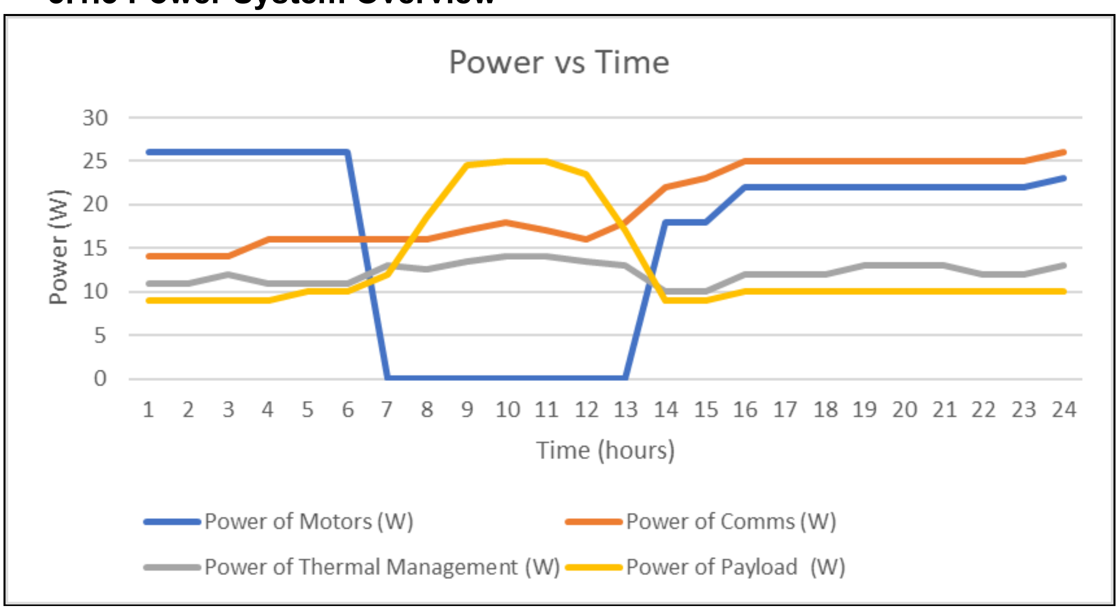


Figure 15: Power usage over time.

The power system of the rover will need to handle four main subsystems: Mobility, Payload, Thermal Control, and Communications. Power will be generated by a simple array of solar panels, each with an output capacity of 12.6w. The bank of four Li Ion batteries has a capacity of 6400mAh each and a max discharge rate of 7.2A. Each battery operates at 18.5V with a peak of 21V and a cutoff of 12.5V. There will be six motors. The nominal power consumption of each motor is 24V but they will be run slightly lower than nominal in order to stay within the parameters of the four Li Ion batteries. Given the specifications, under direct sunlight, the estimated time that it will take to fully charge the battery is 17.2 hours.

3.1.4 Comms and Data Handling Overview

Communication and Data Handling will be divided into two main types: Engineering and Science. Engineering commands will consist of tasks such as determining the position of the rover, mechanical commands, and any other actions that are not directly related to the science goals. Science commands on the other hand, will be mainly focused on the scientific instruments on board the unit. These commands will include issuing orders to the instruments, whether for calibration or to begin data collection, as well as sending collected data back to the communication satellite.

The manner by which data will be sent and received will be through two antennas, a high gain and low gain antenna. The high gain antenna will be the primary antenna, as it will have a more focused beam to allow for higher packets of information to be sent. If that fails, the low gain antenna will act as a backup antenna that is omnidirectional, allowing for a wider range of coverage at the cost of lower bandwidth. Both antennas however, will be equipped with two amplifiers, one of the Ka-Band and the other for the X-Band. The Ka-Band operates at 27.5 to 31 GHz, while the X-Band operates at around 8 - 12 GHz. The purpose of these amplifiers will be similar to that of having a low and high gain antenna. The Ka-Band is far more powerful than the X-band, allowing for much higher data rates. However such high frequencies require more power, and as such the X-Band will be used as a backup to transmit data at lower frequencies.

There will also be auxiliary communication equipment to assist the antennas and amplifiers. A Dual Band Transceiver will be included to allow the antennas to work with such high frequencies, and a steering mechanism will be included to allow the antennas to be always pointed towards the communication satellite. The unit will also be equipped with a Ground Penetrating Radar, Ground Temperature Sensor, and a Surfcam (essentially just a camera) that will allow scientists at the communication satellite to use extra information obtained to better survey the nearby conditions and decide the optimal location to begin sample collection.

The communications system will be primarily focused on being able to send data collected from the Volatile Analyzer to the communication satellite. Any telemetry collected by the VA will be sent through the antennas to the communication satellite over the X-Band or Ka-Band power permitting, where they can then be further analyzed.

The communications system mostly comprises hardware that can be ordered off the shelf from the manufacturer. Most of the components also have flight heritage, adding a layer of security that they will work as intended in the expected operating conditions. In terms of integration, it will be incorporated within the power and thermal system to ensure each component is receiving the necessary power and remains at the ideal operating temperature.

3.1.5 Thermal Management System Overview

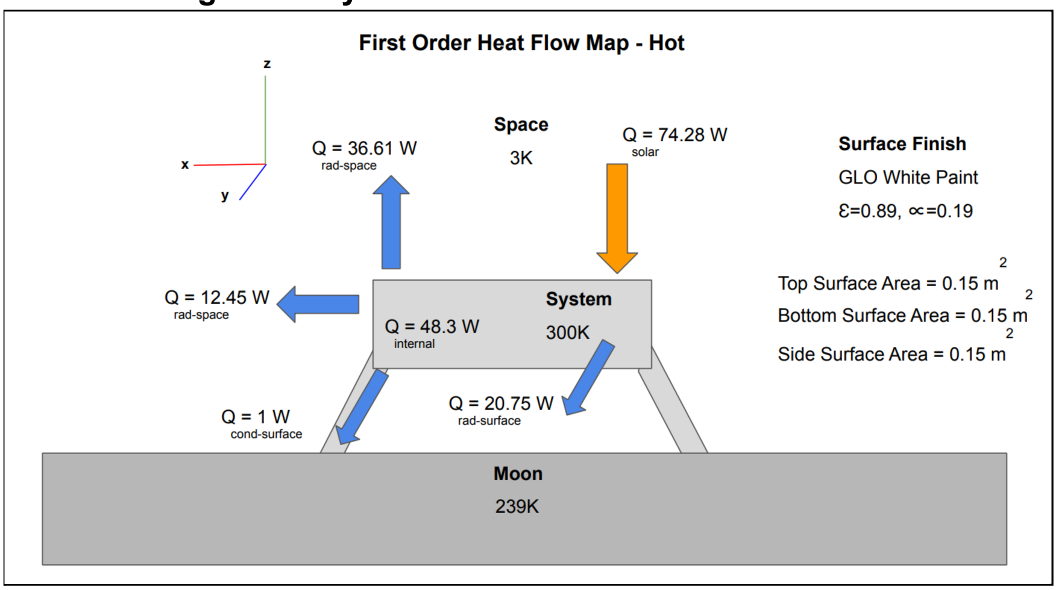


Figure 16: Heat flow (hot)

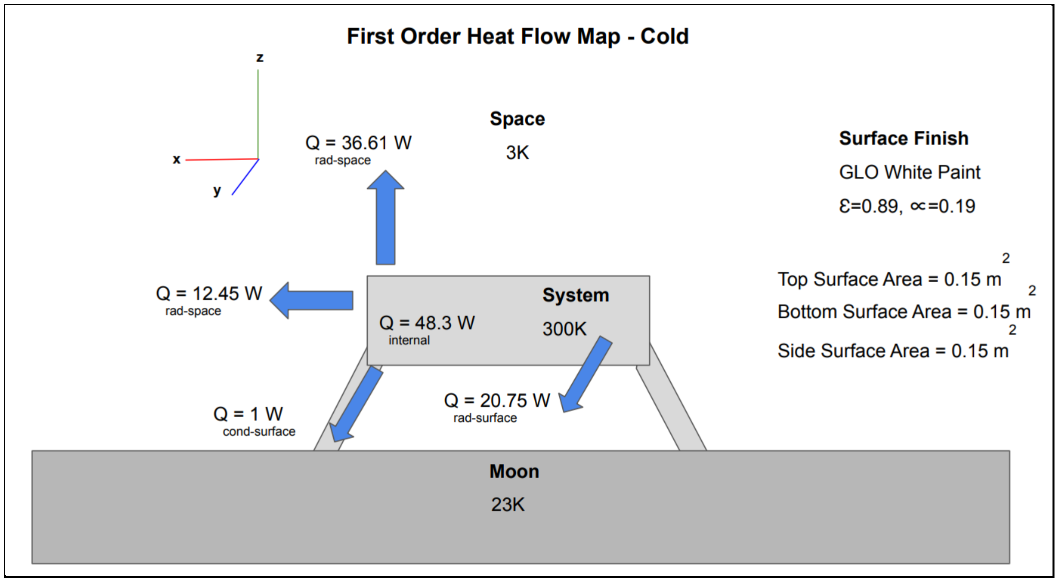


Figure 17: Heat flow (cold)

Because the environmental temperatures are between 23-239K the solutions suggested for the thermal management system are fluid heat pipes, flexible thermal straps, aerogel, and surface finish of GLO white paint. In addition to that, there will be the implementation of a battery management system that monitors each cell of the battery and manages the power before it gets too hot.

As far as the heat flow maps go, the temperatures studied were the anticipated extremes with the hottest temperature being 239 K and the coldest being 23 K.

At its hottest temperature, the radiation that the rover experiences is a total of 74.28 Watts while the internal components generate 48.3 Watts. In this scenario, the amount of heat that enters the rover exceeds the amount of heat that exits it. In order to combat the effects of overheating, the rover is equipped with a phase change heat exchanger manufactured by Lockheed Martin. The way this heat exchanger works is by storing hot aerogel during warm temperatures and releasing cold aerogel that was stored during cool temperatures and vice versa. This temperature control system will be monitored by temperature sensors and run by software that administers the aerogel via copper pipes that surround the rover.

For the coldest case, a more effective way of raising the scientific equipment to operating temperatures is through the use of flex heaters. These flex heaters will be manufactured by All Flex Flexible Heaters due to their expertise in the industry. The operating temperature of the scientific equipment is 300 K and the equipment will be brought to that temperature through the combination of the hot aerogel and flex heaters that will be customized to the right specifications so that they hug the scientific equipment. In this manner, the flex heaters will be able to precisely target the equipment and bring them up to operating temperatures.

3.1.5.1 Calculations

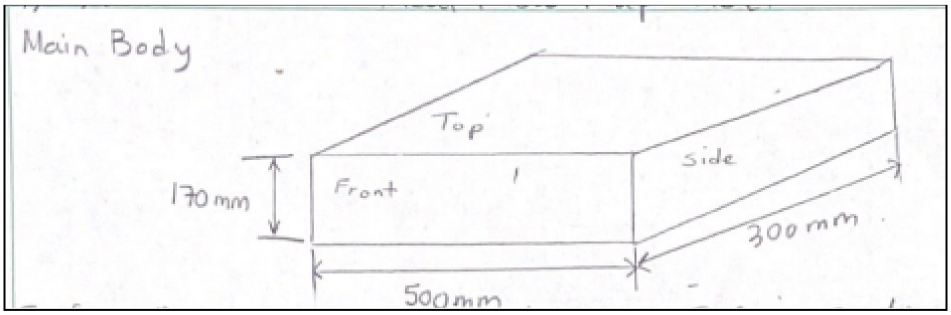


Figure 18: Chassis volume sketch

The heat exchanger system generates 200 kJ of heat for every 4.5 kg of wax coolant. For the 3.14 kg of equipment, 11.25 kg of coolant would be needed. The approximate dimensions of the heat exchanger are 29cm x 15cm x 16cm.

Surface Area

$A_{Front} = 0.5 \times 0.17 = \underline{0.085\ m^2}$

$A_{Top} = 0.5 \times 0.3 = \underline{0.15\ m^2}$

$A_{side} = 0.3 \times 0.17 = \underline{0.051\ m^2}$

Surface Coating

G10 White Paint: $\varepsilon = 0.89$, $\alpha = 0.19$

$\Sigma Q_{in} = \Sigma Q_{out}$

$Q_{int} = 48.3\ W$

$T_\infty = 239\ K$

$\sigma = 5.67 \times 10^{-8}\ \frac{W}{m^2 K^4}$

Solar Flux

$q_{solar} = 1367\ \frac{W}{m^2}$

$Q_{solar} = q_{solar} A \alpha$

Solar Heat Going into the Rover

$Q_{solar,top} = 1367(0.15)(0.19) = 38.96\ W$

$Q_{solar,\ front} = 1367(0.051)(0.19) = 13.25\ W$

$Q_{solar,\ left} = 1367(0.085)(0.19) = 22.08\ W$

$\Sigma Q_{in} = Q_{solar} + Q_{internal} = (41.01) + 2(13.25) + 2(22.08) + 48.3\ W =$

$\Sigma Q_{in} = 157.9\ W$

$\Sigma Q_{out} = Q_{rad-space} + Q_{rad-sufrace} + Q_{cond}$

$Q_{top} = (0.89)(5.67 \times 10^{-8})(0.15)((300)^4 - (239)^4) = 2(36.61) = 73.23\ W$

$Q_{side} = (0.89)(5.67 \times 10^{-8})(0.051)(4{,}837{,}191{,}359) = 2(12.45) = 24.898\ W$

$Q_{Front} = (0.89)(5.67 \times 10^{-8})(0.085)(4{,}837{,}191{,}359) = 2(20.75) = 41.5\ W$

$157.9 \neq 143.63\ W$

$\dot{Q}_{cooling-system} = 14.27\ W \leftarrow$ Aerogel (Hot and Cold)

Cold State

$\Sigma Q_{in} = 48.3\ W + 14.27\ W = 62.57\ W$

$\Sigma Q_{out} = 143.63\ W$

$\longrightarrow \Sigma Q_{loss} = 143.63 - 62.57 = 81.06\ W$

Make up for $\underline{81.06\ W}$ of heat loss.

Figure 19: Thermo Calculations

3.1.6 FMEA and Risk Mitigation

It is important to note that the risk mitigation chart and FMEA chart does not serve as a substitute for all hazard prevention predictability, but rather as a guide for safety assurance of the mission. For every alteration of an instrument, function, or system the risk level changes. In order to determine the risk level of each function, the FMEA considers the Risk Priority

Number (RPN) which is the product of the level of severity, level of occurrence, and level of detection. The higher the RPN, the more important/more consideration the function needs to be taken into account for. A risk summary has also been provided for a general outline and documentation of all risk scenarios that will be likely encountered

Table 3: Risk Mitigation

Function	Failure Mode	Effects	Sev	Cause	Occ	Prevention	Det	RPN	Actions
Solar Array	Hot spots in the solar cells	Potential fire hazard for the rover	9	Poor production quality	3	Perform several test trials before launch and scan through each cell	5	135	Extra screen testing and protection measures to mitigate possible fire hazards
	Dust build up in panel edge	Inefficient energy supply	7	Lunar dust from the lunar regolith on the moon remains on the panel	8	Proper mechanical operation needs to be devised	4	224	Add necessary inclinations to solar arrays and further research upon lunar atmospheric/geological conditions to avoid dust build up
	Open circuit in the connection line	Reduction of energy production	7	Poor connection in solar cell strings	6	Mechanical and electrical engineering needs to be employed to prevent open circuits	5	210	Perform basic circuit maintenance for the solar panels
Li Ion Batteries	Batteries have worn out	Failure to circulate power to the system. Depletion of power	3	Unexpected atmospheric conditions	7	Perform several trials for the batteries in different atmospheric conditions in the laboratories before installations	6	126	Additional power from the CPU will be utilized as back up
	Battery leakage	Metallic corrosion to payload or vehicle	6	Faulty manufacturin g	4	Ensure quality production with the manufacturers	7	168	Ensure safety training by following up with manufacturers. Safety officer needs to perform regular inspections to this area of the Li Ion

									Batteries
	Short circuit from the batteries	Possible explosion, failed circulation	6	Faulty manufacturing	4	Thermal management system needs to have proper installation of electrical, heating, and cooling aspects in order to prevent short circuit	7	168	Perform basic circuit maintenance for the solar panels
	Unexpected increase of wheel life depletion	Mobility and performance of rover will drastically be affected	7	Possible mechanical failure. Poor production quality	5	Provide a software program that can provide situational awareness to the wheels and can adjust it to different conditions	7	245	Different sections of the wheels may be used as a backup in case of a certain area
Wheels	Tears and damages to the wheels	Limited performance of the rover and can result to hindrance in mission goals	8	Uneven lunar surface terrain	6	Have several test trials for the wheels in different terrains to determine the best material for the mission	8	384	Improve adaptability of instruments and improve traction of lunar vehicle
SYSTEM									
	Insufficient cooling of system	Overheating of the system. Possibility of melting	7	Improper installation of heating and cooling devices	6	Install suitable heat shields. Install proper ventilation and storage temperature	6	252	Extra ventilation will be utilized
Thermal Management System	Faulty charging system	Depletion of power to the system.	6	Improper installation of heating and cooling devices	5	Conduct several tests to ensure that there are no installation errors to the system	5	150	In case of continuous charging or unstable charging. Immediate cooling should be taken place for the system
Communications System	Failure in Antenna	Faulty communication with rover	7	Failures in the high gain antenna and low gain	6	Software installation that utilizes another communication instrument aside from	6	252	Computer and electrical engineering teams will devise a software for this risk

				antenna due to inclination or impact from landing		the antennas			
	Hindrance of signal communication	Faulty communication with rover	6	Rover is likely not in the proper range or distance from lunar site to earth grounds	5	Utilization of JMARS to ensure best landing site for better communication	5	150	Mechanical, electrical, and science teams will have to research upon best landing area and position of rover in order for communication not to be disturbed

3.1.6.1 Risk Summary/Mitigation

The following guide has been utilized for the risk-mitigation analysis and risk matrix:

Approach	Criticallity	LxC Trend	L = Likelyhood (1-5)
A - accept	HIGH	↓ - Decreasing (improving)	1 = not likely
M- mitigate	MED	↑ - increasing (worsening)	5 = extremly likely
W - watch	LOW	→ - unchanged	**C = Consequence (1-5)**
R - research		**NEW** - added this month	1 = low consequence
			5 = high consequence

Figure 20: Risk mitigation guide

Table 4: Risk Summary

Team 20 Engineering Risk Summary

ID	Summary	L	C	Trend	Approach	Risk Statement	Status
1	Overheating of components in the payload	3	4	NEW	M	Environmental temperatures are between 23-239K. Rover may only be able to operate in a temperature of 230K-320K. Thermal management control system needs to be researched ans mitigated.	
2	Rover becomes immobile due to depletion	4	5	NEW	M	Lunar terrain may not be suitable for the rover's tracking and chassis in the long run. Mitigation needs to be assigned for the rover to withstand long term mission. Regular inspection and mitigation is required.	
3	Dust build up in solar arrays	2	3	NEW	R	The rover consists of solar arrays. The primary concern is that the solar arrays can build up on lunar dust from the Moon especially with the team's targeted area of landing. Since the team's goals is to investigate on the permanently shadowed regions of the Moon, this will be highly prone to dust particles. Research and mitigate	
4	Damage to the wheels as material wears down	3	4	NEW	R	The rover's wheels will be made out of 2024 aluminum which has disadvantages such as poor weldability and weak corrosion resistance. Grooves will be added to the wheels in order to have better grip on different terrains. The rocker-bogie system will also be researched in order to mitigate this risk.	
5	Damage in the Lithium Ion Batteries	3	5	NEW	W	The rover will consist of Li Ion batteries that will power majority of the subsystems. Lithium Ion batteries are prone to cell damage and may have possible defects from the manufacturing site. The safety and engineering team will conduct several safety test	
6	Failure in the Thermal Management System	2	5	NEW	R	The rover will be in an environment temperature around 23-239K. The thermal management systems ventilation is crucial to maintain the proper flow of heat in the system. Ventilation may be at risk due to measurement contraints provided by the client. Research and mitigate	
7	Failure in Communications System	3	5	NEW	R	The communication system present in the rover consists of a high gain antenna and low gain antenna. If there will be failure in the high gain antenna, the low gain antenna will be used as a backup. However, the low gain antenna signal transmissions would not transmit as well as the high gain antenna which could result in some losses in important data. Research and mitigate	

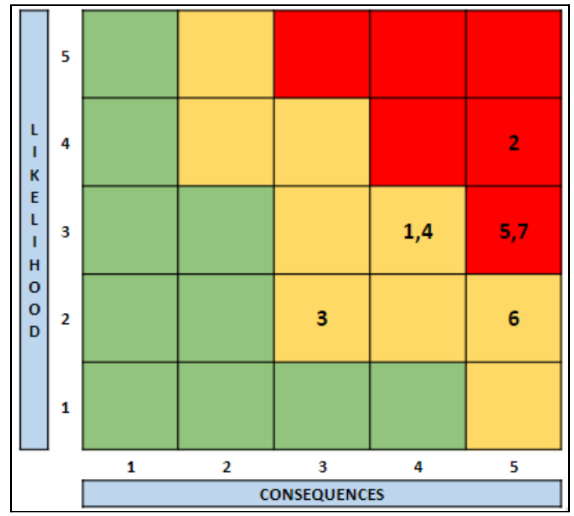


Figure 21: Summary Matrix

3.1.7 Performance Characteristics and Predictions

There are two large weather obstacles that the rover will encounter during this mission. The first are the excursions into permanently shadowed regions. In these areas the rover will be in a region with temperatures around 23k without the ability to charge. As such, 1cm thick aerogel sheets inside along with an extensive heating and cooling system are used in order to maintain a stable internal temperature. In order to further conserve power, science data will not be sent during this period, and instead will be sent during charging outside of permanently shadowed regions. The second weather obstacle that the rover will encounter will be the lunar nights. During this time it will be without charging capabilities as there are no permanently sunny regions nearby. Cameras, science equipment, and the motors will be put on standby during this time. Before the lunar nights, the rover will heat up to its upper operational capacity and its batteries will be fully charged. The rover will be allowed to slowly drop to its lower operational capacity, at which point the heater will activate to prevent further cooling. This is done in order to conserve power.

In the event that the rover drives over rocky terrain, the suspension system is expected to rotate and redistribute the weight over the wheels. This system, coupled with the large wheel size, will allow the rover to traverse over rocks larger than 80mm in height. This will keep the body level with the surface and to make it more difficult for the rover to tip over.

In order to deal with the high levels of radiation on the moon, the rover will be equipped with radiation hardened electronics.

3.1.8 - Confidence and Maturity of Design

Rocker-Bogie suspension systems have been used on four different NASA rover missions with great success. The system in use on the rover follows those designs, but has been simplified to reduce potential points of failure. Solar panels have been used frequently on a variety of space missions to the moon, where they have continued to provide power. As such, this system has a TRL of 6. Aerogel has been successfully used in past spacecraft to insulate martian rovers that experienced similar temperature ranges.

3.2 - Recovery/Redundancy System

With six wheels and six motors, a failure of either won’t cause the rover to become immobile as the other five wheels or motors can compensate. The rover also has two types of antennas and two identical cameras. If either a camera or antenna fails, the other can be used and the mission can still be fulfilled. Since there are multiple separate batteries and solar arrays, if one were to become damaged, the mission could still continue at a significantly reduced pace.

3.3 - Payload Integration

Several of the science instruments are located at the bottom front of the rover, which include the two cameras at the two corners of the vehicle, and the GTS. The GPR and integrated VS/VA unit will be located inside the rover, and will only be lowered outside when necessary. When data collection is to be performed, a hole beneath the rover body will be opened, allowing for the drill of the VS to be lowered and begin drilling. While drilling is occurring, the entire integrated VS/VA unit will be held in place by a frame that is connected to the rover, ensuring that nothing will fall out. In order to avoid unnecessary exposure and contamination, the covering over the hole will only allow for the drill to go through to prevent lunar dust from getting inside the rover.

4. Payload Design and Instrumentation

4.1 Selection, Design, and Verification

4.1.1 System Overview

The payload system of the entire unit will center entirely on two critical components: the Volatile Sampler (VS) and the Volatile Analyzer (VA). These two components will be providing the main chunk of data needed to fulfill the main mission objective of analyzing the volatiles present in PSRs, and as such most of the onboard instrumentation will be chosen and calibrated to support the VS and VA. For that reason, there will be several payload subsystems: The Payload itself, Navigation, Data Handling, Communication, Thermal, and Power.

The first and most important subsystem is the Payload Subsystem, consisting of the VS and VA. These will be powered using a connection from the batteries, and will consume about 15 W. The chief purpose of the Payload Subsystem will be to both collect the volatiles from the regolith and to analyze the samples it collects using the integrated VS/VA unit. The Navigation and Data Handling subsystems will assist the data collection by collecting environmental data around the rover and sending commands to the payload subsystem. Navigation will comprise of a Surfcam, Navcam, Ground Temperature Sensor (GTS), and Ground Penetrating Radar (GPR), while Data Handling will be handled internally by the main computer.

Any necessary data that needs to be sent back to the communication satellite will be handled by the Communication subsystem. This will consist of several antennas, amplifiers, and other auxiliary communication equipment required to be able to send strong enough signals that are both strong enough to be able to communicate with the communication satellite and contain enough information to work with. The communication subsystem will consume roughly 10 watts.

Finally, both the power and thermal subsystems will work in tandem to ensure that all the aforementioned subsystems have the necessary power needed to operate as well as keep all instruments at sustainable operating temperatures.

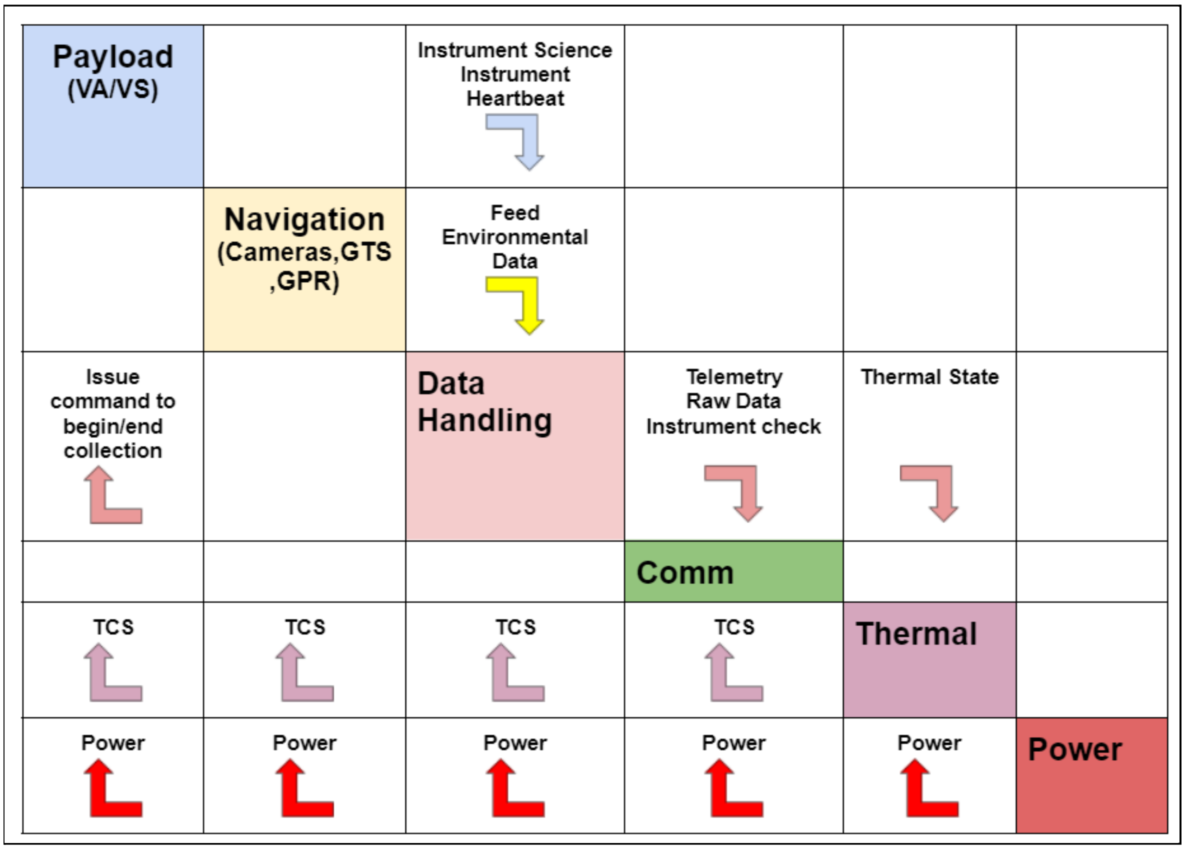


Figure 22: Payload subsystem N^2 chart

4.1.2. Subsystem Overview

The Payload Subsystem consists of an integrated Volatile Sampler (VS) and Volatile Analyzer (VA) unit. The VS portion of the unit consists of a small drill powered by a DC motor that will drill into the regolith. Once it has drilled a predetermined amount, a heating element within the drill heats the regolith into a gaseous phase, after which the gas travels through the unit into the Volatile Analyzer. The VA has a built in Ion Trap Mass Spectrometer (ITMS), a device which uses a combination of electric and magnetic fields to trap ions in a mass spectrometer. This allows the VA to then conduct mass spectrometry on the ions by determining their mass-to-charge ratio, allowing then for the exact molecular formula to be determined.

In order to assist the rover in determining exactly the best place to drill, the Navigation subsystem has several components that will act as visual aids in determining a good drill spot. While the general area in or near the PSR has already been preselected, it is important for the unit to narrow down an ideal spot to begin the data collection. As such, there will be several components of the navigation subsystem that work to precisely determine this spot. The Surfcam and Navcam are two on board cameras that will give a visual feed of the immediate surroundings as well as illuminate the immediate drill site. The GPR will give a general map of the ground beneath the rover, and the GTS will measure the temperature of potential drill sites to see what the drill would best dig into.

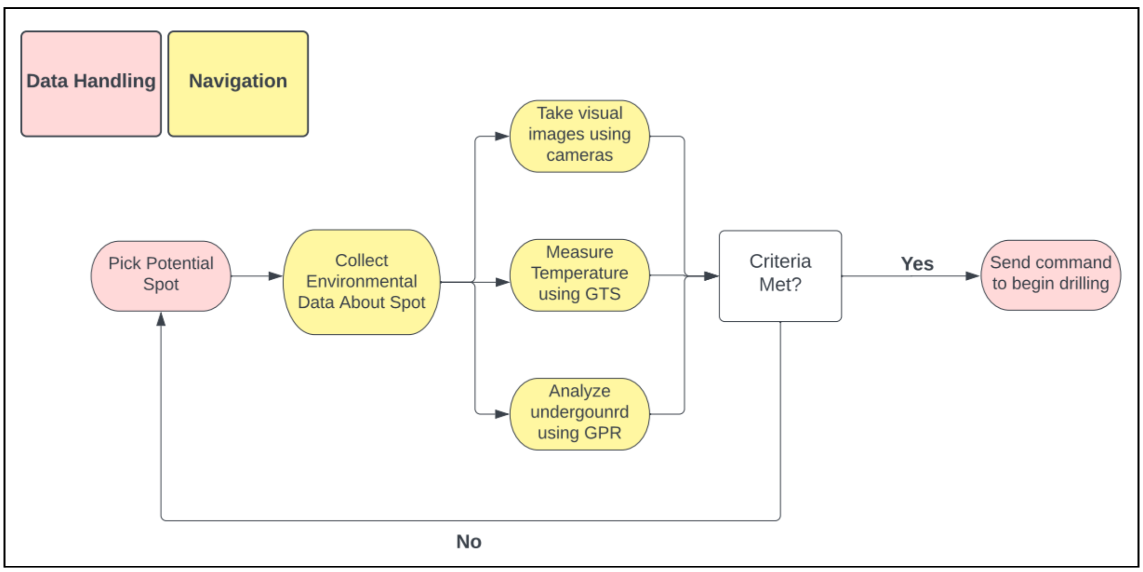


Figure 23: Site selection decision matrix

All the environmental data collected from the Navigation subsystem will be then fed into the Data Handling subsystem. This particular subsystem doesn't have any particular components linked to it, and will be entirely computer based. One of the main functions of Data Handling will be to act as the gatekeeper for potential drill spots. Through a constant back and forth between Navigation, Data Handling will methodically run a series of checks to determine whether or not a potential drill spot is ideal. To more clearly illustrate, a flow chart below illustrates the logic of the program.

The communication subsystem will come into play to send not only the raw data collected by the Payload Subsystem, but will also send telemetry data about where the rover is located as well as diagnostics about the information to the communication satellite. The manner by which data will be sent and received will be through two antennas, a high gain and low gain antenna. The high gain antenna will be the primary antenna, as it will have a more focused beam to allow for higher packets of information to be sent. If that fails, the low gain antenna will act as a backup antenna that is omnidirectional, allowing for a wider range of coverage at the cost of lower bandwidth. Both antennas however, will be equipped with two amplifiers, one of the Ka-Band and the other for the X-Band. The Ka-Band operates at 27.5 to 31 GHz, while the X-Band operates at around 8 - 12 GHz. The purpose of these amplifiers will be similar to that of having a low and high gain antenna. The Ka-Band is far more powerful than the X-band, allowing for much higher data rates. However such high frequencies require more power, and as such the X-Band will be used as a backup to transmit data at lower frequencies.

There will also be auxiliary communication equipment to assist the antennas and amplifiers. A Dual Band Transceiver will be included to allow the antennas to work with such high frequencies, and a steering mechanism will be included to allow the antennas to be always pointed towards the communication satellite. The unit will also be equipped with a Ground Penetrating Radar, Ground Temperature Sensor, Navcam, and Surfcam that will allow scientists to use the extra information obtained to better survey the nearby conditions and decide the optimal location to begin sample collection.

The communications system will be primarily focused on being able to send data collected from the Volatile Analyzer to the communication satellite. Any telemetry collected by the VA will be sent through the antennas to the communication satellite over the X-Band or Ka-Band power permitting, where they can then be further analyzed. The entire communication subsystem is predicted to consume roughly 10 watts.

The Thermal management subsystem’s main goal is, as the main implies, to ensure all the required instrumentation is kept at operable temperatures. While it is important that the entire system remains at an ideal temperature, it is especially important for the Payload Subsystem to remain in the ideal operating temperature, as the heating element within the VS is essential for the VA to deliver accurate data.

Finally, the Power subsystem will provide the necessary wattage for all the scientific instrumentation on the rover.

4.1.3. Manufacturing Plan

Essentially all of the scientific instruments required for this mission can simply be purchased as off the shelf parts, with the exception of the integrated VS/VA unit. This unit will be adapted from the LUVMI mission, and as such cannot simply be purchased. The unit itself comprises several subsections that can be purchased separately, but said components will need to be assembled in-house and tested thoroughly to ensure that it will be able to function as intended once on the moon.

Integration of the science instruments will happen once the basic frame of the rover has been assembled. This will allow for the instruments to be mounted in their correct positions and tested without being bogged down by auxiliary structures and components that aren't required at that stage yet. It is also important to note that the integrated VS/VA unit will have to be integrated and tested in as clean an environment as possible. While components such as the NavCam, Surfcam, etc, should be kept relatively clean, the VS/VA unit is especially important since any contamination in the gas chamber can skew results in the future.

4.1.4. Verification and Validation Plan

With such a large amount of scientific instrumentation on board the rover, it is essential to have a robust verification and validation plan to ensure every component will be working as intended before launching everything into space. As such V&V will be divided into two phases: the first will be individual subsystem testing, while the second will be the system level testing. It is also important to note that at least part of the testing for every component needs to occur in lunar-like conditions, such as in a thermal vacuum chamber.

The first phase of V&V will be to test the individual subsystems. For the payload subsystem, the VA and VS need to be tested separately in conditions similar to conditions they will experience when drilling into the regolith. The VS will need to be tested in a thermal vacuum chamber to test how well the drill inserts into the ground as well as the gas release mechanism. The VA will be tested in similar vacuum conditions, and the testing procedure will involve feeding gasses of known identities to the VA to verify it is analyzing compounds properly. Once both the VA and VS are working as intended, they will be combined into the integrated unit and will once again be placed in the thermal vacuum chamber. The ground will be a mock lunar surface consisting of rocks and gravels, and most importantly the identity and properties of every element or compound within this mock lunar surface will be known. As such, it will be easy to verify that the integrated VA/VS unit is analyzing the properties of the regolith properly.

The next subsystem that will require testing will be Navigation. However it is important to note that testing of the Navigation components needs to happen in the context of Data Handling. For instance, while it is fairly easy to test whether or not the Surfcam and Navcam work, it is more important to make sure they are tuned and calibrated to look for particular criteria for the ideal drill spot as determined by the algorithm. The same applies for the GTS and GPR. While it is important to check that they work, it is also just as essential that they are able to clearly identify points of interest that are relevant to the outlined criteria. For example, the GPR should be able to not only give an image of the area below the rover, but to also identify whether or not there is a hollow area that could potentially collapse if there is too much disturbance on the surface.

Data Handling dovetails quite easily from Navigation. The testing that needs to occur is to basically verify that the algorithm and computer is able to identify all the key pieces of info as provided from Navigation. Once it does that, the system needs to either issue a command to the Payload subsystem to begin drilling, or to issue a command to find a new potential drill spot. In short, V&V for Data Handling will be just to make sure the flow chart in 4.1.2 is being followed accordingly.

The communication subsystem will be one of the more crucial subsystems to test. It is the only way scientists on the ground will be able to receive and send information back and forth to the unit, and if communication fails, then the mission fails. Accordingly, both the high and low gain antenna will need to be tested to see if they are able to send data packets that are of a similar size to the expected data the payload will collect. In addition, both antennas will also need to be tested on both the KA and X-band with their respective amplifiers, ensuring there are sufficient backups in place in case of a component failure. Both long distance and short distance testing will need to be conducted, and the steering mechanisms for the antennas will need to be verified to ensure they will be oriented in the optimal position for receival and transmission.

Finally, both the Thermal and Power subsystems will need to be tested in lunar conditions, as they will be providing most of the thermal and electrical regulation on the rover. Each subsystem can be tested separately at first, but it might also be more beneficial to test them together, as power will be producing some sort of thermal output that needs to be accounted for by the thermal management system. Regardless, these two subsystems need to work in tandem effectively to keep the entire unit at an operable temperature.

Phase 2 of V&V will be to test the entire system to verify all the subsystems are working together effectively. It will use the N^2 chart as a guide to verify the relationships between all the different subsystems are working as intended and smoothly without any issues. A major test that will be required is where the rover will be placed in lunar-like conditions with the aforementioned mock lunar surface. The entire system will then be powered on, and the entire data collection procedure will be tested. Functions that will need to be tested include: ensuring the Navigation and Data Handling subsystems are properly scanning and identifying ideal drill locations and sending commands to the Payload, the Communication subsystem is sending the necessary information from the VA and other auxiliary information back to the communication satellite, verifying the onboard temperatures to see if the Thermal Management system is keeping all instruments at ideal operating temperatures, and lastly seeing if the Power subsystem is supplying all essential components with the necessary wattage. From there, any issues that arise will be troubleshooted and tested again to create a robust and working system.

4.1.5 FMEA and Risk Mitigation

This section discusses the Failure, Mode, Effect, and Analysis (FMEA) Method as well as the Risk Mitigation factors that may affect the science instruments and payload during the mission. In order to monitor the potential risks of each function, the FMEA has been used as a guideline to identify and mitigate all possible failures that may occur in this mission.

In mitigating the potential risk factors present in the payload and scientific instruments, each function or instrument has been ranked utilizing a Likelihood and Consequence Model and each risk title can be represented using a Risk Matrix.

The following criteria has been utilized to determine the criticality and approach to each potential risk that will likely happen to the payload and scientific instruments:

L = Likelyhood (1-5)	LxC Trend	Approach	Criticallity
1 = not likely	↓ - Decreasing (improving)	A - accept	HIGH
5 = extremly likely	↑ - increasing (worsening)	M- mitigate	MED
C = Consequence (1-5)	→ - unchanged	W - watch	LOW
1 = low consequence	**NEW** - added this month	R - research	
5 = high consequence			

Figure 24: Risk Management guide

Table 5: Payload/ Scientific risk assessment

Function	Failure Mode	Effects	Sev	Cause	Occ	Prevention	Det	RPN
High Gain Antenna	Failure to transmit high gain signal to the Earth ground systems	Disconnection of transmission from rover to ground systems; Unavailable communication; Data may not be transmitted	9	Turning or redirection of spacecraft/rover	8	Scanning of different science instruments. Practicing the usage of the HGA through different simulations in different environments in the laboratory can help detect inefficiencies	9	648
	Overheating	Partial destruction of unit; Out of range for connection	7	Collapse	6	Maintaining proper circulation in the thermal and power system	6	252
Low Gain Antenna	Loss of signal	Out of range for connection from rover site to ground control systems	5	Turning or redirection of spacecraft/rover	8	Scanning of different science instruments. Practicing the usage of the LGA through different simulations in different environments in the laboratory can help detect inefficiencies	8	320
MASTCAM-Z	Disconnection	Inability to transfer data; Insufficient imagery needed for the mission and data collection	5	Vibration; Problems in Communication System	8	Assign engineering unit to improve on camera telemetry; test report; record and analyze data during testing to report any errors	8	320
	Damged fuse in electrical current	Camera will become inoperable	7	Overcurrent	3	Electrical current and engineering controls need to be further examined. Issues regarding these areas need to be fix/addressed immediately	7	147
	Failed capturing of image	Insufficient imagery needed for the mission and data collection	7	Vibration; Problems in Communication System	6	Assign engineering unit to improve on camera telemetry; test report; record and analyze data during testing to report any errors	8	336

	Debris/dust build up	Insufficient imagery needed for the mission and data collection	5	Unexpected events with atmospheric conditions	8	Sealing of gaps that could cause any dust build up. Design the rover to have appropriate angles and measurements to avoid dust build up	8	320
	Unexpected shutdown of MASTCAM-Z	Failure to collect data	8	Hardware and software error	4	Proper test trial run and inspection	6	192
Hollow Drill Shell (VS)	Bearing Failure	Motor efficiency will be depleted	4		4	Inspection of all drills and motors will be done by safety, engineering, and science team	4	64
DC Motor (VS)	Bearing Failure	Motor efficiency will be depleted; Reduction in the mobility of the rover	4	Vibration	3	Proper test trial and having the science and engineering team scan through all DC Motors to test and check for defects	4	48
Heating Element (VS)	Decoupling	Thermal expansion; destruction of the unit	6	Expansion and shrinkage from its exposure to varying temperatures; Vibration; Thermal shock	3	Proper installation of heating elements and proper heating control done by science, engineering, and safety team	6	108
Pressure Sensor (VS)	Electrical Overload	Failure in monitoring pressure and can cause errors in measuring certain elements	5	Manufacturing defect	3	Safety team will do inspection of all materials	5	75

Table 6: SCRAM risk summary

ID	Summary	L	C	Trend	Approach	Risk Statement
1	Sudden power outage of rover	3	5	->	M	Possible outage for the rover due to sudden short circuit, thermal expansion, incapability of rover to survive extreme atmospheric conditions. Properly mitigate.
2	High Gain Antenna Fails	2	5	->	R	Failure of High Gain Antenna due to environmental conditions or power issues. Move on to low gain antenna as backup
3	Damage of scientific instruments	3	4	->	M	Depletion of scientific instruments during the duration of the mission may occur. Some instruments may wear out due to defects that may have been overseen. Mitigate to prevent this risk
4	Misjudgement of lunar atmospheric and geographic conditions	3	3	->	A	Failure to categorize atmospheric and geographic conditions due to overseen events during the research. Uncertainty of conditions may also happen beyonf human and machine predictability. Accept conditions if present
5	Failure of proper data transmission	3	4	->	M	Antenna, imaging, sampling, or any scientific instrument that are part of the communications and data handling are prone to errors due to atmospheric conditions, mechanical errors, and electrical errors. Mitigate for proper data transmission.

6	Failure of VS/VA unit to detect volatiles present in lunar regolith	4	4	->	R	Scanner may not be efficient to detect all/most volatiles possibly due to geographic conditions not suitable for the instruments. Research more regarding this risk for better outcome of scanning and detection
7	Failure of rover to perform sampling techniques	3	5	↑	R	Rover unable to properly sample the lunar regolith once drilling begins. Research more to ensure that this scenario will not occur

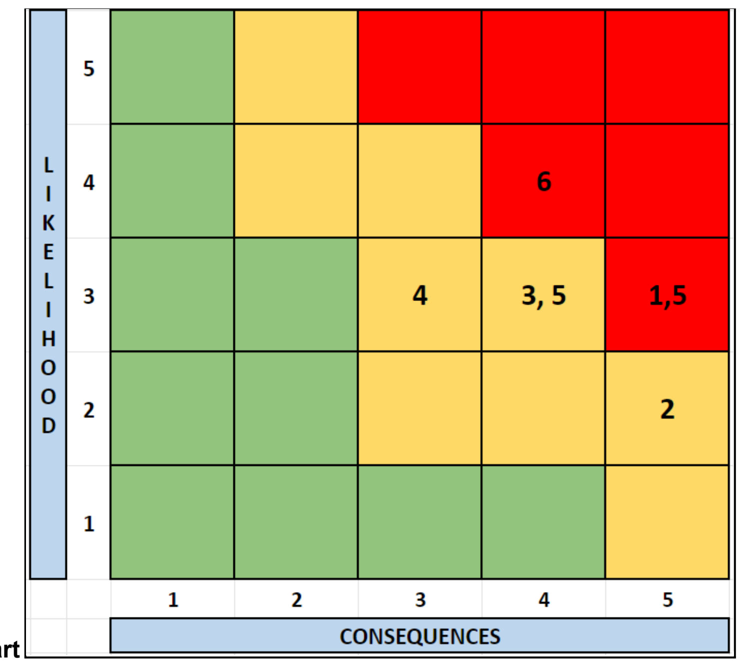


Figure 25: Risk summary chart

4.1.6 Performance Characteristics

Of the scientific instrumentation that will be carried by the rover, many of them will already have flight heritage on previous interplanetary missions. For instance, both the GTS and GPR have flight heritage from the Curiosity and Perseverance rovers from Mars, and as such should have no issues operating within PSRs. On the other hand, instruments that do not already have flight heritage will be tested thoroughly in lunar-like conditions here on Earth to ensure that they will work as intended once in the actual environment. For instance, both the high gain and low gain will be tested to ensure that they do not run into any of the described risks, such as being in an area where they will be unable to reach the communications satellite.

Testing in lunar conditions will also be extremely important to ensure the instrumentation will work as intended. Components such as the cameras or communication hardware are susceptible to lunar dust since it can get into the hardware and clog up the system. As such, performing component level testing on both cameras as well as communication hardware will be necessary to see the effect of the lunar dust. In addition, system level testing will be required to see if the rover can operate in the expected temperature of a PSR. PSRs can reach as low as around -150°C, therefore rigorous testing of the thermal system will be needed to see if the components will be kept at the necessary operating temperature.

<u>4.2. Science Value</u>

4.2.1. Science Payload Objectives

The main objective of the science payload is to understand the characteristics and origin of volatiles found within the permanently shadowed regions (PSRs) found on the lunar surface, as well as evaluate their potential for use by future human missions on the moon. The secondary objective will be to determine whether or not the presence of one compound is an indicator of another, related compound, which will ideally streamline further resource acquisition trips in future trips to the moon.

These objectives were chosen primarily because the current knowledge of what is on the moon is still rather elementary. It is understood that the moon holds a non-trivial amount of potential for resources that could be used for future missions, but at the same time not enough about these resources is known. Furthermore, it is important to build a complete picture about the environment and conditions that could potentially impact resource collection, and for that reason sending in a rover to perform reconnaissance will give scientists on Earth invaluable knowledge about the state of volatiles within PSRs.

4.2.2. Science Traceability Matrix

Table 7: Traceability Matrix

Science Goals	Science Objectives	Science Measurement Requirements	
		Physical Parameters	Observables
Planetary habitats #6: Beyond Earth, are there contemporary habitats elsewhere in the solar system with necessary conditions, organic matter, water, energy, and nutrients to sustain life, and do organisms live there now? *(National Research*	Measure the volume and identities of volatiles within the Permanently Shadowed Regions (PSRs) of the Amundsen Crater Region	Identify the different chemical structures that reside within the polar regolith	Obtain mass spectroscopy graphs from the regolith that will have distinct peaks at certain mass to charge ratios
	Identify chemical and/or physical relationships between lunar volatiles within PSRs	Identify the different chemical structures that reside within the polar regolith	Obtain mass spectroscopy graphs from the regolith that will depict different sized peaks at certain M/Z Ratios
	Determinte the ease of extraction and/or extraction of lunar volatiles within PSRs	Identify or estimate the volume of volatiles within PSRs	The pressure reading as the volatiles are sampled from the lunar regolith that detemrine how much volatiles are being released

Instrument Performance Requirements		Instrument	Mission Requirements
M/Z Ratio	0-50	Volatile Sampler	Rover must effectively determine and position the Volatile Sampler drill bit over a stable drilling spot
		Volatile Analyzer	Vehicle must determine the temperature of the drill spot is within operating conditions of the VA
M/Z Ratio	0-50	Volatile Sampler	Rover must effectively determine and position the Volatile Sampler drill bit over a stable drilling spot
		Volatile Analyzer	Vehicle must determine the temperature of the drill spot is within operating conditions of the VA
Pressure	1-2 mBar	Volatile Sampler/Volatile Analyzer Unit	Rover must effectively determine and position the Volatile Sampler drill bit over a stable drilling spot
Time	0-90 minutes	Volatile Sampler/Volatile Analyzer Unit	Rover must effectively determine and position the Volatile Sampler drill bit over a stable drilling spot

4.2.3. Payload Success Criteria

The success of the payload will be defined by whether or not all the instruments are able to effectively support the Payload subsystem in its main task of collecting information about the polar regolith. As such, every subsystem will have a specific goal it will aim for towards the greater goal of mission success.

The Payload subsystem itself has a fairly straightforward goal of being able to collect information about the volatiles in the regolith. The amount of samples it will take is variable based on the expected mission life, but at the very least it should be able to take samples from several PSRs in the designated region so that scientists back on Earth can acquire a decent picture about the state of volatiles there.

Data Handling and Navigation will work closely together to identify ideal spots for drilling for the Payload subsystem. The GTR, GPR, and both cameras of Navigation should be providing clear data where set criteria can be identified by Data Handling. For instance, the GTR should be reading temperatures of the ground that the VS can drill into, while the GPR should be identifying that there is enough solid ground for the drill to dig into without risk of unusual underground structures. If one of these devices from Navigation fails, the identification of an ideal drill spot can still continue with at least one functioning camera.

The Communication subsystem has the most redundancies in place to ensure that there will always be a communication pathway to the rover. Not only are there two antennas of varying strengths, but there are also two amplifiers for each antenna that will provide two radio bands to communicate with. Following that, success criteria for communication is as simple as just being able to uplink and downlink the data from the rover back to the communication satellite.

Finally, for the Thermal and Power subsystem, the success criteria is once again straightforward. If all instruments are operating at ideal temperatures and are powered sufficiently, then they have succeeded. If not, there are non mission critical components that the Payload subsystem could go without. In addition, it is also possible to place the rover in a sleep mode, allowing for the bare minimum functions to be performed while at the same time troubleshooting potential problems back on Earth.

4.2.4. Experimental Logic, Approach, and Method of Investigation

The way all of the different payload subsystems work together allows for an adaptable and flexible investigation procedure. Regardless of what PSR the rover decides to analyze, the instrumentation on board is designed to work together in such a way that will allow for ideal drilling spots to be identified and regolith samples to be collected and subsequently analyzed. The general flow of investigation that the science mission will conduct is as follows: A general path will be determined throughout the polar region (site B3 near Amundsen crater as mentioned previously) that the rover will follow.

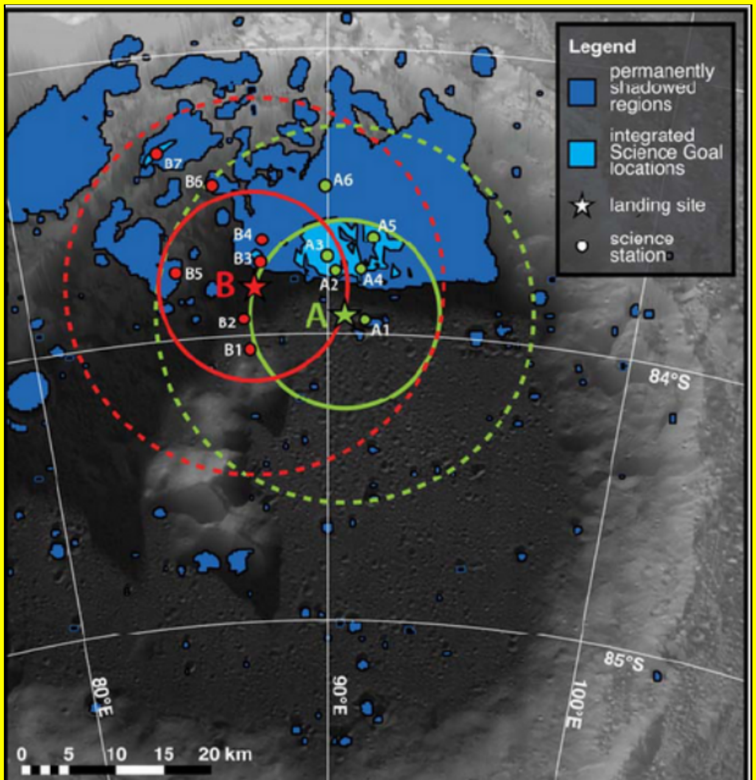


Image Source:
https://www.researchgate.net/publication/258674649_Volatiles_at_the_Lunar_South_Pole_A_Case_Study_for_a_Mission_to_Amundsen_Crater

Figure 2 (repeated): Selected landing and science sites

As the rover follows the path, it will take detours to craters and PSRs of interest, where at that point it will enter Science mode and begin scanning for ideal drilling spots. Once it has scanned, identified, and collected the necessary data, it will resume along the path until a new area of interest is found. Through this method, the rover will be able to collect a large swath of data from a relatively large region, giving scientists valuable info on the state of volatiles at different locations on the moon.

4.2.5. Testing and Calibration Measurements

Once the rover is up and operating, testing and calibration will have to occur for the entire system to ensure that everything is functioning properly. To begin, once the rover leaves the landing area, it will perform a system check by having each instrument send a test measurement to the communication satellite in the form of a test package. This test package will include environmental data of the landing site given by navigation, as well as diagnostic data of the instruments to ensure that each one is working properly.

After the test package is sent and everything is confirmed to be in order, the rover will drive onto the lunar surface and take background measurements with the navigation and just the VA, determining how the motion of the rover (e.g. kicking up lunar dust) affects the release of volatiles. This is necessary since while lunar conditions can be simulated on Earth, it is important to do another test run in the operating environment to ensure the VA/VS unit won't be contaminated with lunar dust.

Further diagnostics will also need to be taken as the rover continues on the mission. For example, occasionally it would be necessary to take multiple samples from one small area and check to see they are all within a similar margin of error. If the measurements are too far off from one another, then it is clear that recalibration is required.

4.2.6. Precision of Instrumentation, Repeatability of Measurement, and Recovery System

Many of the instruments on board the rover will inevitably have some sort of range of precision. The GTS for instance, has an accuracy of ± 5 K, and the VA/VS unit is vulnerable to feeding bad data if there is some sort of contamination in the VA chamber where volatile gas is analyzed. Another point of contention will be from the interaction between the Navigation and Data Handling subsystems. The system is designed such that environmental data collected from Navigation is processed for certain criteria by Data Handling. The unfortunate truth however, is that the algorithm can be prone to mistakes if the data given to it isn't as clean as it should be. For instance, the GPR only gives a resolution of as small as about 3 to 12 inches thick underground. While that may be sufficient for some sites, it may not be for others. As such Data Handling could potentially have issues properly identifying vulnerable underground structures, and failure to do so could cause the rover to drill in non-ideal locations. Therefore, it will be important to consider those factors in mind when collecting data.

Repeatability of measurements is something that can be easily checked throughout the lifespan of the instrumentation. As discussed in 4.2.5, if necessary multiple samples can be taken from the same location to confirm all the samples fall within the same margin of error. As for recovery, not every piece of instrumentation is essential to achieve the mission goal. The two linchpins of the entire scientific payload are the VS and VA. If those fail, then the mission cannot be completed. Environmental data can still be sent back to Earth, but the rover will no longer be able to collect volatile data. On the flipside, not every piece of navigation equipment is necessary for the VA/VS to do its job. Data Handling will be designed to take as little as one input from Navigation to identify a spot, and while that is not ideal, it allows for the mission to continue even if certain instruments fail.

4.2.7 Expected Data And Analysis

For the purposes of illustrating expected data, the LUVMI mission has already provided expected data for what the VA/VS unit would deliver. Below are the results given by the VS as it makes contact with the regolith. Based on the graph, it shows that as the drill makes contact with the regolith, large amounts of volatiles are released. The rise in pressure is also higher for higher regolith contents.

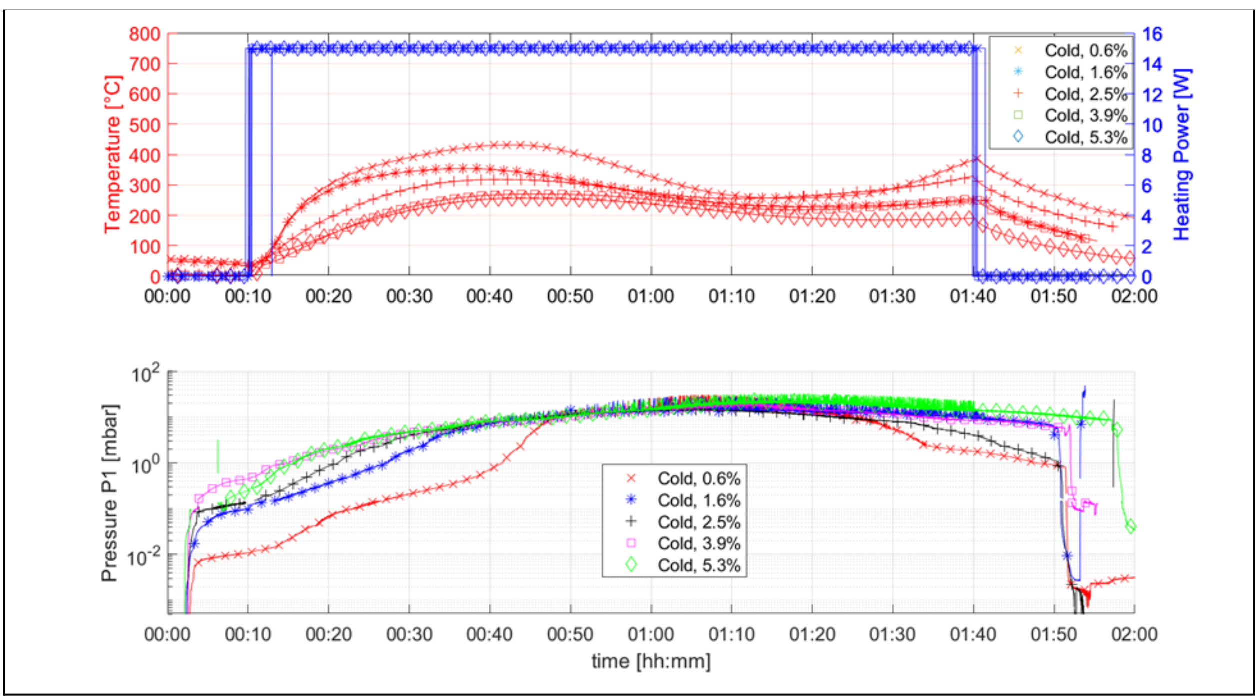


Figure 26: Gas extraction results with the VS and various water contents

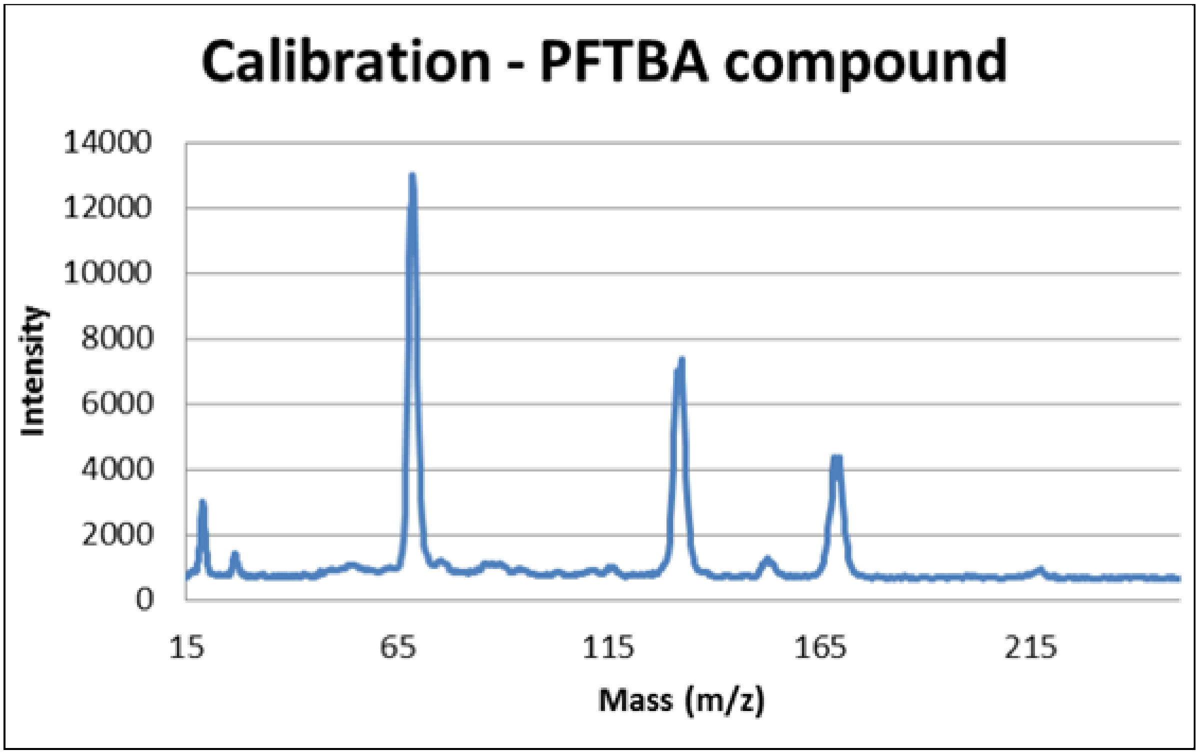


Figure 27: example data from the VA ITMS

The above figure shows the mass spectrum obtained with the VA ITMS with a flow of PFTBA reference gas being admitted into the vacuum chamber. The pressure within the vacuum chamber during the analysis was 2×10-6 mbar. The water peak (m/z=18) is always present and is a result of water vapor outgassing from the walls of the vacuum chamber

For testing the Integrated VS/VA unit, the LUVMI team used a sample of 0.2% water content at ambient temperature. The graphs below depict the readings from the VA, where the top plot shows the water (m/z = 18) response over a 90 minute period. The six individual plots are the mass spectra at different points in time, and based on the clean peak at m/z = 18, the sample volatile is very clearly water.

The next figure shows the profile of m/z=18 (water) extracted from the simulant material during the 90 extraction experiment. The six individual mass spectra show an increase in measured m/z 18 as the experiment progressed.

It should also be noted that with actual data collection, the m/z curves will not be as clean as during the diagnostic testing. There will be multiple peaks present along the m/z chart, and as such it will be easier to identify patterns between different volatiles based on what peaks are present.

The expected data will be very similar to the results obtained from the testing methods for the LUVMI rover due to the similarity in the VA/VS instrumentation. The data obtained will be analyzed to understand the physical and chemical relationships between the volatiles. This might yield a pattern in volatile distribution which would help future missions on the moon to successfully predict possible locations for a particular volatile. Additionally, the Amundsen crater potentially hosts solid Carbon-dioxide which can be verified using the data obtained by the VA/VS.

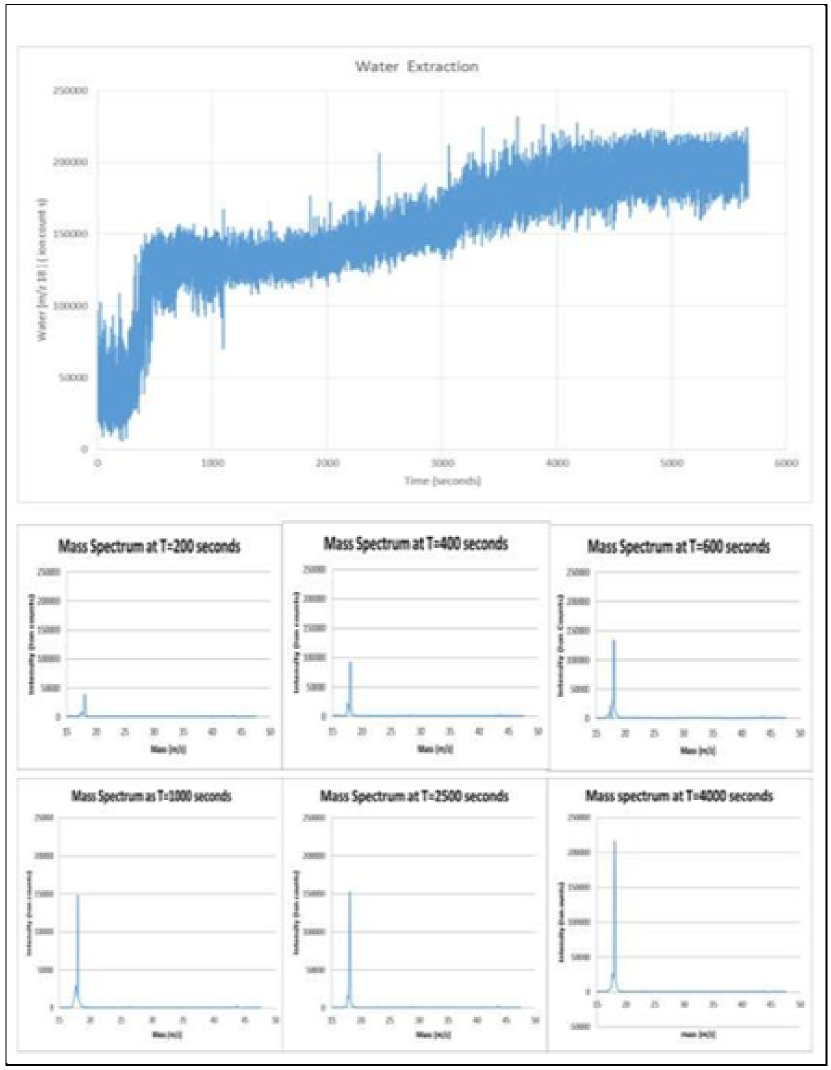


Figure 28: Sample data from water samples

5. Safety

5.1 Personnel Safety

5.1.1 Safety Officer

Nate Dee has been designated as Team Caelum safety officer. Topics of interest to the safety officer include manufacturing and assembly hazards for the engineering team and standard laboratory safety for the science team.

Making safety a habit reinforces set procedures and is an important aspect in space exploration. The role of the Safety Officer is to train personnel on different expected (and unexpected) hazards and how to properly mitigate them. The Safety Officer is also responsible for enforcing safety protocols during all evolutions of the project.

Each sub team has been tasked with identifying hazards specific to their portion of the project for submission to the safety office. These are identified in the next section.

5.1.2 List of Personnel Hazards

A personnel hazard is anything that threatens a person's physical safety or health. Hazards can come in various forms such as chemical, electrical, mechanical, and auditory.

5.1.2.1 Chemical Hazards

Chemical hazards can be present at any time during the manufacturing, testing, and packaging processes. Such chemicals can range from everyday cleaning products to industry-specific materials. Personnel will be required to be familiar with and follow all procedures and recommendations outlined by the Material Safety Data Sheets (MSDS), which will be available in every workspace.

5.1.2.2 Electrical Hazards

Rover electrical systems need to be able to store large amounts of power. Care must be taken when assembling and testing these components. The rover will also have very sensitive electronic components, so electrostatic discharge (ESD) is a big concern and poses a substantial risk to the components.

5.1.2.3 Mechanical Hazards

The manufacturing process presents a number of physical safety hazards as well. Lathes, mills, and other manufacturing equipment all involve the use of rapidly moving drills and parts that can seriously injure their operator upon contact. If a machine malfunctions or is used improperly, personnel may be exposed to fast moving shrapnel. Vacuum and thermal testing expose the probe to extreme environments that would be hazardous to any personnel in the wrong area at the wrong time. During vibration testing, parts of the rover may become loose and can become hazards to personnel in the vicinity.

5.1.3 Hazard Mitigation

The first line of hazard mitigation is always training. Having all the safety equipment in the world and the most meticulous procedures in place won't do anything unless personnel know how to use the equipment and follow the approved procedures. Under this philosophy, all personnel shall attend an annual safety briefing in order to be authorized to perform any work with project SCRAM, regardless of the individual's experience or seniority.

The team will follow all safety precautions outlined by NASA's Office of Safety and Mission Assurance. The primary reference will be SP-2010-580, Volume 1 of the NASA System Safety Handbook (and subsequent volumes).

In case of an accident, there will be hazmat spill kits, medical kits, AED's, and emergency showers/ eyewash stations placed in clearly marked and unobstructed locations throughout the work space.

5.1.3.1 Chemical Hazards

Personnel must be aware of the characteristics of any chemical they use or work around throughout the manufacturing and launch process. A comprehensive collection of MSDS shall be available at every hazardous material (Hazmat) storage area. Personnel are expected to be aware of hazmat markings and their meanings, and to always wear the appropriate PPE as outlined in the MSDS. When working with multiple types of hazmat, the minimum required PPE is everything that is needed to meet the requirements of every material used.

5.1.3.2 Electrical Hazards

Electrical safety is not only for the safety of personnel, but also for the protection of equipment. When working on high voltage equipment, the power must be shut off and proper lock out/ tag out procedures followed. If power is required to be on, personnel will wear insulated PPE, remove all metallic objects from their person, and a second person shall be present as a safety observer.

When working with sensitive electronic systems, standard electrostatic discharge (ESD) precautions must be taken. Work shall be done at a certified ESD workbench or with an approved work mat when a bench is not available. Other ESD protection devices such as wrist straps and ESD bags will also be used.

5.1.3.3 Mechanical Hazards

In order to mitigate the hazards from mechanical processes, there shall be readily available operator manuals for every piece of equipment used, similar to the collection of MSDS mentioned under the chemical hazard mitigation section. Machine operators will be required to wear impact resistant eyewear, safety footwear, and hearing protection. Some machines will require additional PPE and it is the operator's responsibility to ensure they have the appropriate gear.

6. Activity Plan

6.1 Budget

This section offers insight into the expenses that the mission will endure. For the ten members in the team, the total salary estimation is $5.2M. The flights and transportation was calculated based on the team members' school location. The team members will be driven to the closest airport and will board a flight to Melbourne International Airport where they will be transported to Cape Canaveral, Florida. The lodge and food was calculated using the per diem rates given by the US GSA rates in Florida.

The total project cost has been estimated to be around $122.7M.

Table 8: SCRAM Budget

	# People on Team	FTE Year 1	FTE Year 2	FTE Year 3	FTE Year 4	FTE Year 5	FTE Year 6
Science Team:	4	1	1	1	1	1	1
Engineering Team:	4	1	1	1	1	1	1
Administrative Team:	2	1	1	1	1	1	1

NASA L'SPACE Mission Concept Academy Budget - *SCRAM*

Year	Yr 1 Total	Yr 2 Total	Yr 3 Total	Yr 4 Total	Yr 5 Total	Yr 6 Total	Cumulative Total

PERSONNEL							
Science Team	$ 320,000.00	$ 320,000.00	$ 320,000.00	$ 320,000.00	$ 320,000.00	$ 320,000.00	**$ 1,920,000.00**
Engineering Team	$ 320,000.00	$ 320,000.00	$ 320,000.00	$ 320,000.00	$ 320,000.00	$ 320,000.00	**$ 1,920,000.00**
Administrative Team	$ 160,000.00	$ 160,000.00	$ 160,000.00	$ 160,000.00	$ 160,000.00	$ 160,000.00	**$ 960,000.00**
Total Salaries	$ 800,000.00	$ 800,000.00	$ 800,000.00	$ 800,000.00	$ 800,000.00	$ 800,000.00	**$ 4,800,000.00**
Total ERE	$ 223,280.00	$ 223,280.00	$ 223,280.00	$ 223,280.00	$ 223,280.00	$ 223,280.00	**$ 1,339,680.00**
TOTAL PERSONNEL	$ 1,023,280.00	$ 1,023,280.00	$ 1,023,280.00	$ 1,023,280.00	$ 1,023,280.00	$ 1,023,280.00	**$ 6,139,680.00**
TRAVEL							
Total Flights Cost	$ 2,142.00	$ 2,142.00	$ 2,142.00	$ 2,142.00	$ 2,142.00	$ 2,142.00	**$ 12,852.00**
Total Hotel Cost	$ 2,950.00	$ 2,950.00	$ 2,950.00	$ 2,950.00	$ 2,950.00	$ 2,950.00	**$ 17,700.00**
Total Transportation Cost	$ 1,562.00	$ 1,562.00	$ 1,562.00	$ 1,562.00	$ 1,562.00	$ 1,562.00	**$ 9,372.00**
Total Per Diem Cost	$ 3,330.00	$ 3,330.00	$ 3,330.00	$ 3,330.00	$ 3,330.00	$ 3,330.00	**$ 19,980.00**
Total Travel Costs		$ 9,984.00	$ 9,984.00	$ 9,984.00	$ 9,984.00	$ 9,984.00	**$ 49,920.00**
OUTREACH							
Total Outreach Materials	$ 12,230.0	$ -	$ -	$ -	$ -	$ -	**$ 12,230.0**

	0						0
Total Outreach Venue Costs	$ 600.00	$ 600.00	$ 600.00	$ 600.00	$ 600.00	$ 600.00	**$ 3,600.00**
Total Outreach Costs	$ 12,830.00	$ 600.00	$ 600.00	$ 600.00	$ 600.00	$ 600.00	**$ 15,830.00**
OTHER DIRECT COSTS							
Total Outsourced Manufacturing Cost	$ 40,000,000.00	$ 2,345,326.00	$ 2,110,000.00	$ 1,100,000.00	$ 1,090,000.00	$ 1,090,000.00	**$ 47,735,326.00**
|> Science Instrumentation	$ 25,000,000.00	$ 1,000,000.00	$ 1,000,000.00	$ 1,000,000.00	$ 1,000,000.00	$ 1,000,000.00	**$ 30,000,000.00**
|> Other COTS Components	$ 15,000,000.00	$ 1,345,326.00	$ 1,110,000.00	$ 100,000.00	$ 90,000.00	$ 90,000.00	**$ 17,735,326.00**
Total In-House Manufacturing Cost	$ 475,000.00	$ 305,000.00	$ 30,000.00	$ 30,000.00	$ 30,000.00	$ 10,000.00	**$ 880,000.00**
|> Materials and Supplies	$ 475,000.00	$ 305,000.00	$ 30,000.00	$ 30,000.00	$ 30,000.00	$ 10,000.00	**$ 880,000.00**
Total Equipment Cost	$ 3,734,646.46	$ 3,734,646.46	$ 3,734,646.46	$ 3,734,646.46	$ 3,734,646.46	$ 3,734,646.46	**$ 22,407,878.76**
|> Manufacturing Facility Cost	$ 234,646.46	$ 234,646.46	$ 234,646.46	$ 234,646.46	$ 234,646.46	$ 234,646.46	**$ 1,407,878.76**
|> Test Facility Cost	$ 3,500,000.00	$ 3,500,000.00	$ 3,500,000.00	$ 3,500,000.00	$ 3,500,000.00	$ 3,500,000.00	**$ 21,000,000.00**
In-House Manufacturing Margin	$ 2,104,823.23	$ 2,019,823.23	$ 1,882,323.23	$ 1,882,323.23	$ 1,882,323.23	$ 1,872,323.23	**$ 11,643,939.38**
Total Direct Costs	$ 47,350,579.69	$ 9,438,659.69	$ 8,790,833.69	$ 7,780,833.69	$ 7,770,833.69	$ 7,740,833.69	**$ 88,872,574.14**
Total MTDC	$ 41,748,6	$ 3,836,69	$ 3,188,86	$ 2,178,86	$ 2,168,86	$ 2,138,86	**$ 66,464,6**

	10.00	0.00	4.00	4.00	4.00	4.00	**95.38**
FINAL COST CALCULATIONS							
Total F&A	$ 4,174,861.00	$ 383,669.00	$ 318,886.40	$ 217,886.40	$ 216,886.40	$ 213,886.40	**$ 5,526,075.60**
Total Projected Cost	$ 51,525,440.69	$ 9,822,328.69	$ 9,109,720.09	$ 7,998,720.09	$ 7,987,720.09	$ 7,954,720.09	**$ 94,398,649.74**
Total Cost Margin	$ 15,457,632.21	$ 2,946,698.61	$ 2,732,916.03	$ 2,399,616.03	$ 2,396,316.03	$ 2,386,416.03	**$ 28,319,594.92**
Total Project Cost	$ 66,983,072.90	$ 12,769,027.30	$ 11,842,636.12	$ 10,398,336.12	$ 10,384,036.12	$ 10,341,136.12	**$ 122,718,244.66**

The remaining budget of $27M will be used for extra funding for the project

6.1.1 Travel

In accordance with the mission requirements, the launch date that the team has chosen will be in October, 16 2024. The launch will be located at Cape Canaveral, Fl next to the Kennedy Space Center. The team has decided to book the flight on *Delta Airline*s under coach class, and has booked a roundtrip from October 14 2024 until October 18 2024 as per the details provided by client (duration of stay should be two (2) days before the launch and two (2) additional days after the launch).

The members are mostly located in the Western regions of the U.S. nine of the ten members are located in California, and one is located in Washington.

6.1.1.1 Total Flight Cost

The location of departure for each personnel should be near their school location and the Team has been separated into three (3) travel groups:

A. Mahesh, Leonel, Madhavi, Courtney, and Hulbert
B. Michael, Miguel, Jordan, and Shye
C. Nate

The following chart provides the details of the total cost flight budget. All pricing rates have been collected from Delta Airlines price rate list for roundtrips.

Table 9: Flight details

	Name of Personnel(s)	# Members	From	To	Departure Time	Arrival Time	Indiv. Price	Total Cost
A	- Mahesh Acharya - Leonel Hernandez - Madhavi Prakash - Courtney Songco - Hulbert Zeng	5	LAX	MLB	10:30 AM	6:00 PM	$141.00	$705.00
B	- Michael Francesconi - Miguel Garza - Jordan Wong - Shye Alyss	4	SFO	MLB	9:59 AM	6:30 PM	$161.00	$644.00
C	- Nate Dee	1	PSC	MLB	7:00 AM	6:40 PM	$954.00	$954.00
								$2,303.00

The total flight cost will be **$2,303.00**.

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6.1.1.2 Total Hotel Cost

The team decided to book a 5-day stay at the Fairfield Inn Titusville which will be a 19 minute travel time to the Kennedy Space Center. The administration team recommends a total of 5 rooms with 2 members per room with one single occupancy. From the hotel's website https://www.marriott.com/reservation/rateListMenu the pricing per night will be approximately $118.00 per room. The total cost for hotel accommodations will be **$2950.00** (plus taxes).

6.1.1.3 Total Transportation Cost

The team has a total of 5-days for rent which includes gas and parking allowance. The pick-up and drop-off location for the vehicle will be near the MLB Airport

Table 10: Ground transportation cost

	Name of Personnel	# members	Type of Vehicle	Brand	Capacity	Baggage Capacity	Rate Per Day	Total Cost (with Gas and Parking)
A	- Mahesh Acharya - Leonel Hernandez - Madhavi Prakash - Courtney Songco - Hulbert Zeng	5	Midsize SUV	Nissan Rogue	5	4	$82.99	$457.48
B	- Michael Francesconi - Miguel Garza - Jordan Wong - Shye Alysse	4	Midsize SUV	Nissan Rogue	5	4	$82.99	$457.48
C	- Nate Dee	1	Economy	Mitsubishi Mirage	4	2	$69.98	$401.79
								$1,316.75
Parking	$30.00							
Gas	$60.00							

All rates for the vehicle rent are based from www.enterprise.com.

The total transportation cost will be **$1316.75.00.**

6.1.1.4 Total Per Diem Cost

According to the GSA rates https://www.gsa.gov/travel/plan-book/per-diem-rates/per-diem-rates-lookup/?action=perdiems_report&state=FL&fiscal_year=2022&zip=&city= in Brevard County, Florida, where the launch site will be held. The per diem rate for M&IE is $74.00, bringing the per diem cost to **$3330.00** total for all team members.

6.1.1.5 Total Outreach Cost

Table 11: Outreach budget

For Junior & Senior High School Students	
Speaker fee	$1,000.00
Production	$600.00
Food&Beverages	$600.00
Giveaways items	$800.00
	$3,000.00
For Community College Students	
Speaker fee	$2,500.00
Production	$800.00
Food&Beverages	$790.00
Giveaways (1-Month Subscription for autoCAD)	$350.00
	$4,440.00
For Non-STEM Employees	
Speaker fee	$2,500.00
Production	$900.00
Food&Beverages	$890.00
Giveaway (1-MonthSubscription for Kindle Unlimited)	$500.00
	$4,790.00
TOTAL COST	**$12,230.00**

The venue will average around $100.00 per hour. Each event will last for 2 hours making the total cost of the venue $600.00. This brings the total outreach cost to **$12,830.00**.

6.1.1.6 Other Direct Costs

The team will contract with the Bay Area Environmental Research Institution for the rate of **$21M** to manufacture the scientific instruments needed for the mission, and for test facilities as well.

6.2 Schedule

The team's desired launch date will be in October 2024. The entire mission spans to six (6) years which includes the construction, testing, and on-surface mission. A total of two (2) years will be spent for the development of this concept, and an additional four (4) years for scientific exploration of the Moon. Below in this section will contain the development and operational schedule for this mission concept:

Table 12: Project schedule

ID#	TASK	ASSIGNED TO	PROGRESS	START	END	DAYS	MARGIN
1	**Phase A: Concept and Technology Development**		100%	1/17/22	2/15/22	30	9
1.1	Review and update documents in Pre-Phase A	All	Complete	1/17/22	1/19/22	3	
1.2	Monitor progress against plans	Engineering, Science	Complete	1/20/22	1/22/22	3	
1.3	Review on tools/instruments needed for the mission architecture	Engineering, Science	Complete	1/23/22	1/26/22	4	
1.4	Develop and baseline top-level requirements and constraints including internal and external interfaces	Engineering, Science	Complete	1/27/22	1/30/22	4	
1.5	Research on costs of material (build vs. buy decision making) for budget planning	Admin, Engineering, Science	Complete	1/27/22	2/5/22	10	
1.6	Research on different ground systems for the mission	Science	Complete	1/27/22	2/5/22	10	
1.7	Schedule Margin			2/5/22	2/13/22	9	
1.8	◆ Milestone: Completion of SRR		Complete	2/14/22	2/15/22	2	
2	**Phase B: Preliminary Design and Technology Completion**		100%	2/15/22	4/11/22	56	8
2.1	Define requirements needed for the system design	Engineering	Complete	2/15/22	2/24/22	10	
2.2	Create schedule for system design review and development of concept	Admin, Engineering	Complete	2/15/22	2/24/22	10	
2.3	Design Prototype Needed for the Payload	Engineering, Science	Complete	2/15/22	3/6/22	20	
2.4	Design Prototype for ESL model	Engineering, Science	Complete	3/6/22	3/25/22	20	
2.5	Validate System Requirements Review	Engineering, Science	Complete	3/6/22	4/2/22	28	
2.6	Validate System Design Review	Engineering, Science	Complete	3/6/22	4/2/22	28	
2.7	Review and Modify System Designs for Safety	All	Complete	3/6/22	4/2/22	28	
2.8	Schedule Margin			4/3/22	4/10/22	8	
2.9	◆ Milestone: Completion of PDR		Complete	4/10/22	4/11/22	2	

3	**Phase C: Final Design and Fabrication**		**0%**	**4/12/22**	**2/25/23**	**320**	**15**
3.1	Finalize software program needed for payload	Science	Not complete	4/12/22	6/10/22	60	
3.2	Design layout for the hardware and its electrical system	Engineering, Science	Not complete	6/11/22	6/30/22	20	
3.3	Develop and refine preliminary plans (communications)	Science	Not complete	7/1/22	7/20/22	20	
3.4	Refine the manufacturing and assembly	Engineering, Science	Not complete	7/21/22	8/4/22	15	
3.5	Verify and validate engineering units and system designs	Engineering	Not complete	8/5/22	8/24/22	20	
3.6	Fabricate (or code) the product	Engineer, Science	Not complete	8/25/22	10/13/22	50	
3.7	Identify and update risks	Admin, Safety Officer	Not complete	10/14/22	10/23/22	10	
3.8	Layout hardware needed for system architecture	Engineering	Not complete	10/14/22	11/12/22	30	
3.9	Monitor project progress against project plans	Admin	Not complete	10/14/22	11/12/22	30	
3.10	Prepare launch site checkout and post launch activation and checkout	Science	Not complete	10/14/22	11/12/22	30	
3.11	Conduct unit tests for hardware involved with the system	Engineering	Not complete	10/14/22	11/12/22	30	
3.12	Finalize appropriate level safety data package and updated security plan	Science, Safety Officer	Not complete	11/13/22	12/2/22	20	
3.13	Refine orbital debris assessment	Science	Not complete	12/3/22	1/21/23	50	
3.14	Schedule Margin			1/22/23	2/5/23	15	
3.15	◆ Milestone: Finalize CDR and SIR		Not complete	2/6/23	2/25/23	20	

4	**Phase D: System Assembly, Integration and Test, Launch**		**0%**	**2/26/23**	**6/23/23**	**118**	**10**
4.1	Update documents developed and baselined in previous phases	Admin	Not complete	2/26/23	3/2/23	5	
4.2	Monitor and compare project progress with scheduled plans	Admin	Not complete	2/26/23	3/2/23	5	
4.3	Identify and update risks	Admin and Safety Officer	Not complete	2/26/23	3/2/23	5	
4.4	Integrate/assemble components according to the integration plans	Engineering	Not complete	3/3/23	3/17/23	15	
4.5	Perform verification and validation on assemblies	Engineering	Not complete	3/18/23	5/26/23	70	
4.5.1	Perform system qualification verifications, including environmental verifications	Engineering	Not complete	3/18/23	5/26/23	70	
4.5.2	Perform end-to-end tests for ground system	Engineering	Not complete	3/18/23	5/26/23	70	
4.5.3	Perform end-to-end tests for space element	Engineering	Not complete	3/18/23	5/26/23	70	
4.5.4	Perform end-to-end tests for data processing systems	Engineering, Science	Not complete	3/18/23	5/26/23	70	
4.5.5	Assess and approve verification and validation results	Engineering, Science, Project Manager	Not complete	3/18/23	5/26/23	70	
4.5.6	Resolve verification and validation discrepancies	Engineering, Science, Project Manager, Safety Officer	Not complete	3/18/23	5/26/23	70	
4.5.7	Archive documentation for verifications and validations performed	Admin	Not complete	5/27/23	5/31/23	5	
4.5.8	Perform baseline verification and validation report	Engineering, Science, Project Manager	Not complete	6/1/23	6/5/23	5	
4.6	Train and prepare all operators and maintainers for the mission	Admin, Engineering, Science, Project Manager, Safety Officer	Not complete	6/1/23	6/5/23	5	
4.7	Document all lessons for future studies and	Admin	Not complete	6/1/23	6/5/23	5	
4.8	Schedule Margin			6/6/23	6/15/23	10	
4.9	◆ Milestone: Completion of TRR, PLAR, and ORR		Not complete	6/15/23	6/23/23	9	

5	Phase E: Operations Phase		0%	6/24/23	5/14/27	1421	30
5.1	Finalization and preparation of all requirements before launch	All	Not complete	6/24/23	10/15/24	480	
5.2	Launching of Payloader	All	Not complete	10/16/24	6/7/26	600	
5.3	Activate spacecraft to perform mission	All	Not complete	6/8/26	9/15/26	100	
5.4	Conduct the intended mission	All	Not complete	9/16/26	1/13/27	120	
5.5	Collect data from samples	All	Not complete	9/16/26	1/3/27	110	
5.6	Prepare for deactivation	All	Not complete	1/4/27	1/14/27	11	
5.7	Complete post-flight evaluation reports	All	Not complete	1/15/27	2/13/27	30	
5.8	Develop final mission report	All	Not complete	2/14/27	3/15/27	28	
5.10	Schedule Margin			3/16/27	4/14/27	30	
5.11	◆ Milestone: Complete FRR		Not complete	4/15/27	5/14/27	30	

6.3 Outreach Summary

This section discusses the different strategies on how to increase the public awareness and appreciation of STEM programs/projects to the younger generations. A part of NASA’s duty aside from space exploration is also to educate people regarding the influence of science and research in their everyday lives. In reaching out to different communities, social media platforms, and free ebooks related to several STEM topics.

6.3.1 Communities

The team plans to implement presentations for high school and middle school students to highlight all of the STEM related opportunities that will be open to them. A particular reason why young students may not be actively involved in STEM career paths or STEM based lessons is due to lack of exposure and uncertainty of career choice.This is why the team plans on organizing symposiums/conferences that relates to STEM Appreciation and Career-Decision Making. Due to the COVID-19 pandemic, the team will follow the guidelines established by the CDC in order to build a safer environment for the audience. The chart below provides details for the outreach.

Table 13: Outreach plan

	Demographic		
	Junior & Senior High School Students	**Community College Students**	**Non-STEM Employees Interested in transitioning to a STEM Career**
Title of The Event	*Back to the Future! A history of STEM milestones that changed the 21st Century*	*One step closer: Immersion to the STEM Workforce*	*Plan B: Rethinking and Reopening your Career Path*
Topics	History of Science; History of NASA; Major contributions of Science that impacted our modern technology;	STEM opportunities to community college students; benefits of being involved in the STEM Workforce; Application of STEM to real world scenarios	Where to start in building a STEM career; Free available sources for STEM materials; The diversification and inclusion of the STEM community/workforce over the years
Venue	Webinars or Selected High Schools in Los Angeles, Oakland, and San Francisco California	Webinars or Selected Community Colleges in Los Angeles, Oakland, and San Francisco California	Webinars or Local venues in California or Washington
Duration	1 hour and 30 minutes	1-2 hours	1-2 hours
Who to contact	Principals; STEM teachers; Coordinators of the District of selected school	President of the Community College; Student Council President; Operations Manager; Frontdesk	Venue hosts
Speaker(s)	STEM Employee or historian who has vast knowledge in Science and Technology history	STEM Interns and former Community College students in the STEM workforce	STEM Professionals
Giveaways	Pencils, Notebooks, USB Flash Drives	1-Month subscription to AutoCAD	1-Month subscription to Amazon Prime
Social Media Platforms to Advertise in	Instagram, Reddit, Twitter, Snapchat	Facebook, Instagram, Reddit, Twitter, Snapchat	Facebook, Instagram, Reddit, Twitter

6.3.2 Social Media Platforms

The latest generation of children are deemed to be “digitally native”. Social media has become highly influential with one’s lifestyle and habits. The team plans to create engaging content on various platforms such as Instagram, Twitter, TikTok, and Youtube.

6.3.3 Free Online Resources

A possible factor why there may be a decline in STEM appreciation is due to the lack of resources that students and employees who are interested in a STEM career face. STEM textbooks and readings may be unaffordable to students, thus making it challenging for the newer generations. Utilizing the social media apps, symposium events, and webinars. The administration team will link the free online materials (Khan Academy, NASA website, JMARS, Free online textbooks (provided by *Rice University*), etc.)

6.4 Program Management Approach

Caelum is divided into three subsections: Engineering team, Science team, and Business Administration team. Along with this, the team also consists of a Project Manager (PM) and Deputy Project Manager (DPM) to handle the overall logistics of the mission concept. The two manager positions were intended to be chosen by vote from other team members, but only two people put their names in for consideration, so they were given the spot.

After the PM and DPM roles were filled, the sub teams needed to have a leader established. This was also done on a volunteer basis with the PM and DPM excluding themselves from consideration to allow other members to step into a leadership role. Once all leadership was established, the PM informed the team that a military-style chain of command would be used. This means that if a team member not in a leadership role has an issue, they go to their sub team lead. If the lead can't solve it, then the issue is escalated to the DPM and PM. The team's organization chart can be seen below.

With the chain of command established, the project began with sub team leaders assigning different tasks for their members, while the project management kept the team on track with deadlines and requirements that needed to be completed.

As a means of communication and monitoring the mission's progress, the team reached an agreement to meet every Sunday at 18:30 PST for group meetings to discuss the agenda. During the meetings, the sub team leaders are responsible for reporting on the progress and plans of their team.

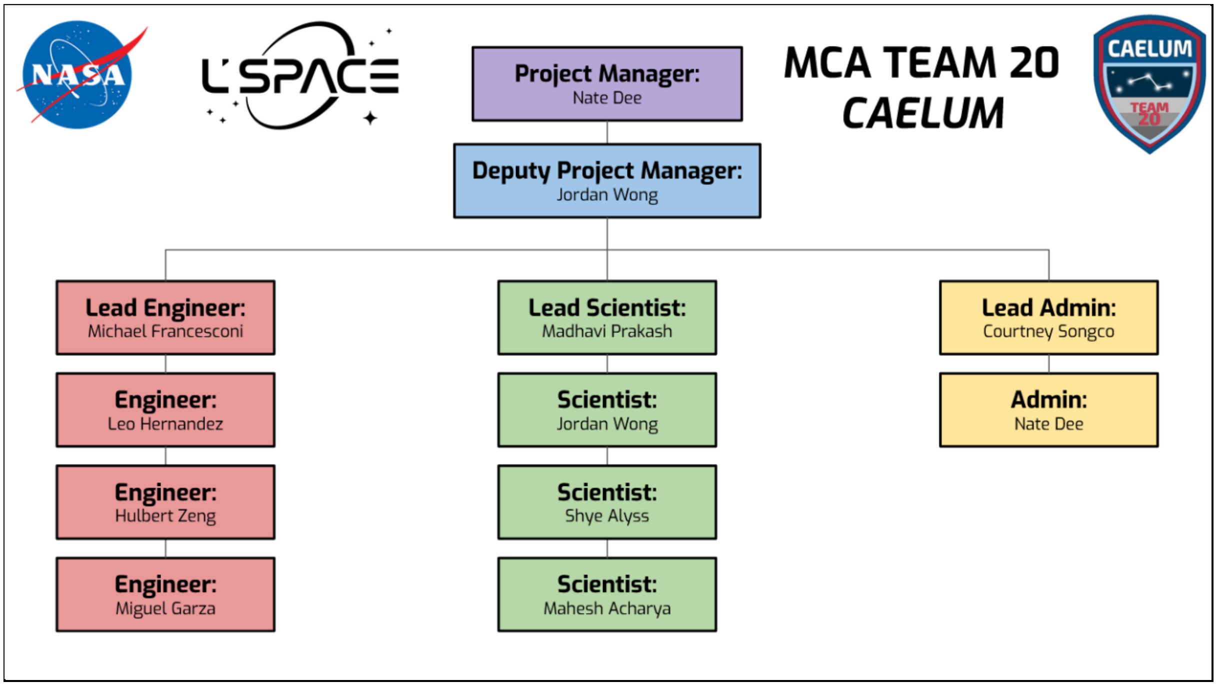

Figure 29: Caelum's organizational structure

6.4.1 Tracking progress and accountability for assigned tasks

6.4.1.1 Zoom

In order for each member and subteam to be accountable in completing their assigned duties. A Zoom conference meeting is held every Sunday evening at 6 PM. A zoom meeting has been effective in discussing the agenda and deadlines. Each team leader has to discuss the tasks that their team has accomplished. It is also the team leader's responsibility to report any conflict happening within their team in order to have these issues resolved immediately. Other members are highly welcome as well to voice their concern over any topic that is relevant to the team discussion. The meeting is also a place where members can give suggestions and improvements to the PDR.

6.4.1.2 Discord

Discord has been the most convenient platform to reach out with all members. It is flexible to all members and makes it easier to view recent updates and announcements.

6.4.1.3 Google Docs

Google Docs allows members to collaborate on a single document at any given time. It also has a feature that allows users to see who has and has not contributed to the PDR. Team members can use the suggestion, comment, or chat feature for better means of communication and for better tracking of progress.

6.4.1.4 Gantt chart

A gantt chart was created at the beginning of the academy and was utilized to keep members up to schedule. This chart also assigned the different responsibilities for each team for a better system of organization in accomplishing assigned tasks. Upcoming deadlines and weekly meetings are listed in the gantt chart as well.

6.4.2 Conflicts and resolutions experienced during the program

6.4.2.1 Time zone conflicts

There are two (2) members who are currently residing out of the United States during the most run of the program. One member, Madhavi Prakash, who currently serves as the Science Team Leader, is located in India during the academy. While another member, Courtney Songco, who serves as the Business Administration Team Lead, is stationed in the Philippines. This resulted in some absences by the team leaders.

RESOLUTION: Project manager or deputy project manager were substituted in case of absences by either team leads mentioned. If a member is not able to attend the weekly meetings, they need to inform the group in advance to avoid delays in the meeting that could cause time conflicts.

6.4.2.2 Departure of team members

Due to schedule conflicts of several former team members. Team Caelum has lost four (4) members during the run of the course. This caused major adjustments in the chain of command and responsibilities.

There have also been delays in some portions of the deliverable due to the shortage in members.

Resolution: The team requested for an extension for the assigned deliverable.

6.4.2.3 Interdependence conflicts

There are often times when some tasks depend on another personnel's final output. Some members are not able to submit their required task on the deadline due to personal reasons, prior engagements, or emergencies. This resulted in a causal delay in the final output.

Resolution: All team leaders and managers have prepared a backup plan or outline in order to submit the assigned deliverable on or before the deadline. Team members can also volunteer to fulfill the missing requirements.

6.4.2.3 Technical Difficulties

During the later stages of building this PDR, the Google documents file started experiencing technical glitches that would take random images from the document and repeat them on every page with no way to undo it. This happened at least twice and caused the team to have to revert to a version that was a few hours or even a day older, losing valuable progress.

Resolution: The Project manager started downloading independent backup copies multiple times while editing the document so that a more recent copy would be immediately available should the system glitch again.

7. Conclusion

Caelum’s mission is to explore the characteristics and origin of volatiles found within the permanently shadowed regions found on the lunar surface in preparation for a permanent human presence.

The rover, now formally named New Hope, will spend its time on the lunar surface using a ground penetrating radar, two cameras, and a ground temperature sensor to map out subsurface features as well as a specialized integrated Volatile Sampler and Analyzer to study the volatiles of the south pole’s permanently shadowed regions (PSR’S). It will obtain data about what elements are present within the volatiles, after which further conclusions can be made to characterize the volatile profile of PSRs where sampling was conducted.

The team will start the Critical Design Review around June 2022. This is to ensure that the mission will meet the scheduled time of launch, budget, and performance requirements that are crucial before the actual launch. The team will complete the final system designs through testing, performing different simulations, and detailed analyses that will improve the results of the mission. A recommendation for the next mission milestones is to do more extensive research regarding the rover’s design that could be suitable for the extreme frigid conditions present in the lunar atmosphere while maintaining the mission constraints provided by the client.