Leviathan

Team 17

Preliminary Design Review

Final Report

July 26th, 2021

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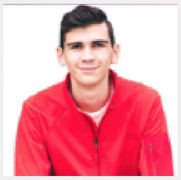
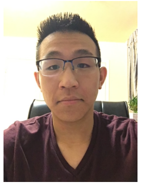
1. Introduction and Summary

1.1 Team Introduction

Table 1.1 - Team Introduction

Name	Team / Role	Major	University
Quintin Nelson	Project Manager / Engineering	Aerospace Engineering	Penn State
Jon Reyes	Deputy Project Manager / Business	Information Systems	Stony Brook
Kien Tran	Lead Business	Computer Engineering	Virginia Tech
Jaya Bannarbie	Deputy Business	Computer Science	South Florida
Francisca Arias	Lead Scientist	Physics & Mathematics	Amherst
Nicolas Sanchez	Deputy Science I	Biomedical Engineering	Florida State
Hena Imran	Deputy Science II	Astronomy	Maryland
Emma Clancy	Lead Engineer	Mechanical Engineering	Drexel
Grace Floring	Deputy Engineer	Aerospace & Mechanical Engineering	Case Western Reserve
Alex Shum	Engineering	Aerospace Engineering	Central Florida
Evan Xhumba	Engineering	Engineering Mechanics & Aerospace	Wisconsin Madison
Ananya Jain	Engineering	Biomedical Engineering	Florida

Table 1.2 - Team Background

Team Member		**Additional Background / Skills**
	**Quintin Nelson**	Lead Project Manager. Relevant Experience in C++, Fusion 360, Siemens NX. Taken courses in thermodynamics, chemistry, materials, and dynamics. Experience with business development, presentations, project development (PDR/CDR).
	**Jon Reyes**	Relevant experience in Software Engineering, Digital Design, Finance and Natural Sciences in Physics and Biology. (Google/IBM Cloud, Java, JavaScript, Python, Spreadsheets, MATLAB, TinkerCAD, Arduino, Circuit Design in Logisim, Photoshop)
	**Kien Tran**	Relevant experience in C++, C, Verlog, html, Java, Cad, Circuits and wiring, Finance, Customer service, Machine learning assistant researcher, and the Engineer math and science classes
	**Jaya Bannarbie**	Relevant coursework includes java programming, Autocad, solidworks, Calc I/II/III, Ordinary Differential Equation, and Physics
	**Francisca Abdi Arias**	Lead Scientist. Relevant coursework includes Calc I/II/III, Physics (Mechanics, Electromagnetism), Electronics, and Programming in Java, Python, Labview, MatLab, and C.
	**Hena Imran**	Relevant coursework includes Calculus, Linear Algebra, Physics (Digital Electronics, Nuclear Physics, Modern Physics), C++, and Inorganic Chemistry.

	**Nicolas Sanchez**	Relevant coursework includes Calc I/II, Chem I/II and lab, Bio I/II and lab, as well as experience in Circuitry and Wiring, Electronic Device Repair and Construction, and basic C++.
	**Emma Clancy**	Lead Engineer. Relevant CAD experience with Solidworks, Inventor, Crea, and Fusion 360. Relevant coursework included mechanics of materials, manufacturing processes, continuum mechanics, and applied engineering numerical & analytical methods
	**Grace Floring**	Relevant experience in a variety of CAD software, including SolidWorks, Inventor, and PTC Creo. Coursework completed includes Design and Manufacturing, Propulsion, Aerostructures, and Design of Fluid and Thermal Elements.
	**Alex Shum**	Relevant experience in SolidWorks, Python, C, MATLAB, and Arduino. Relevant coursework in Solid Mechanics, Thermodynamics, Fluid Mechanics, and Measurements. Research experience in Nanoscience.
	**Evan Xhumba**	Relevant experience in CAD software including SolidWorks. Completed coursework including Calc I/II, Chem I/II, Physics, and Design. Also have some experience with wires and circuits.
	**Ananya Jain**	Relevant experience in Clinical Engineering Design, Materials Engineering, CAD (OnShape), MATLAB, JAVA, Arduino. 3 years of combined lab/computer-based research (Simulation, Chemical Engineering, and Mechanobiology)

1.2 Mission Overview

1.2.1 Mission Statement

The purpose of this mission is to assist NASA's plans to establish a presence on the moon by researching the abundance of water-ice within the moon's surface. This mission focuses specifically on the moon's Permanently Shadowed Regions (PSRs) at the Lunar South Pole. The objective of this mission is to accurately find and measure the presence of near-surface water-ice. This will allow future NASA plans to use in-site resources to sustain both fuel and air resources in order to remove the inefficiency of expense in continuous resupply of Earth's resources. A land rover will be utilized to measure water-ice at one specific crater near the south pole. The mission will officially start once the rover detaches from the lunar orbiting spacecraft at an altitude of 10km about the lunar surface. The rover will use ground penetrating radar and neutron spectrometry to measure and map water-ice near the surface to an accuracy of 1% or better. By understanding and researching the lunar ice, NASA scientists may be able to further understand the origins of the Earth and Moon, and better prepare for future lunar missions [1].

1.2.2 Mission Requirements

Table 1.3 - Power

ID	Requirement	Rationale	Verification
1.1	The rover shall not use more than 1900 W of power	Batteries are used for power. More batteries/external power are not available.	Test
1.2	The rover shall run purely on batteries	The rover will run in a PSR, where no sunlight is available. Thus, solar panels are not an option. Nuclear power was also ruled out by constraints.	Demonstration
1.3	The rover shall obtain all of its power from one power source	Batteries are the sole power source and 'protective space' is limited	Inspection
1.4	The vehicle shall be able to operate at full capacity for a minimum of 120 hours	Based on battery power availability and how long the rover needs to operate for	Test / Redundancy System

Table 1.4 - Communication

ID	Requirement	Rationale	Verification
2.1	The rover shall communicate with the orbiter at minimum of 100 km	Prerequisite constraint from mission profile	Demonstration
2.2	The rover shall send data by radio waves	Radio waves are the best application for data transferal and have been used by NASA for multiple missions.	Analysis
2.3	The rover shall keep its communications electronics within the body	Radiation and debris could damage electronics. Since data transfer is the sole reason for the mission, communications electronics must be kept safe.	Inspection

Table 1.5 - Movement

ID	Requirement	Rationale	Verification
3.1	The payload shall be a rover on the ground	The scientific instruments are best used on the ground. Ground rovers also allow for more precise data collection.	Test
3.2	The rover shall run on wheels	Due to time, precision, and intricacy of the data, it is important to have precise movement.	Demonstration
3.3	The rover shall turn using differential steering	Mass constraints and simplicity of rover design do not allow for intricate steering mechanics.	Demonstration

Table 1.6 - Thermal Control

ID	Requirement	Rationale	Verification
4.1	The rover’s internal temperature shall not fall below 273.15 K	Batteries, as well as other electronics, do not work well below 273.15 K	Test
4.2	The rover shall protect electronics from radiation	The Moon has no atmosphere, so radiation can easily penetrate electronics, hurting their performance	Inspection
4.3	The rover shall include a housing unit for the Neutron Spectrometer that shields it from radiation, but still allows it to be exposed to the ground	Protection is needed, but the spectrometer must be exposed to the ground for data collection	Demonstration

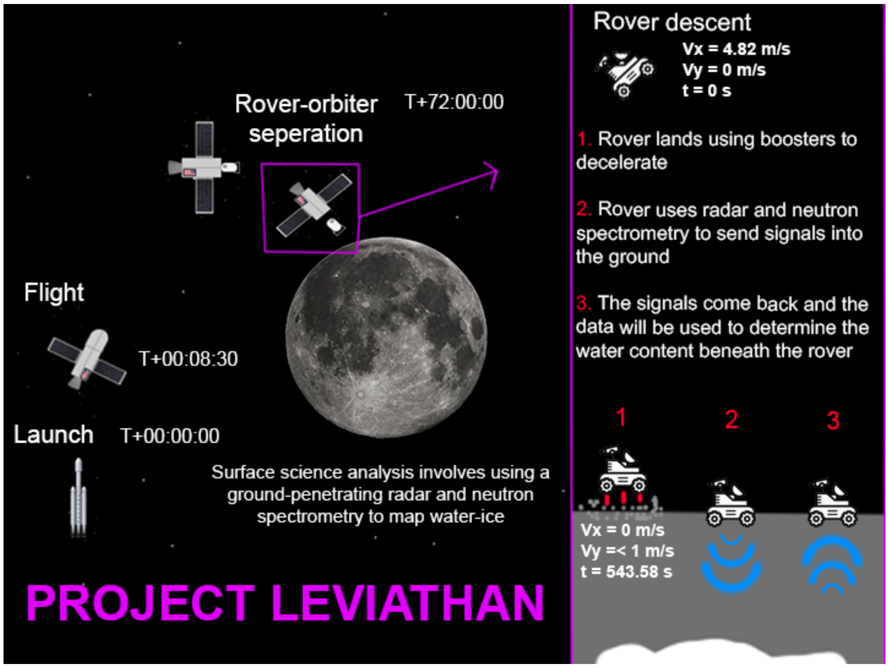
Table 1.7 - Mission Constraints

ID	Requirement	Rationale	Verification
5.1	The spacecraft shall not exceed 180 kg (396.8 lb)	Mission Constraint	Inspection
5.2	The instrument shall not take up more than 60.1 cm x 71.1 cm x 96.5 cm (23.7 in x 28 in x 38 in)	Mission Constraint	Inspection
5.3	The mission budget shall not exceed $200 million (USD)	Mission Constraint	Inspection
5.4	The abundance of near surface water-ice shall be mapped at a scale of a few kilometers	Mission Constraint	Demonstration
5.5	The abundance of water-ice in the top 1 meter of regolith shall be determined at approximately ±1% accuracy or better, at a spatial sampling of ~100m	Mission Constraint	Test

1.2.3 Mission Success Criteria

Along with following the above constraints, the mission success criteria includes securing protection of the scientific payload, appropriate deployment of instruments and tools, collection of scientific data, and data transmission back to the Earth from the Moon for further analysis.

1.2.4 Concept of Operations



Surface science analysis involves using a ground-penetrating radar and neutron spectrometry to map water-ice

1. Rover lands using boosters to decelerate

2. Rover uses radar and neutron spectrometry to send signals into the ground

3. The signals come back and the data will be used to determine the water content beneath the rover

Figure 1.1 - COO

“Project Leviathan” consists of a lunar rover landing on the Moon for scientific studies. A rocket will launch from Earth and enter Low Earth Orbit. Once orbits have been transferred, the payload will fly to the Moon. Once in the Moon’s orbit at about 10 km above the surface, the rover will detach and descend to the surface. Once on the surface, the rover will use ground-penetrating radar and neutron spectrometry to scan for water-ice.

1.2.5 Major Milestones Schedule

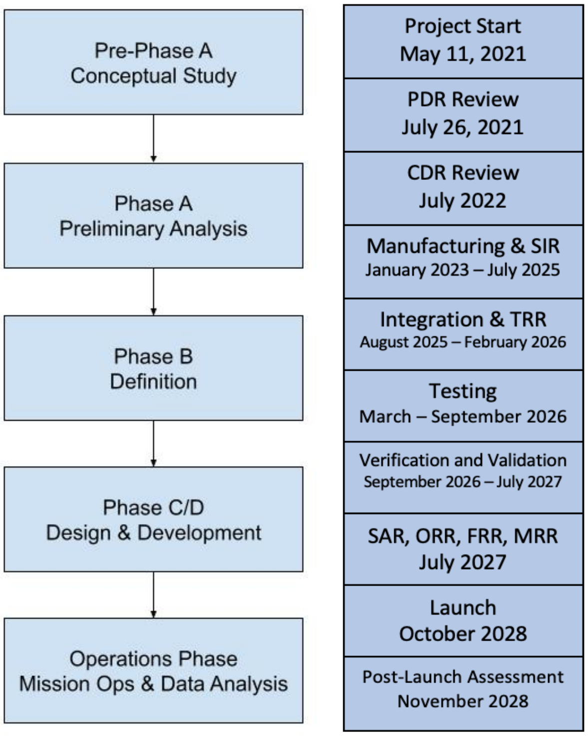


Figure 1.2 - Milestone Schedule

Phase A: Preliminary Analysis

- May 11, 2021 - Project start
- June 14th, 2021 - Concept of Operations, preliminary research finalized

Phase B: Definition

- June 21st, 2021 - Budget, Mission Schedule finalized
- June 28th, 2021 - Finalize landing site on Moon, finalize both scientific studies and engineering summary
- July 5th, 2021 - Safety plan finalized

Phase C/D: Design and Development

- July 26th, 2021 - PDR Materials Due, submission
- August 2021 - July 2022 - PDR refining, project maturation
- July 2022 - CDR
- July 2022 - January 2023 - CDR review, feedback, manufacturing setup

- January 2023 - Start Manufacturing
- July 2025 - Finish Manufacturing, System Integrations Review (SIR)
- August 2025 - Integration begins
- February 2026 - Integration end, Testing Readiness Review (TRR)
- March 2026 - Testing begins
- September 2026 - Testing end, Verification Testing start
- January 2027 - Verification Testing end, Validation Testing start
- July 2027 - Validation Testing end, System Acceptance Review (SAR)
- Operational Readiness Review (ORR)
- Flight Readiness Review (FRR)
- Mission Readiness Review (MRR)

Phase E: Operations Phase

- October 2028 - Launch at Cape Canaveral
- November 2028 - Post-Launch Assessment Review

1.3 Descent Maneuver and Vehicle Design Summary

The rover will be made primarily of 6061 Aluminum (Al) which has good mechanical properties and is able to withstand immense amounts of stress. The drawback with using this material would be the weight of the overall mission. The total mass of the vehicle is approximately 159.34 kg. The volume of the rover totals to 732 x 439 x 693 mm when “stowed” aboard the transport rocket. During descent to the moon, the rover extends to a volume of 892 x 565 x 693 mm. The rover consists of a main body, made of 6061 Aluminum, that houses lithium thionyl chloride (Li-SOCl2) batteries, the RIMFAX radar electronic box, the data processing system, the communication instruments, and the neutron spectrometer. The legs, made of aluminum tubing, attached on the side of the housing, are positioned “upward” during launch to allow for a smaller volume and extend during landing to allow a clearance underneath the rover. Additionally, the neutron spectrometer, further discussed in section 1.4, will extend from the housing to be external to the vehicle in order to function once on the moon. The infrared camera, which allows the rover to navigate in the permanently shadowed region, is positioned on the top of the rover to allow for 360° views. Further analysis of the vehicle design can be found in section 3.1.

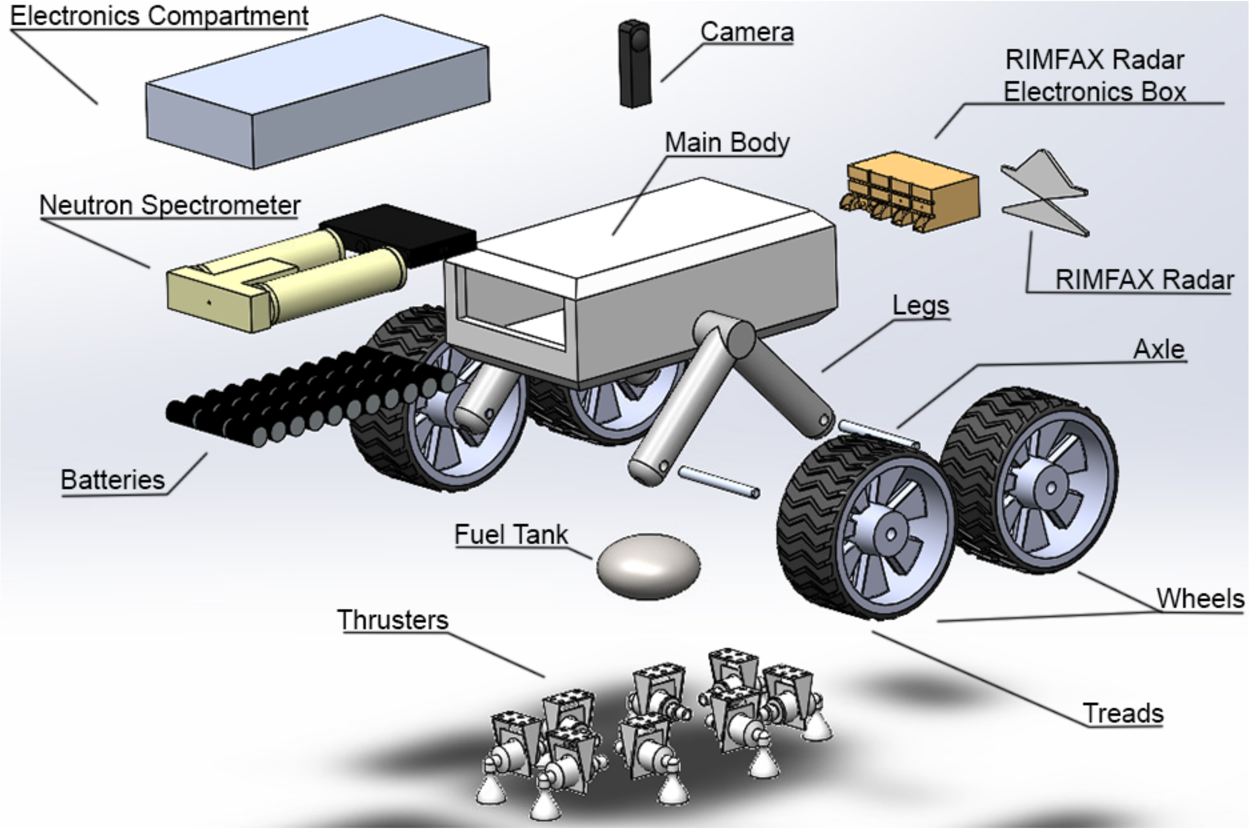


Figure 1.3 - Rover Design

The intended landing site for the rover is in Shoemaker crater near the lunar south pole. The descent maneuver is broken into two phases. Stage 1 is responsible for orienting the vehicle above its intended landing position as well as decelerating the payload from its orbital velocity as well as its acceleration towards the moon's surface. Starting at an altitude of 10km above the lunar datum, the vehicle uses a propellant burn to slow the payload from approximately 1675.20 m/s orbital velocity to negligible velocity in the x-direction, and 51.51 m/s in the (-y)-direction (axes are labeled in the EDL graphic below), ending at an altitude of 0km. To properly align the vehicle, the entry angle shall be a minimum of 75°. Stage 2 is responsible for the vertical descent to the bottom of Shoemaker crater, and decelerating the vehicle for a safe landing. During this stage, the legs of the vehicle unfold. A <1 m/s descent velocity when the rover reaches the surface is ideal, but the vehicle can withstand landing speed of up to 5 m/s. Due to the negligible atmosphere on the moon, a heat shield is not necessary. The EDL subsystem consists of eight, MRE-15 monopropellant thrusters that utilize hydrazine as a propellant, totaling a mass of 21 kg. Additionally, a steep descent angle could be taken. Total descent time is approximately 544 seconds.

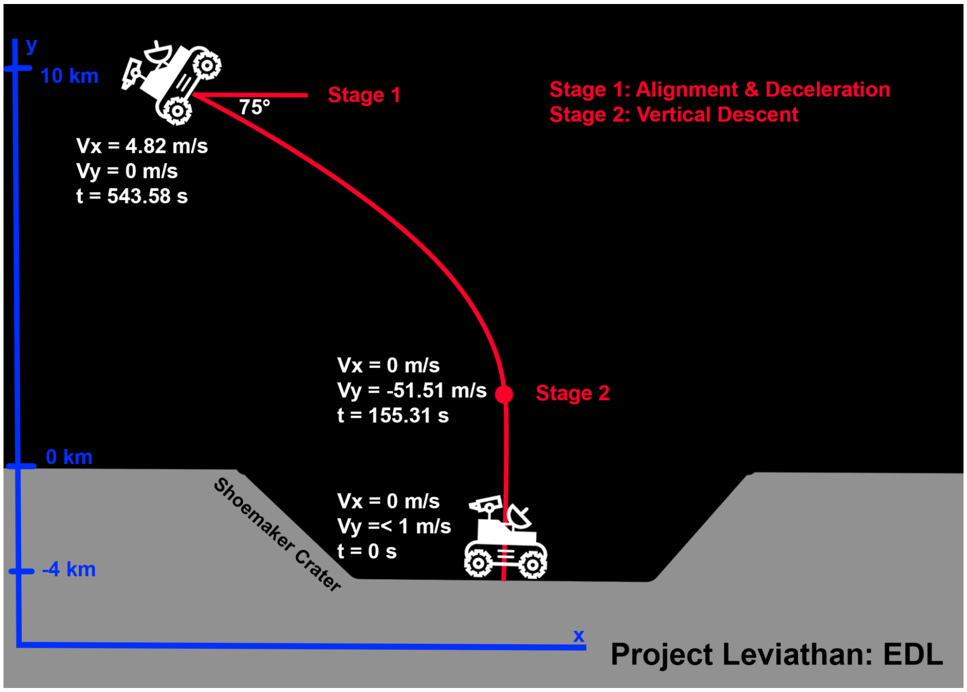


Figure 1.4 - Vehicle EDL

1.4 Payload and Science Instrumentation

The rover will be equipped with a Ground-Penetrating Radar (GPR) based on the Radar Imager for Mars' Subsurface Experiment (RIMFAX), which will gather information on subsurface features, like clusters of water-ice, using radio waves that are transmitted into the subsurface and then reflected back into the radar system. Depending on the frequency utilized, depths of up to 10 meters can be probed. Resolution and radio emission frequencies are inversely related, with higher frequencies providing greater resolution but providing less penetration and vice versa [2].

Since the GPR is only able to reliably distinguish water when it exists in higher concentrations relative to regolith [3], the rover will also employ a Neutron Spectrometry System

(NSS), which will instead measure changes in the number and energy of neutrons coming from the Moon [4]. The NSS will be used primarily to hone in on possible clusters of water-ice within a radius of about 150 km with a sensitivity of at least 10 ppm of hydrogen [5], so that the rover may then approach a possible water-ice cluster and confirm its presence with the GPR system.

The rover will also feature a radio transmitter and receiver to collect and retransmit the data generated by the instruments. This will be an X-band Omni Antenna capable of frequencies between 8100 and 8600 megahertz. This receiver will work alongside the communications system to send the data back to Earth for data processing and analysis. The instruments will be mounted on the front and underside of the rover.

2. Evolution of Project

2.1 Evolution of Mission Experiment Plan

Iteration 1: Preliminary Goals & Design

Initially, the team was uncertain as to whether the mission would be carried out by a lander or an orbiter; despite this, the consensus was that it would most likely be a lander. Regardless, and in adherence to the mission concept prompt, the mission goal would be to, in short, search for water on the lunar South Pole. At this early stage, the scouting area was not well defined beyond the fact that it would have to be a PSR on the lunar south pole. Radar and Neutron Spectroscopy systems were considered from the beginning as tools which would be useful in the discovery of water. Infrared and Hydrated Salt spectrometry were also considered as possibilities for water scouting instruments but were eventually discounted in favor of the aforementioned devices. The experimental plan was not defined much beyond that the devices on the probe would scan for water in a PSR on the lunar south pole.

Iteration 2: Scouting Areas & Preliminary Experimental Procedure

At this stage, the option of using a lander to complete the mission was solidified. The locations of Cabeus, Shackleton, and Shoemaker craters were taken into consideration when deciding on the scouting location. These craters were found to all contain sizable PSRs with a good possibility for finding water. The science instruments were also solidified at this stage as including a GPR, NSS, Navcam, and antenna. The devices would be used as follows: the NSS would be used to search out areas of higher water concentration, the Navcam would help a team of Earth scientists navigate toward it, the GPR would activate upon reaching such an area and would give a more in depth look to the local subsurface to see whether or not large pockets of water ice were present.

Iteration 3: PDR Section 4 Draft

At the draft stage of PDR section 4, the team finalized the scouting location as Shoemaker crater. There was research done on preceding usage of the instruments onboard the rover by NASA and precedents were found for GPR and NSS in NASA's RIMFAX and NRVSS systems respectively. The instruments onboard the rover were therefore based on these two systems. The Navcam, which had been previously conceptualized as a normal camera, was changed for an infrared camera due to the lack of natural lighting in lunar PSRs which conventional cameras require for operation. As in the case of the NSS and GRP, the team did research on infrared cameras for operation on the moon and found NASA's LCIRiS tool. Since this tool was developed directly for use on the moon, the rover's Navcam was directly based on LCIRiS. The experimental procedure stayed largely the same as the one outlined in the previous section with the minor change that the rover would employ the antenna to communicate with Earth scientists for navigation.

Iteration 4: Refinement and Final Draft

The rover's science instruments, and mission concept were finalized in the previous section. At this final stage of development, the greatest changes occurred in the experimental procedure carried out by the rover. Although the basic procedure remained the same, there was a lot of refinement and research done to clarify some of the more vague aspects of the previous procedure. These were the following: search patterns were assigned to the rover's instruments, a specific threshold of interest was assigned to the NSS, the data communication procedure was made more robust, and the search protocols were specified.

2.2 Evolution of Descent Maneuver and Vehicle Design

Iteration 1: Brainstorm

Figure 2.1 shows the initial sketch of the first design of the rover, and Figure 2.2 shows the initial rough CAD model. The ideas for this iteration of the lander were based on the engineers' knowledge of currently operating rovers, specifically NASA's Mars rovers. It featured a rectangular body structure that could house equipment inside with four wheels extending from the body. A key initial feature of the vehicle design was attaching the scientific instrument, which at this point was undetermined, via a moveable arm to broaden the area at which the instrument could operate. Solar power could not be used due to the nature of the permanently shadowed regions (PSRs), and nuclear power was ruled out due to the safety factors as well as weight and size requirements that the team felt it would not be able to constrain to. For landing and descent, a parachute and heat shield system was proposed (not pictured). At this point, no landing site had been determined, so more specifics regarding entry, descent, and landing were not discussed.

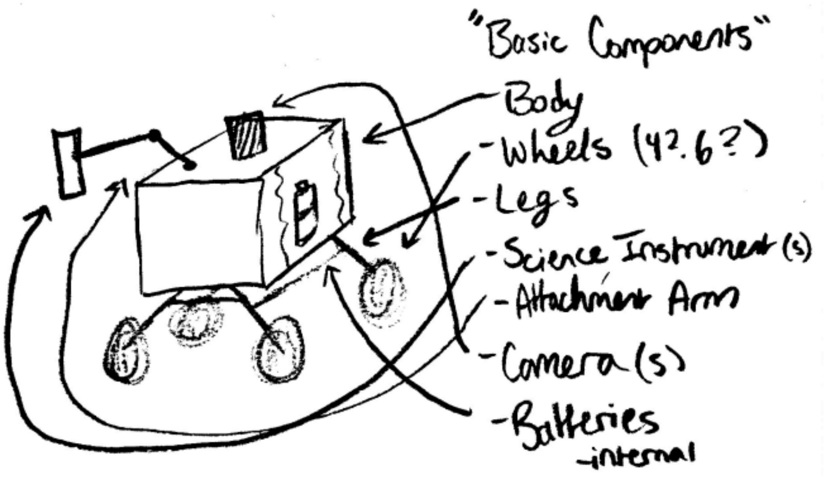


Figure 2.1 - Iteration 1 Initial Sketch

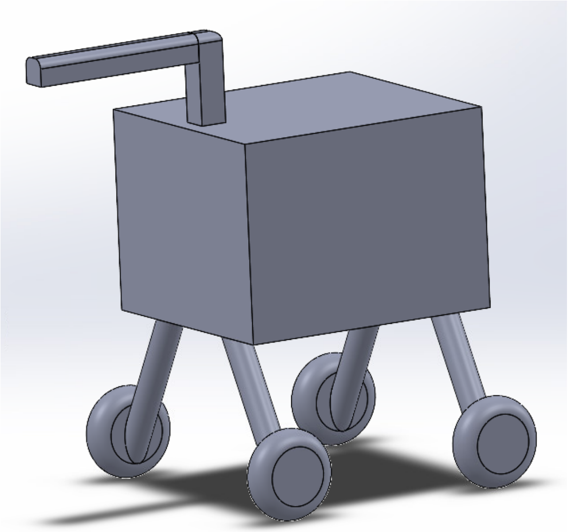


Figure 2.2 - Iteration 1 Initial CAD Model

Iteration 2: Design

At this stage, features of the rover were individually examined and researched to better create the vehicle. A main scientific instrument had been determined, a neutron spectrometer, and the bulkiness and the weight of the instrument ruled out the use of housing it on the end of an arm. Additionally, the CAD model was more fleshed out, as shown in Figure 2.3. The neutron spectrometer and RIMFAX radar were added, as well as a 360° camera on top of the rover for both navigation, hazard avoidance, and scientific data collection. The initial descent and landing features were also abandoned. Research into the moon's atmosphere, or lack thereof, ruled out the use of a parachute as a deceleration mechanism, and also rendered a heat shield unnecessary. Instead, thrusters would be used to slow the rover's descent to the surface, as well as provide altitude control.

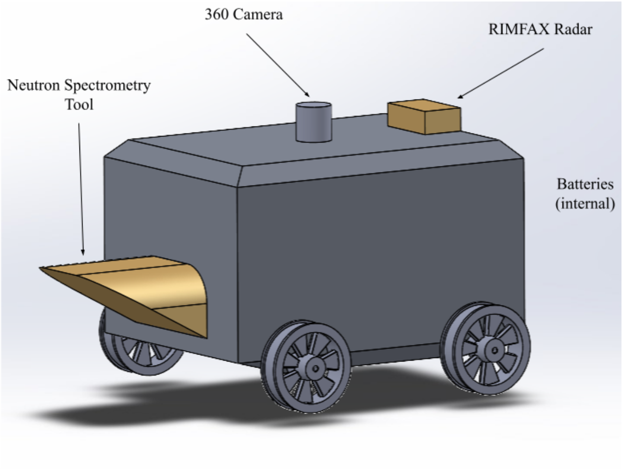


Figure 2.3 - Iteration 2 CAD Model

Iteration 3: Maneuverability

A big problem with iteration 2 was that the bottom over the rover was very low and therefore close to the ground. The rocky terrain of the moon would require the vehicle to be able to maneuver on terrain that is not flat or smooth. For iteration 3 (shown in Figure 2.4), the vehicle housing was lifted to allow minor rocks and debris to be able to pass underneath the rover, which would also allow the rover to take more direct routes when navigating the surface of the moon and therefore use less batteries. Also, the wheels were made bigger to allow for further distance for less power, and a suspension system was added for stability. Additionally, the thrusters were left on the rover in order to be able to provide a controlled descent all the way to the surface, without having to release the thrusters from a certain height so that they wouldn't fall into the rover's landing site. In order to better lift the rover off of the ground, since the thrusters hang below the body, while also staying within the volume constraint, the legs of the rover were designed to fold horizontally while in transit to the moon aboard the rocket, but extend downwards during landing to provide extra height. The Neutron Spectrometry tool and the RIMFAX Radar CAD models were refined through further research. An electronics box was added for the Radar.

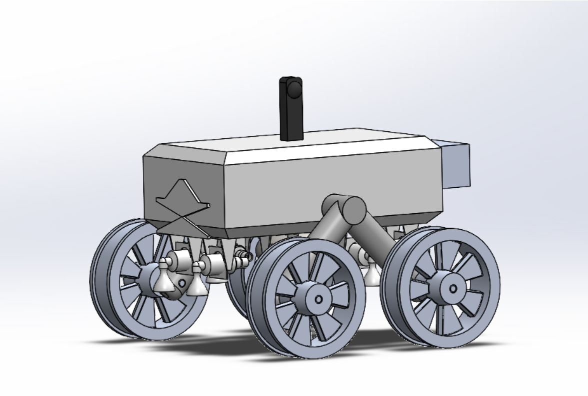


Figure 2.4 - Iteration 3 CAD Model

Iteration 4: Refinement

The final iteration of the rover was just refining the current features. Treads were added to the wheels to allow the rover to operate in the sandy terrain of the moon. The spectrometer was also integrated into an extension style system similar to the legs, so that it would be housed in the body during launch, both for space constraints and protection, but then extended to a workable position during descent to the lunar surface. Figure 2.5 shows the finalized CAD model.

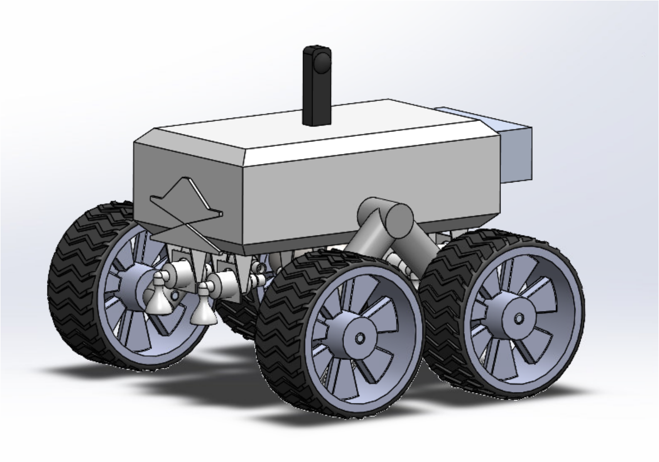


Figure 2.5 - Iteration 4 CAD Model

2.3 Evolution of Payload and Science Instrumentation

Iteration 1: Brainstorming Ideas

For the science payload, a multitude of different instruments were taken into consideration. At first, a Neutron Spectrometer and an Infrared Spectrometer were considered along with a Ground Penetrating Radar. Then, some thermal methods were also considered for the payload. Later, a navigational camera was discussed for the rover. Further information was needed regarding all the brainstormed methods before choosing the final scientific instruments.

Iteration 2: Selection of Scientific Instruments

The mission's main scientific objective was to map the water-ice on the south polar region of the Moon. So, a neutron spectrometer was the best choice because they have been used in many missions before for this purpose. Infrared spectrometers are basically used to determine the chemical functional group present in any compound, which would have been helpful if the mission's objective was to find the impurities present in the lunar water/ice. The neutron spectrometer has been previously used in many studies for the detection of water on the Moon and Mars by NASA, proving it to be more useful for this purpose than Infrared Spectrometers.

Due to the limited information available, thermal methods were not a good pick for the mission's payload. A Ground Penetrating Radar was also part of this mission's payload.

Not wanting to rely only on the Neutron Spectrometer's data for mapping the depth distribution of water, the RIMFAX instrument was chosen for this mission with the purpose of scanning underneath the lunar surface to search for any water or ice reservoirs and providing high-resolution data of its distribution. The choice for a navigational camera was still to be made.

Iteration 3: Finalizing the Scientific Instruments for Payload

An infrared camera was chosen by the science team for the rover's navigation and to take photos of the lunar surface to send them back to Earth for closer inspection. An infrared camera such as NavCam was selected because of the execution of the mission in the shadowed regions of the Moon. As this type of camera can translate the heat signatures of objects in colors, it was the best instrument to add in the payload for the rover's navigation.

With the selection of the NavCam, the science team finalized the payload for the mission. Staying within the given budget and the mass and volume constraints, the mission's final payload was decided to include a Neutron Spectrometer System to detect the water, a Ground Penetrating Radar to search for underground water-ice, and an Infrared Camera for the navigation of the rover and to take images of the surroundings.

3. Descent Maneuver and Vehicle Design

3.1 Selection, Design, and Verification

3.1.1. System Overview

The lunar lander (also referenced as a “rover” or “vehicle”), has a total mass of 159.34 kg and an encompassed volume of 732 x 439 x 693 mm when in the “stowed” position, and a volume of 892 x 565 x 693 mm when in the “extended” position. The material volume used is 0.036 m^3.

The vehicle is designed to be compact and fit within the volume constraint of 60.1 cm x 71.1 cm x 96.5 cm when being transported to the moon, but utilize more space once on the lunar surface. It consists of a main body made out of 6061 Aluminum (Al) to provide sufficient strength and protection for the scientific components. Within the body (in the stowed position) lies 33 Lithium Thionyl Chloride (Li-SOCl2) batteries, the RIMFAX Radar electronic box, the spectrometer housing, the spectrometer data processing module, the spectrometer sensor, the motor, and the communications instruments. Attached to the body are legs, also made of 6061 Aluminum alloy, which raise the body up in order to give it more clearance to the ground. One set of two legs is one part, and there is one attached to either side of the rover. Attached to the legs is an axle, four total, where each has a wheel attached so that they may freely rotate. The center of the wheels are made of 6061 Aluminum Alloy, and the treads on the outside of the wheel are made of Silicon Rubber in order to provide traction. On the bottom of the main body are the eight MRE-15 monopropellant thrusters, and the propellant tank. On the front of the rover is the RIMFAX Radar, and when the rover is in full operation (on the lunar surface), the housing for the spectrometer extends out 320 mm from the back side of the rover to expose the spectrometer sensor. When the rover is in stowed condition the housing extends 90 mm. On the top of the main body sits the infrared 360 camera for navigation and data collection. Figure 3.1 shows the CAD model of the completed rover.

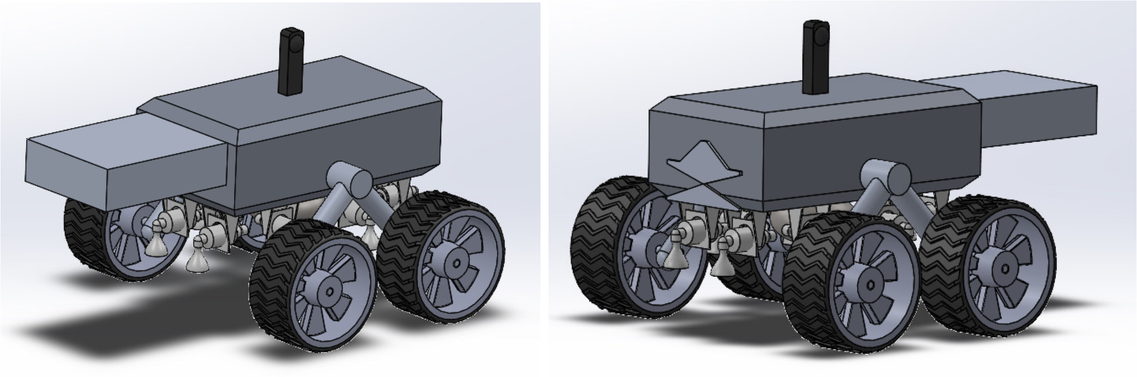


Figure 3.1 - Vehicle Assembly Model CAD

The moon's thin atmosphere creates negligible heat generation and drag on the vehicle upon descent. Since a heat shield was not necessary, no separate landing vehicle was created, and instead the landing subsystem was integrated directly on the rover. Additionally, a parachute was not needed to slow the vehicle's descent. The target landing location is Shoemaker Crater, which has a PSR of approximately 1080 km^2, which takes up the majority of the crater. It is located between 27-63.5° longitude and (-88.6)-(-87.4°) latitude.

The vehicle descent starts at an altitude of 10km above the lunar datum. Shoemaker crater has a depth of approximately 4 km below the lunar datum [6]. The vehicle starts at 10 km with an orbital velocity of 1675.20 m/s, or 4.82 m/s relative to the surface of the moon (x-direction). The vehicle starts with negligible velocity towards the surface of the moon at this point, (-y-direction), and is only under the force of the moon's gravity. The total descent and landing takes 544 seconds and is broken into two parts: Stage 1 ("Alignment/Deceleration") and Stage 2 ("Vertical Descent"). Eight MRE-15 monopropellant thrusters, which provide a maximum of 86N of thrust each, act as both attitude control and deceleration. During stage 1 the rover will descend to the lunar datum at an entry angle of 75°, decelerating until the vehicle has a velocity of 0 m/s in the x-direction and a velocity of 51.51 m/s toward the surface of the moon. Time until landing at this point is 155 seconds. Stage 2, "Vertical Descent", decelerates the vehicle as it moves directly toward the crater's surface until it approaches the surface with a <1 m/s velocity. Figure 3.2 shows the vehicle's descent.

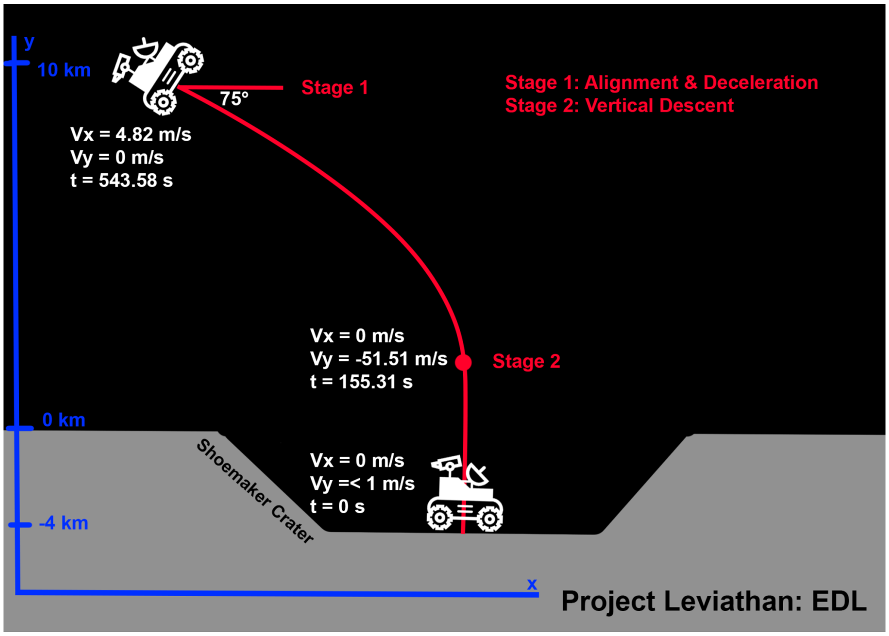


Figure 3.2 - Vehicle EDL

3.1.2. Subsystem Overview

The main body was chosen to be made of 6061 Aluminum (Al) due to it's reliable strength while also keeping the vehicle within the mass constraint of 180 kg. The material chosen has an elastic modulus of $6.9\text{x}10^{10}$ N/m^2, a tensile strength of $1.24\text{x}10^{8}$ N/m^2 [7], and a mass density of 2700 kg/m^3 [8]. The walls vary in thickness, with thicknesses including 35 mm, 25 mm, and 20 mm [9]. This was done to maximize space within the body but keep the walls as thick as possible in order to prevent damage to the internal elements. The body is a simple box shape with 25 mm chamfers on the corners in order to prevent damage to the corner.

The legs are made from aluminum tubing for both its strength, rigidity, and density. The legs consist of two rods connected together at a ninety degree angle at the joint with a third, smaller rod that is 80 mm long. The two rods are identical with a length of 221.53 mm. The diameter of all rods is 60 mm. The wheels and axles are made out of 6061 Aluminium Alloy, which has its properties described above [10]. Each wheel has seven spokes with fillets on their edges to reduce drag and distribute stress over a larger surface area. Each wheel has a diameter of 254 mm and a thickness of 101.6 mm.

Since the body of the rover is held above the ground to avoid damage from rocks and other debris, the rover has a slightly high center of gravity, approximately 319 mm off of the ground. However, due to the spacing of the wheels, the rover can climb hills at a max of 41°, assuming that the rover's wheels would experience no slippage. However, for safety purposes, the vehicle will be programmed to avoid steep inclines and declines and will stay within the basin of Shoemaker crater.

Four motors are used to control the rover's wheels. Electric motors developed by GE Industrial Motors are used [11]. These motors have a mass of .23 kg each and can provide between up to 5000 HP per motor [12]. Additional wiring and controls for an electrical system were not explored further in depth. The mission utilizes a computer to control the vehicle's path, using current input from the scientific instruments to determine which directions appear most promising to finding water-ice, as well as the camera and radar providing hazard avoidance. The rover will steer like a tank, or by varying the speed of the wheels on one side. This was chosen because with the design the wheels are not able to pivot, which also simplifies the internal mechanisms. Because they cannot pivot, changing the speeds of the wheels is the best option for this design.

The scientific instruments housed in and on the rover include a Neutron Spectroscopy System (NSS), a Ground Penetrating Radar (GPR), and an Infrared Navigational Camera (Navcam). The NSS has a sensor module that measures 21.3 x 32.1 x 6.8 cm and a data processing module with dimensions of 13.9 x 18.0 x 3.0 cm. It's total mass is 3.2 kg. This instrument uses approximately 1.5 watts of power. A housing encompasses the NSS, and extends out from the body when transitioning from the stowed position to the operating position. This is done by two ball bearing side mount slides, similar to those seen in drawers. It is powered by one of the motors. The GPR consists of an electronics box, 19.6 x 12 x 6.6 ccm, and an antenna, 12 x 9.8 x 0.66 cm, and has a mass of 3 kg. This instrument requires between 5-10 watts of power. The Navcam measures 20 x 20 x 10 cm and weighs 6.2 kg. It requires 2.2 watts of power. Antennas used are retractable to fit inside the body of the rover during launch and landing to limit possible damage. More details on the spectrometer and radar can be found in section 4 of the PDR.

As previously discussed in 3.1.1, the vehicle's descent is controlled by eight MRE-15 monopropellant thrusters developed by Northrop Grumman [13]. They each have a mass of 1.1

kg and a size of 119mm x 318 mm. The thrusters have a gimbal with a total rotational range of travel of +/-36°. They use hydrazine as their propellant. Each thruster provides a thrust of 86N at maximum operating pressure of 400 psia. A rolling diaphragm with a volume of 1327.35 cm^3 (81 in^3) [14], developed by Moog, is used to house the hydrazine [15]. The thrusters remain attached to the vehicle throughout the whole descending process and even after landing. This is to control the landing acceleration but also to avoid the risk that removing the thrusters could potentially land in the vehicle's path and impede motion or damage the rover legs during release. When the rover is on a flat surface with the legs unfolded, the thrusters remain 126.32 mm (~5 in) above the surface.

Due to the research being conducted in a permanently shadowed region (PSR), the rover cannot rely on solar energy for power. Instead, the rover will be powered using non-rechargeable lithium ion batteries [16]. With each battery providing 68.4 Wh each, the rover will use approximately 36 batteries, although additional will be included as backups. Each battery weighs just 0.053 kg each. The diameter of one battery is 33.5 mm and the height is 61.5 mm [17]. The batteries will be stored inside the body of the rover. One benefit of conducting research in the PSR is the lack of need for a thermal control system to protect the rover against extremely high temperatures. In depth research was not conducted on shielding from extremely low temperatures.

3.1.3. Dimensioned CAD Drawing of Entire Assembly

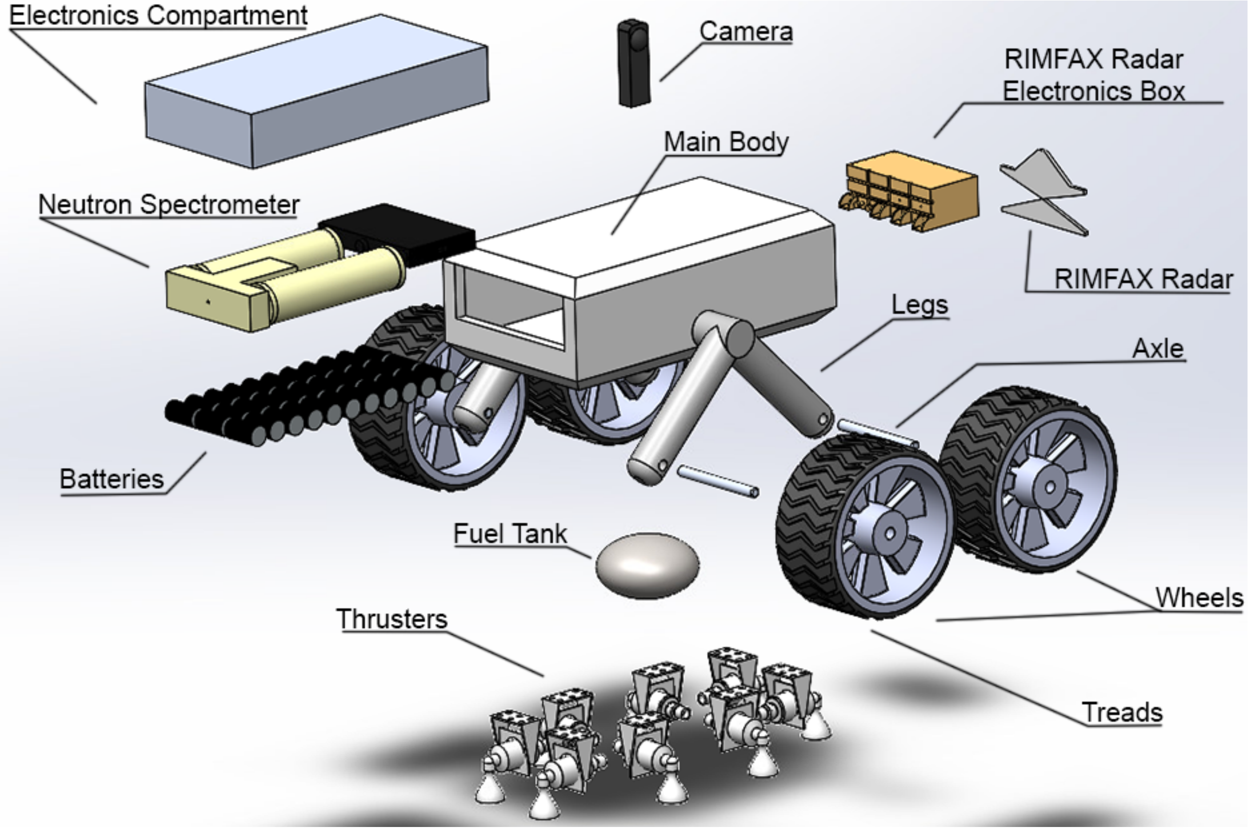


Figure 3.3 - Vehicle Exploded View

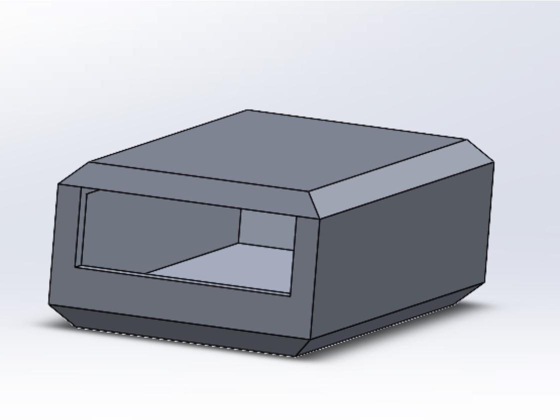


Figure 3.4 - Main Housing/Body

Figure 3.5 - Wheels

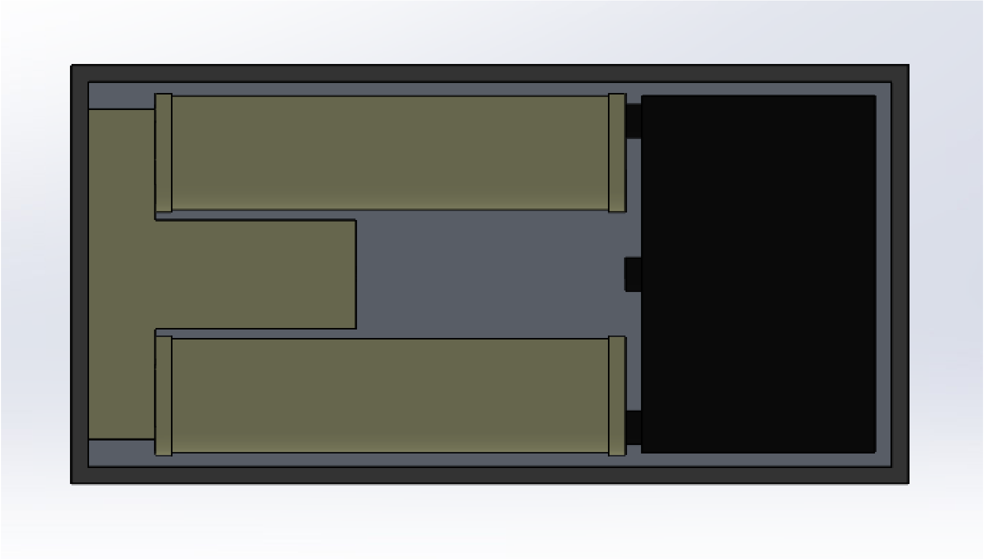


Figure 3.6 - Vehicle Compacted, Internal Components

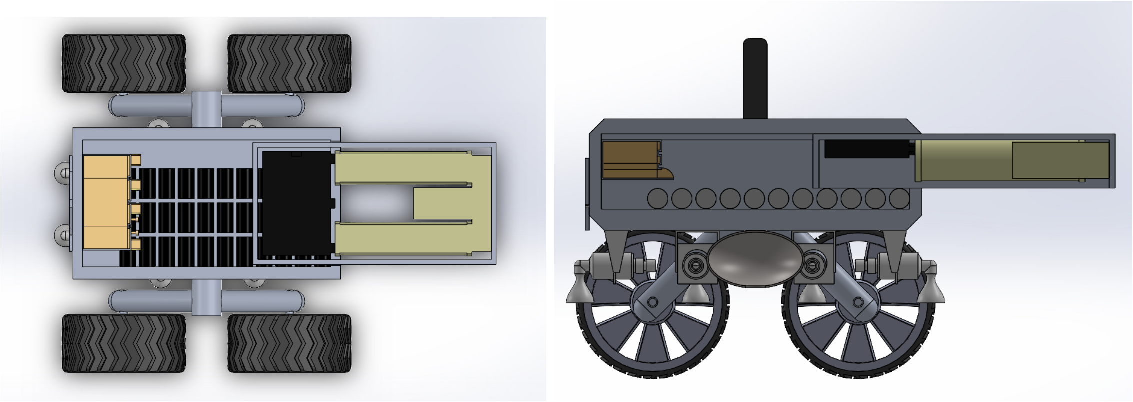


Figure 3.7 - Top Down Section View *Figure 3.8 - Side Section View*

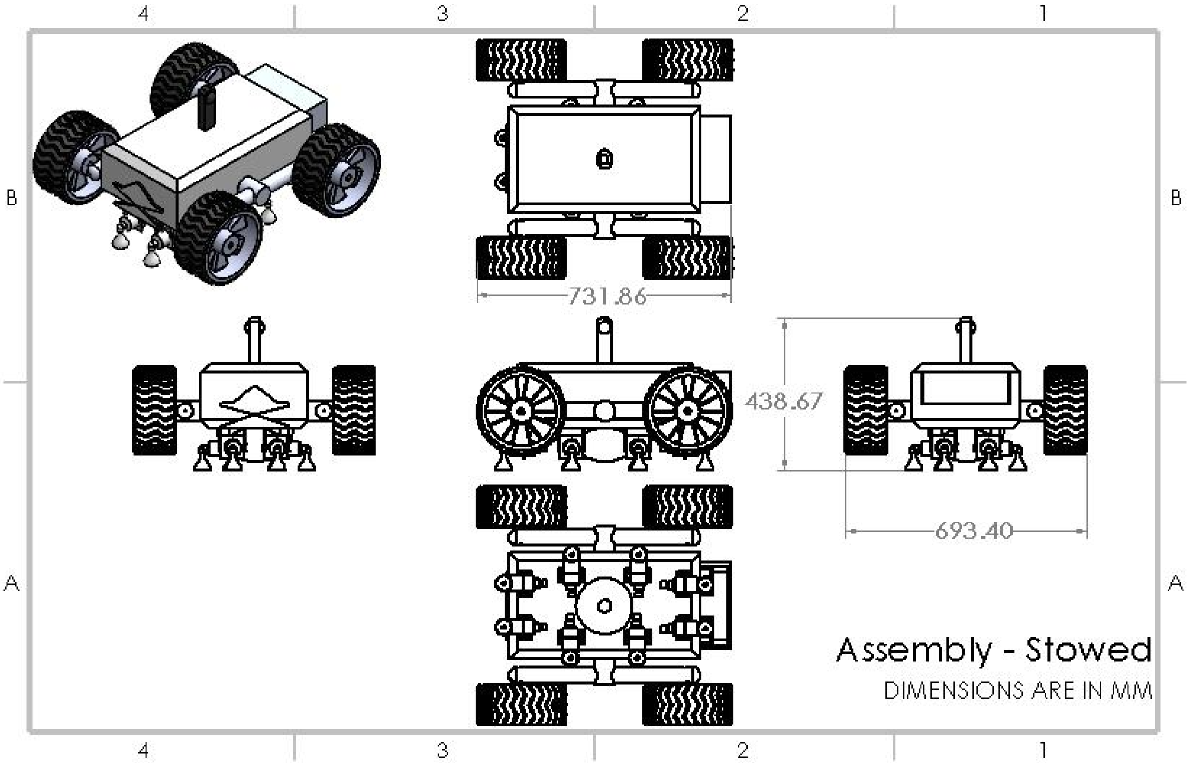
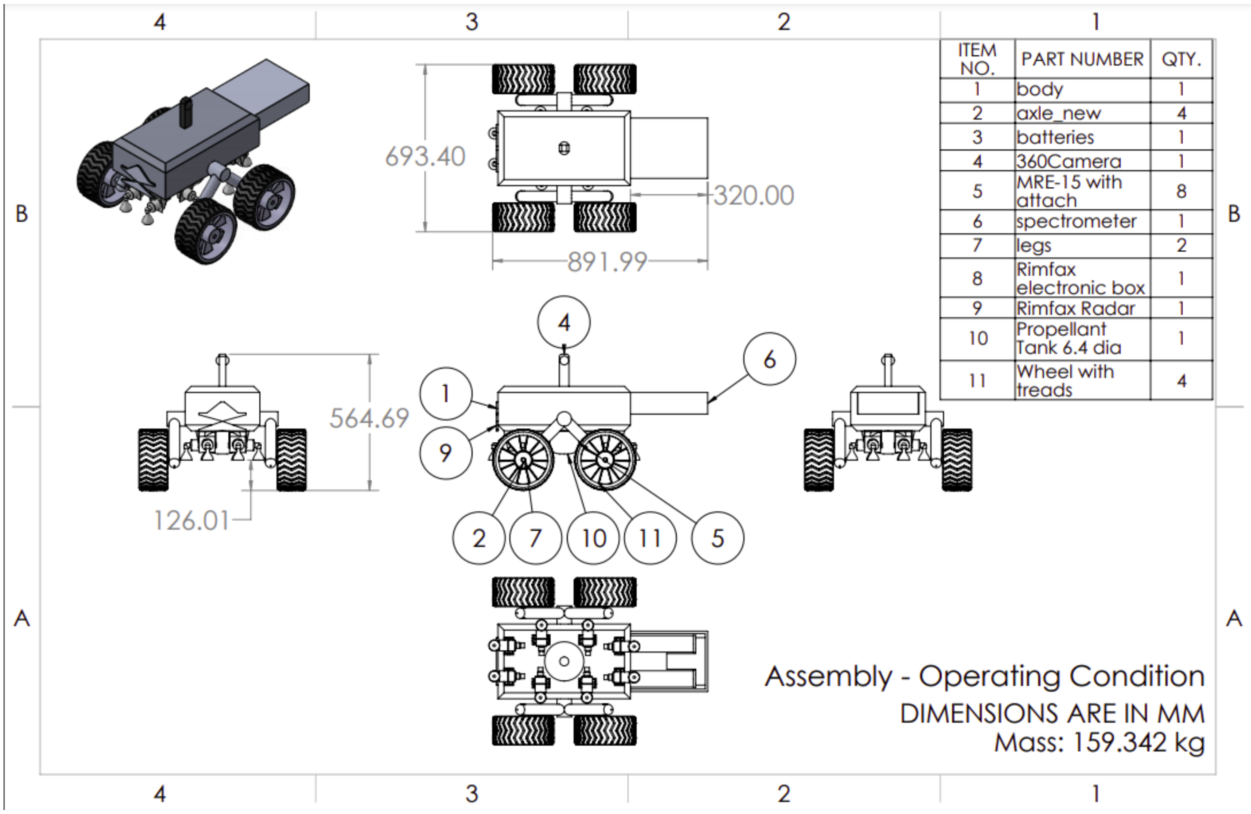


Figure 3.9 - Dimension Drawing, Assembly "Stowed"



ITEM NO.	PART NUMBER	QTY.
1	body	1
2	axle_new	4
3	batteries	1
4	360Camera	1
5	MRE-15 with attach	8
6	spectrometer	1
7	legs	2
8	Rimfax electronic box	1
9	Rimfax Radar	1
10	Propellant Tank 6.4 dia	1
11	Wheel with treads	4

Figure 3.10 - Dimension Drawing, Assembly "Operating"

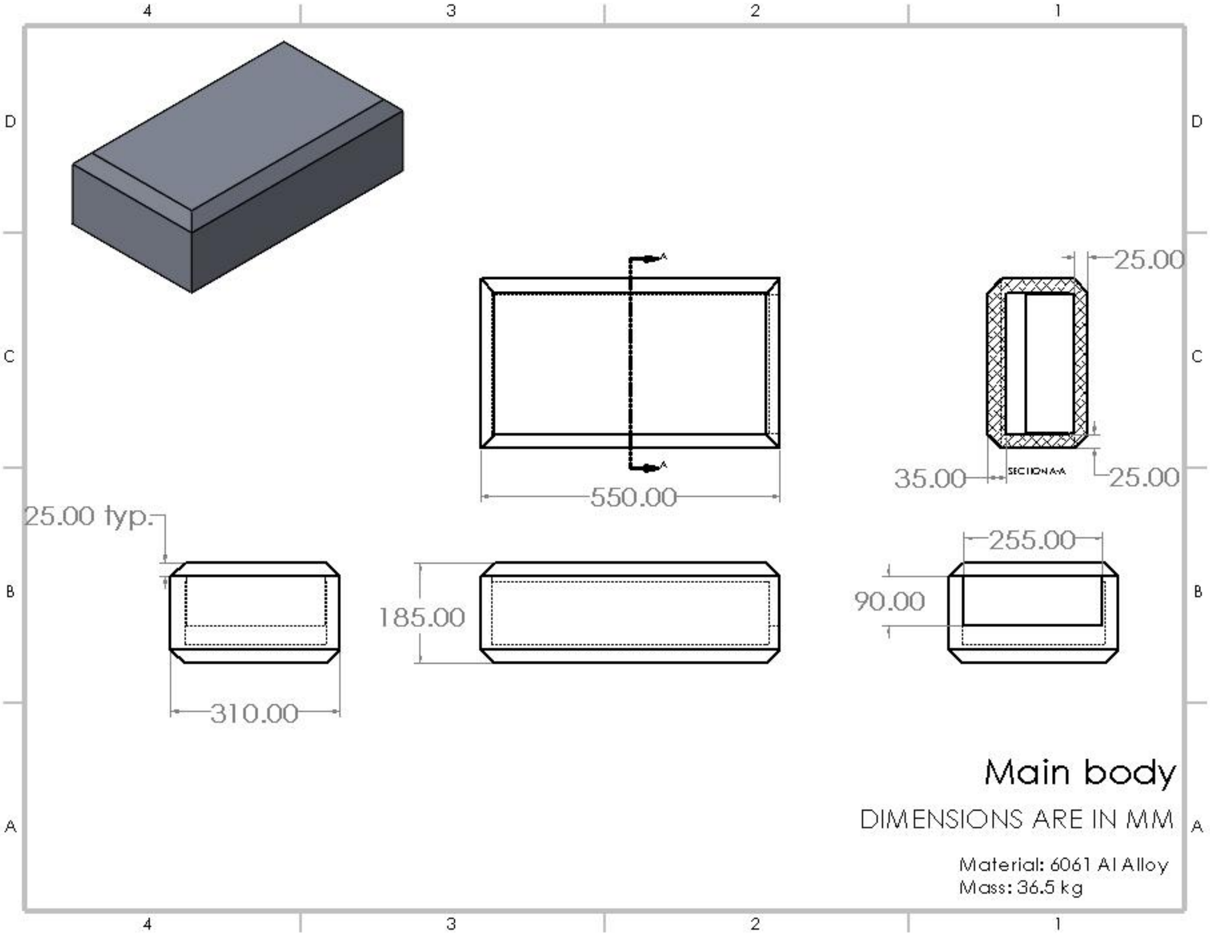


Figure 3.11 - Dimension Drawing, Main Body

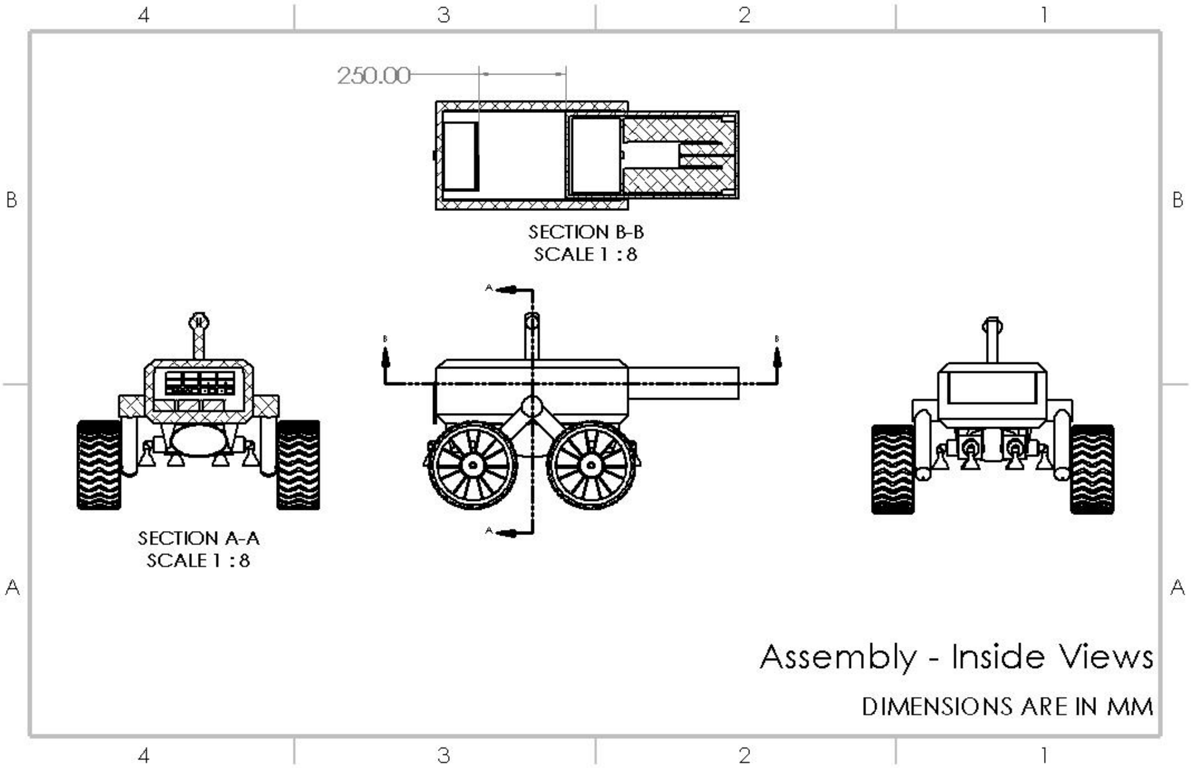


Figure 3.12 - Assembly Cutaway View

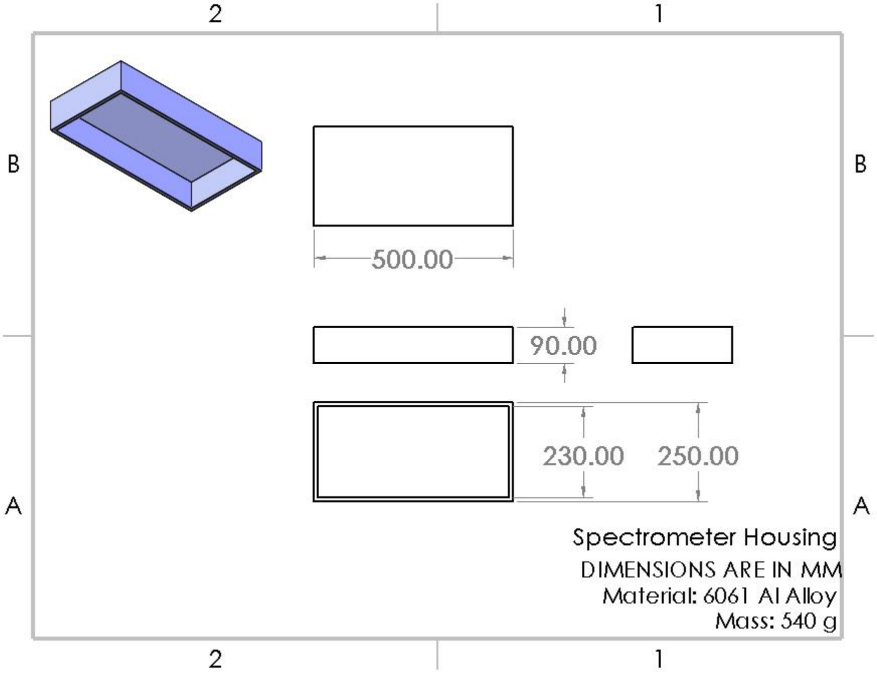


Figure 3.13 - Spectrometer Housing

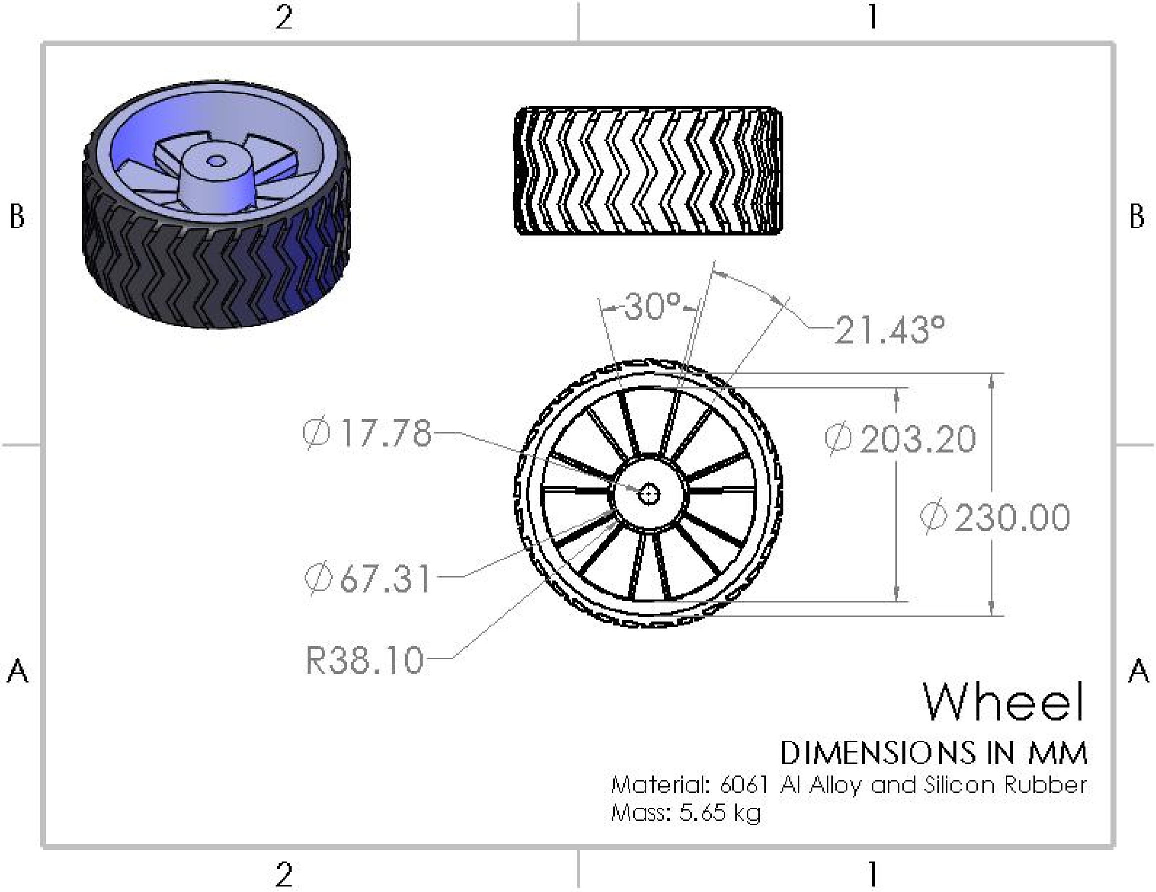


Figure 3.14 - Wheels

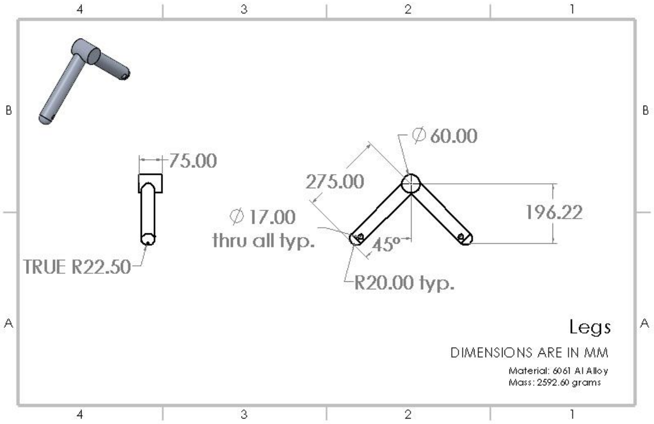


Figure 3.15 - Legs

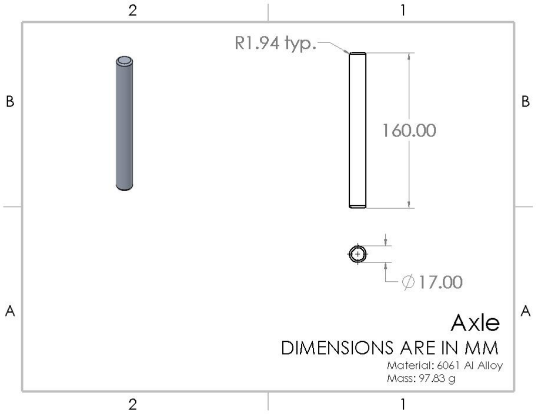


Figure 3.16 - Axle

Solidworks was utilized to create the CAD models and drawings [18].

3.1.4. Manufacturing and Integration Plans

The custom pieces of the rover include the main body/housing, the legs, and the attachments for certain scientific instruments. The main body will be made out of aluminum sheet that will be cut and welded into the desired shape. To get a high quality weld that can survive the moon's environment, this work will need to be outsourced to a professional shop. The legs will be manufactured similarly, by outsourcing the build, although they will be made with aluminum tubing. The wheels will be purchased in their final form, and just need to be attached via screws to the legs.The legs will then fold to fit inside the transport rocket. Similarly, the custom attachments for all instruments and for the thrusters will be welded, but with additional validation steps taken to ensure that at all points of the welding process the instruments still fit within the part and can be adequately secured to the vehicle.

For consistency and each of manufacturing, the same length screws were used for all attachments when possible. This also limits the cost of manufacturing as the hardware can be bought in bulk. For the attachments for each scientific instrument (spectrometer, radar, camera, etc.), see section 4.1.4.

The thrusters and propellant tank are secured on the bottom of the rover. The thrusters are spaced along the perimeter of the vehicle's main body to distribute the load, as well as providing ample opportunity for attitude control. The propellant tank then fits in the center of the vehicle, below the housing. In order for these components to not impact with the moon at the end of the rover's landing, the legs will unfold to their extended position during descent to ensure that the thrusters are no longer the lowest part of the body.

3.1.5. Verification and Validation Plans

Since the majority of the rover is made using aluminum, steps will be done to ensure that the aluminum that is purchased is strong enough to survive the forces the rover will experience. A section of aluminum tubing that is used for the rover legs will be put under a tensile test to verify the material's strength. The aluminum sheets for the housing of the rover will undergo radiation and temperature tests to confirm that the material will protect the batteries and other internal components. To verify that the rover is being manufactured properly, regular measurement checks will be conducted to ensure that the individual components of the rover, as well as the overall assembly, all fall within the tolerance limits. All codes developed for the rover's mission will be run through simulations before being approved. Verification testing is further explored in Table 3.1.

Table 3.1 - Verification

ID	System	Place	Specs.
VE-1A	Materials - Aluminum Sheet	Manufacturing Lab	Tensile test - Before manufacturing of the vehicle begins, the aluminum will undergo multiple tensile tests to confirm the strength of the material
VE-1B	Materials - Aluminum Sheet	Manufacturing Lab	Compression test - Before manufacturing of the vehicle begins, the aluminum will undergo multiple tensile tests to confirm the strength of the material
VE-2A	Materials -	Manufacturing	Tensile Test - Before manufacturing of the

	Aluminum Tube	Lab	vehicle begins, the aluminum will undergo multiple tensile tests to confirm the strength of the material
VE-2B	Materials - Aluminum Tube	Manufacturing Lab	Compression test - Before manufacturing of the vehicle begins, the aluminum will undergo multiple tensile tests to confirm the strength of the material
VE-3	Measurements - Body	Manufacturing Lab	All parts should match engineering drawings within a tolerance of ±1 mm / ±0.1°
VE-4	Measurements - Legs	Manufacturing Lab	All parts should match engineering drawings within a tolerance of ±1 mm / ±0.1°
VE-5	Measurements - Wheels	Manufacturing Lab	All parts should match engineering drawings within a tolerance of ±1 mm / ±0.1°
VE-6	Computer	Computer lab	Simulations - Computer simulations will be run at key stages of development as well as on the final vehicle to ensure that all potential bugs are found and that the program runs as expected

Once the rover is completed, computer checks will be run to certify that the code is still working correctly and that all the scientific instruments are performing as they should. To test that the rover will work on the rocky conditions expected on the moon, the completed rover will be transported to an environment similar to the moons, specifically the Mojave desert, to test the rover's ability to drive and function on rocky terrain. Also the thermal environment and radiation will be replicated in scientific facilities. Additionally, the radio and antennas used for communicating with the orbiter will be tested at a greater distance than expected to perform under to ensure that the scientific data is able to get back to Earth. Validation testing is further explored in Table 3.2.

Table 3.2 - Validation

ID	System	Place	Specs.
VA-1	Manufacturing - Weldment	Manufacturing Lab	Nick Break Testing - A sample of aluminum sheet purchased from the same batch as used for vehicle manufacturing shall be welded alongside the rover and used for a nick break test to test for weld discontinuities and to test if such discontinuities could withstand the forces the rover will experience.
VA-2	Measurements - Body	Manufacturing Lab	All parts should match engineering drawings within a tolerance of ±1 mm / ±0.1°
VA-3	Measurements - Legs	Manufacturing Lab	All parts should match engineering drawings within a tolerance of ±1 mm / ±0.1°
VA-4	Measurements - Instrument Placement	Manufacturing Lab	All parts should match engineering drawings within a tolerance of ±1 mm / ±0.1°
VA-5	Vibration	Johnson Space Center (JSC) - General Vibration Laboratory (GVL) [19]	JSC vibration labs will be used to do a vibe test on the propulsion system
VA-6	Vibration	Johnson Space Center (JSC) - Hazardous Vibration Test Stand [20]	JSC vibration labs will be used to simulate launch-induced vibration as well as the structural dynamics of the vehicle

VA-7	Communication	Mojave Desert, California	The radio and antennas will be paired with those aboard the orbiter and tested at a distance of minimum 150 km
VA-8	Movement	Mojave Desert, California	To verify that the rover can navigate the moon’s terrain, the rover must be able to autonomously travel at a speed of no less than 3 m/s when in motion without getting stuck or exerting excess power
VA-9	Movement/ Navigation	Mojave Desert, California	The rover shall be able to navigate autonomously around obstacles and determine the best path to take given feedback from both the hazard avoidance system and scientific data
VA-10	Radiation	Radiation Effects Facility - Goddard Space Flight Center [21]	All equipment shall continue to perform as expected when exposed to 1000 microsieverts per day (24 hr) over a 1 week (168 hr) period to simulate the average radiation experienced on the moon
VA-11	Temperature	Johnson Space Center (JSC) - 15-Foot Chamber [22]	The rover shall be able maintain all performance abilities at -300°F (89K, -184°C) for 1 week (168 hr).

3.1.6. FMEA and Risk Mitigation

It is important to look at all possible failures, risks, and errors that could potentially occur to or within the payload for the success of any mission. To do this, the team has considered the main risks which could affect the success of the mission. They are the following:

- Rover stalling/flipping
- Debris contamination
- Thermal control
- Radiation
- Worldwide supply chain issues
- And transport of flammable materials

Each potential risk to the payload of the mission was given a ranking based both on likelihood and consequences (LxC trend). Additionally, the approach taken by the team to mitigate the risk (legend) can be found in Table 3.3 below.

Table 3.3 - Risk Types

Criticality	**Risk Mitigation**	**L x C Trend**	**Approach**
High	Change approaches to problem	Decreasing (improving)	M- Mitigate
Medium	Manage problem and brainstorm alternative process	Increasing (Worsening)	W- Watch
Low	Monitor	Unchanged	A- Accept
			R- Research

There are four main approaches to deal with risks: Mitigate, Watch, Accept, Research. An "Accept" approach is when a certain level of risk is accepted when it is within the tolerance of the program. A "Mitigate" approach demands actions that will address the problem and create solutions to decrease consequences. The "Watch" approach involves the observation of the issue and the creation of novel plans if the situation worsens. The "Research" approach is a detailed effort to better understand the risk and brainstorm ideas on how to reduce uncertainties.

The most important risks associated with lunar operation of the rover are presented in Table 3.4 with an accompanying risk matrix in Figure 3.17. The team will perform careful monitoring in order to help mitigate risks.

Table 3.4 - Mission Risks

Rank	**Risk Title**	**Trend**	**Approach**	**Likelihood**	**Consequence**
1	Rover stalls or flips over on the surface of the moon	unchanged	Mitigate	2	5
2	Debris slips inside rover due to inadequate sealing, damaging essential hardware	unchanged	Watch	1	4
3	Extreme temperatures damage rover exterior exposing internal hardware to damage	unchanged	Watch	1	2
4	Radiation degrades or destroys electronics within rover	unchanged	Watch	1	2
5	Material costs exceed budget, due to worldwide supply chain issues	unchanged	Watch	4	3
6	Spectrometer sleeve may provide inadequate protection while in the open position	unchanged	Watch	2	5

7	Spectrometer sleeve could malfunction and not move due to electronic error	unchanged	Mitigate	2	5
8	Thrusters are connected to a fuel tank, which contains flammable material	unchanged	Mitigate	2	5

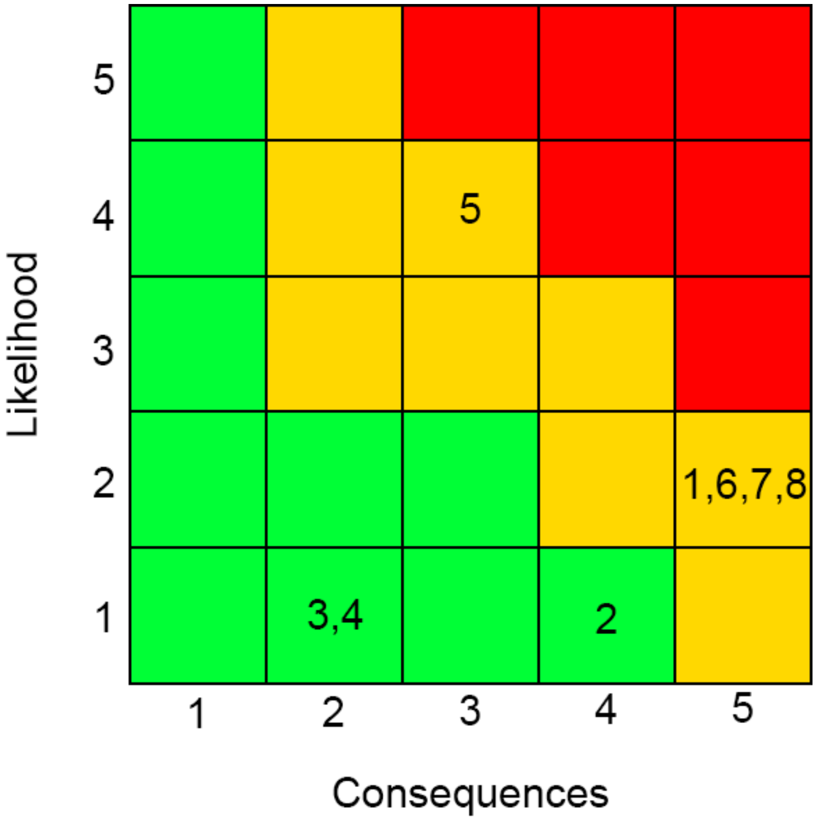


Figure 3.17 - Risk Matrix

The most essential thing to do to mitigate the above risks is to perform many tests at multiple time points. Many of the risks identified are due to the fact that the Moon’s environment is harsh. Debris, temperature, and radiation are big factors. That said, testing in an accurate environment is essential. While these risks will be kept in mind during integration of the rover, it will not be until environmental testing that these risks can be accurately addressed. Potential mitigation of these could include better sealant, dust mitigation technologies, and perhaps a safer electronics housing unit. Risks that involve the mechanical operation of the vehicle, such as flipping or fuel tank damage, will have to be addressed once testing begins. Potential mitigations to these problems could include wheel mechanics redesign, a repositioning mechanism, and a change in location of the fuel tank.

The supply chain issue is an issue that could affect manufacturing, but is a problem that is out of individual control. Once manufacturing grows near, this risk will be readdressed. If materials are still hard to find, the best case scenario would be to look over the rover's materials again. Worst case scenario, the timeline of the mission will have to be changed.

3.1.7. Performance Characteristics and Predictions

Once in orbit of the Moon, it is expected that the rover will drop from the carrier orbiter and begin descent toward the surface. Monopropellant boosters on the rover allow for a slower and cleaner landing. The boosters will create enough upward acceleration to allow the rover to have a low impact velocity.

Once on the surface, the rover will begin scientific studies. The body of the rover was designed to protect the scientific instruments. The thick main body protects the instruments from potential debris and radiation. The wheels were designed to include suspension to allow for easy rolling across the rough Moon surface. Additionally, the wheels have treads which creates more traction and will prevent the rover from potential hazards such as tipping over. Due to its fragile nature and importance to the mission, extra protection for the neutron spectrometer was implemented by fitting it into a housing storage within the rover. Once in use, the neutron spectrometer will slide outwards. To summarize, the body itself was designed to protect against the environmental hazards of the Moon.

Since the Moon has no atmosphere, there are no weather-related obstacles to address.

3.1.8. Confidence and Maturity of Design

The design uses a simple booster system to land on the Moon. Calculations have been performed to determine how much thrust the rover needs in order to land safely and with minimal impact on the moon surface. The rover consists of parts made of 6061 Aluminum (Al), which has a tensile strength of 1.24×10^8 N/m^2. This material is known for its high strength and corrosion resistance, and is used in structural and motor vehicle applications, which is highly applicable to this rover.

Detailed verification and validation testing will be conducted of all materials, including various tensile, temperature, vibration, radiation, and measurements testing. Regular measurement checks will be conducted during manufacturing to ensure that values are within tolerance limits. Computer systems, including code, and scientific instruments will also undergo regular testing to make sure that all systems are working properly.

Risks and mitigation have been thought out to ensure the least likelihood of failure once the rover lands on the moon. A steepness calculation has been done to validate that the rover can handle the terrain it will travel on the moon without flipping over/failing to travel further. A power analysis has been conducted to determine how much power is necessary for all of the instruments and motors on the rover, and appropriate batteries including extra are included in the body to ensure the rover will last the duration of the mission. Utilizing the Shoemaker Crater as a landing zone will help protect the rover's landing, as there will not be a lot of bumps and holes.

Once on the surface, utilizing a dual-instrument approach by using a neutron spectrometer and a radar will help strengthen the data that will be collected. The rover approach itself was fit for these instruments, such that they will be closer to the ground and cover a more intricate path. The shell and casings for the instruments were designed with safety in mind, keeping them safe of debris and other hazards. The original design did not include many aspects for risk mitigation, but a careful analysis was thought out and impacted further iterations of the design, such as lifting the bottom of the thrusters higher off the ground to offer more clearance, and adding treads to the wheels to prevent slipping/getting stuck. This design has been thoroughly thought out, taking into account multiple aspects of traversing the lunar surface. The confidence that this design will succeed in completing the mission objective is high.

3.2 Recovery/Redundancy System

First, almost every scientific instrument will have a housing developed for it, in order to protect against any unknown factors such as loose regolith and any other intense storms that the rover may encounter. The main body's wall will vary in thickness; 35mm, 25mm, and 20mm. There had to be enough space on the inside of the body for all the instruments/parts, but also have the walls be thick enough to prevent damage to the interior. There will also be extra batteries kept inside the rover past its energy requirements, in case somehow the main batteries get damaged or broken. Each battery has a voltage of 3.6 volts, so by having 36 batteries in total there will be 129.6 volts available, not counting the extra batteries. Despite the batteries having a significantly higher voltage power than many other primary batteries, the rover will be sending a replacement for each battery (72 total) which adds up to 259.2 total volts. In preparation for possible damage to an antenna, the antennas will be able to be expanded into and out of the rover, so that the antennas will be out of sight and not be able to be harmed during landing and other hazardous situations. Also an extra wheel will be produced to ensure that if one breaks, there will be another ready to go. Our wheels will be manufactured to have treads made of silicon rubber in order to provide traction, and prevent the rover from tipping or slipping. The hazard avoidance system will be vital in detecting threatening objects and/or situations to the rover. All scientific calculations, especially FMEA, will use a safety factor of at least 1.5.

3.3 Payload Integration

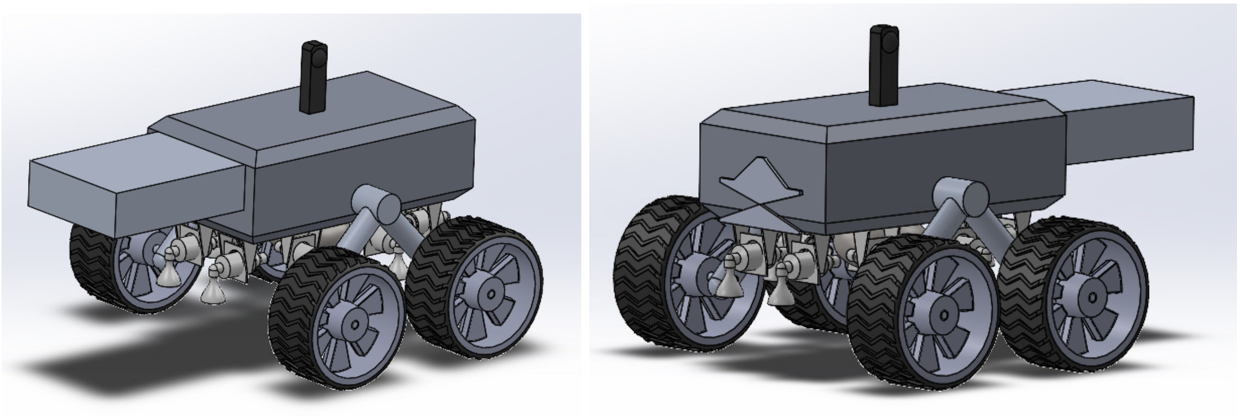


Figure 3.1 - Vehicle Assembly Model CAD (repeated)

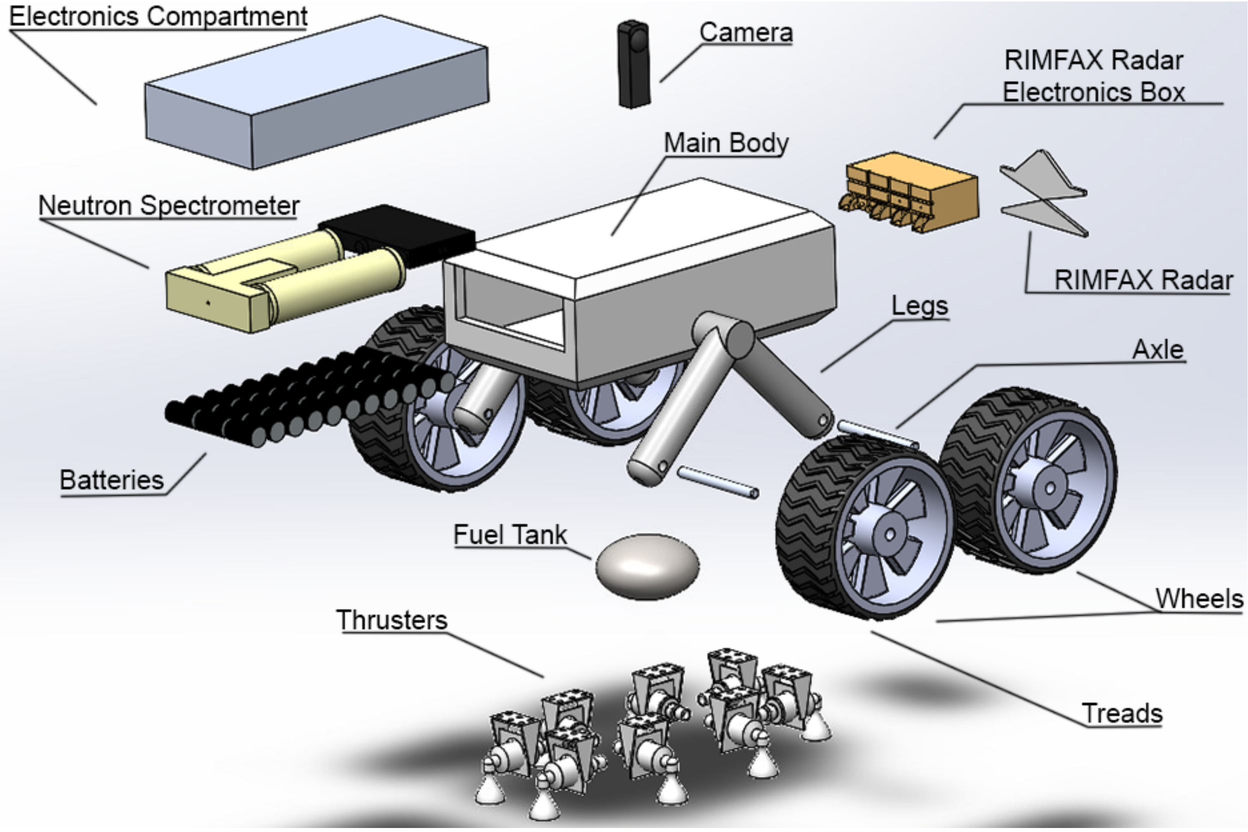


Figure 3.3 - Vehicle Exploded View (repeated)

Pictured in Figure 3.3 is an expanded view of the rover. Starting from the bottom up, there are 8 thrusters that are connected to the propellant tank, which are then screwed firmly to the bottom of the main body. The thrusters will be placed on the perimeter of the main body with the fuel tank firmly in between them in the middle, to ensure that the load is distributed in order to give the rover as smooth of a control as possible. The wheels of the rover are attached to the legs by an axle (4 in total) which is connected to the leg of the rover that is welded to the side of the main body. All welding done to the main body and legs will be done by hired members from the American Welding Society. Going inside the main body of the rover are the 33 Lithium Thionyl Chloride (Li-SOCl2) batteries, the RIMFAX Radar electronic box, the spectrometer housing, the spectrometer data processing module, the spectrometer sensor, the motor, and the communications instruments. The ground penetrating radar is positioned so that when the rover is on the moon and in full operation, it is in the front in order to detect water-ice. The GPR is made up of an electronics compartment and a retractable antenna to prevent damage. In full operation, the housing of the spectrometer (which is inside the main body), extends 320mm outwards at the back of the main body in order to scan for and collect data. Since the spectrometer is extremely important for the success of this mission, when the rover is in stowed condition the spectrometer housing only extends 90mm out, allowing the spectrometer itself to be protected from any potential hazards. This motion will be done in a similar fashion to how a drawer opens, with two ball bearing side mount slides, which is powered by one of the motors. On top of the rover sits the infrared 360 degree NavCam camera, which aids the rover in navigation and data collecting.

4. Payload Design and Science Instrumentation

4.1 Selection, Design, and Verification

4.1.1 System Overview

There will be 4 main internal systems onboard the rover: the Scientific Payload (1), Command and Data Processing (2), Communications (3), Power (4), and Rover Body (5). System 1 will include all the scientific instruments onboard the rover, i.e, the Ground Penetrating Radar (GPR), Neutron Spectroscopy System (NSS), and Infrared Navigational Camera (Navcam). It will pass on the raw data it collects to system 2. System 2 will consist of a small onboard computer, a BAE RAD 750 Processor, with core clock of 110 to 200 MHz, which will process data and communicate with system 3 as well as run programs for systems 1 and 5 [23]. System 2 will additionally regulate system 4 via the distribution of power to all the rover's systems. System 3 will be an X-band Omni Antenna capable of frequencies between 8100 and 8600 megahertz requiring 0.075 Watts which will send data to Earth for interpretation and receive instructions from Earth to pass along to system 2 to give commands to system 1 [24]. System 4 will be a set of 33 LiSOCl2 batteries, with each battery providing 68.4 Wh each. These batteries will supply power to systems 1-3 and 5. System 5 will be composed of four 28V motors which reach up to 100 rpm as well as a Warm Electronics Box (WAE) for heating.

Scientific Payload	Raw Data			
Payload Commands	**Command & Data Processing**	Transmission Protocol		Motor Regulation
Instructions from Earth	Transmission Acknowledgement	**Communications**		
~15 Watts to Payload	5 Watts to Computer	0.075 Watts to Antenna	**Power**	
Temp Control	Temp Control	Temp Control	Temp Control	**Rover**

Figure 4.1 - N^2 chart depicting the relations between payload systems

4.1.2 Subsystem Overview

There are three main components of the rover: data acquisition, data relay, and power supply. The onboard computer is the data relay's main element. It regulates the rover's internal and external systems, i.e, communication between the antenna and science payload, battery functionality, and movement. The power supply is composed of the batteries, which supply power to all the rover's systems. Data acquisition consists of the rover's scientific instruments and a communication antenna. The scientific instruments are a Ground Penetrating Radar (GPR), a Neutron Spectroscopy System (NSS), and a Navigational Camera (Navcam). The NSS is based on the one in use in NASA's VIPER rover [25]. Neutron Spectroscopy operates by measuring the change in energy of a neutron which scatters off of a sample. This can be used to test a wide variety of physical phenomena among which are the atomic compositions of a sample. On the rover, this translates to being able to both detect hydrogen in the lunar regolith and its relative concentration beginning at a very low detection threshold of ~100ppm at a depth of ~1m [26]. This in turn serves to detect and zero in on areas with possible high concentrations of water-ice for the GPR to operate in. The GPR used in the rover is based on *Perseverance*'s RIMFAX system. It will scan the lunar subsurface to a depth of ~10m using radio waves to detect geological features, most importantly, pockets of water-ice [27]. This will help the rover find (a) suitable source(s) of water on the lunar south pole. Due to the lack of light to allow the use of conventional cameras, the rover's Navcam operates in the infrared spectrum. The camera is based on NASA's L-CIRiS, developed for use on the moon [28]. The Navcam will allow safe navigation of the rover across the terrain present in Shoemaker Crater and will allow Earth scientists to plan routes for the rover once it is operational. Once data is collected by the scientific instruments, it is passed on to the computer which processes it and then sends it to the antenna. The antenna then sends the data to Earth and awaits incoming instructions from the Earth scientists.

Table 4.1 - Technical Specifications for the Neutron Spectrometer System [29]

Mass	3.2 kilograms
Power	1.5 Watts
Volume	21 x 32 x 7 centimeters
Sensitivity	~100 parts per million

Table 4.2 - Technical Specifications for the Radar Imager for Mars' Subsurface Experiment [30]

Mass	3 kilograms
Power	5-10 Watts
Volume	19.6 x 12 x 6.6 centimeters
Frequency Range	150-1200 MegaHertz
Vertical Resolution	15-30 centimeters

Table 4.3 - Technical Specifications for the Lunar Compact Infrared Radiometer in Space [31]

Mass	6.5 kilograms
Power	< 9 Watts
Volume	20 x 20 x 10 centimeters
Frequency Range	7.5-13.5 micrometers
Focal Length	4 meters to horizon
Resolution	< 1 centimeter
Image Type	Panoramic

4.1.3 Manufacturing Plan

The scientific payload manufacturing plan is scheduled to last 12 months. As the payload is mainly composed of scientific instruments utilized in other NASA missions, manufacturing will primarily consist in purchasing Commercial-Off-The-Shelf (COTS) instrumentation and the adaptation of previous missions' instruments to the mission's parameters. The primary goal is to purchase every subsystem and have it be delivered to the manufacturing plant by January 2024 leaving up to 4 months per instrument to test and prepare each one of them for the moon's environment, while also leaving 7 month until the manufacturing phase ends in July 2025 for any additional repairs or adjustments needed.

The Technology Readiness Levels (TRL) are a measurement system used to assess how mature a particular technology is. Seeing as the high-TRL heritage instruments purchased will need to be adapted to both fit in the rover and work properly in a new environment, their TRL will drop, needing more testing to bring them back to a proper functionality level. The science personnel will test and adapt the NSS, GPR, Infrared NavCam, and Comms System once they are delivered. The adaptations will include shielding from cold temperatures, manufacturing the body of the rover into a Warm Electronics Box, and the design of new fittings to couple with the rover's chassis and internal computer system. Section 4.2.5 includes information about the testing and calibration of the instruments after manufacturing.

The NSS used on VIPER and the Comms System will be purchased from NASA's Ames Research Center and Lockheed Martin Advanced Technology Center, the RIMFAX GPR system will be purchased from the Norwegian Defence Research Establishment, and the L'CIRIS camera will be purchased from Ball Aerospace and Technology. These manufacturers have been chosen because they own the original parts and designs that achieved high TRL for the missions the instruments were included in, namely *VIPER* and *Perseverance.* The order is scheduled to be placed in December 2022 to give enough for the instruments to be shipped so as to not delay the manufacturing plan scheduled to start in January 2024.

Table 4.4 - Schedule

	Manufacturing Start	1/1/2024	**Manufacturing End**	12/27/2024
		Start	**End**	**Days Worked**
Instrument	**NSS**	January 2 / 2024	April 26 / 2024	84
	GPR	April 29 / 2024	August 30/2024	88
	NavCam	September 2 / 2024	October 30 / 2024	42
	Comms System	November 4 / 2024	December 27 / 2024	38
			Total (Accounting for Holidays)	252

4.1.4 Validation and Verification

Infrared imaging cameras can detect the energy emitted from any object in the infrared range of the electromagnetic spectrum (3-30 microns) and produce images of the radiation. It also translates the heat signatures of objects in colors on scale. Lighter colors show higher temperatures and darker colors show low temperatures or wet areas [32]. Infrared cameras will image the surface of the crater on the moon, and Earth based scientists will receive the images. If an image were to show a darker color with respect to its surroundings, it could be further verification of the presence of the ice or water in the crater.

The Neutron Spectroscopy System works by measuring the number and energy of the neutrons scattering off of a sample. When neutrons strike any particle similar to their size like hydrogen , they lose energy in a manner particular to the substance they struck [25]. It is this loss of energy which allows for the detection of the presence of hydrogen on the moon and thereby the possible presence of water-ice.

Like RIMFAX, the Ground Penetrating Radar (GPR) will send two sets of data into the rover for any given reading of the subsurface. The first signal will be to make sure that the signal was both sent and calibrated properly for reflection. The internal log will note an update if the first indicates that the current calibrations are accurate for the reading. The second signal will measure the reflections. If the first signal doesn't properly calibrate the GPR, the data from the second signal will be ignored as it will not be considered accurate. If at any given point the first signal fails to calibrate the system, or the second signal fails to return any measurements from the reflections, it can be deduced that the GPR is not functioning properly [33].

The payload will go under a lot of testing to ensure its functionality. All the instruments will require a lot of testing to make certain that they will be able to structurally withstand the landing impact without losing precision or functionality. The testing will be done in the manufacturing phase. The engineering that was developed is predicted to remain at a reasonable temperature and to produce sufficient power while all planned experiments are being conducted by the payload. Further research will be needed to develop in the payload such as acceleration forces, impulses, and vibration testing. These components will all be tested individually, as well as in conjunction with each other and scientific instruments.

4.1.5. FMEA and Risk Mitigation

It is important to look at all possible failure modes, risks, and errors possible in the payload for the success of any mission. To do this, the team has considered the main risks which could affect the success of the mission. They are the following:

- Instrument failure
- Power loss
- Data loss or transmission problems
- Interference of the Lunar environment
- Damage to payload due to landing or the surface of the crater.

Each potential risk to the payload of the mission was given a ranking based both on likelihood and consequences (LxC trend). Additionally, the approach taken by the team to mitigate the risk (legend) can be found in Table 4.5 below.

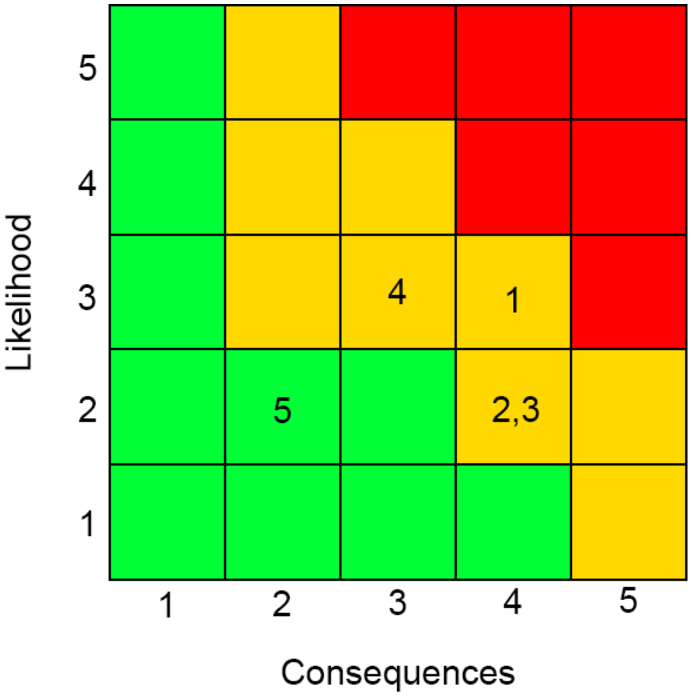
Table 4.5 - Legend for both Risk Management Table and Risk Matrix

Criticality	**Risk Mitigation**	**L x C Trend**	**Approach**
High	Change approaches to problem	Decreasing (improving)	M- Mitigate
Medium	Manage problem and brainstorm alternative process	Increasing (Worsening)	W- Watch
Low	Monitor	Unchanged	A- Accept
			R- Research

The most important risks associated with lunar operation of the rover are presented in Table 4.6 with an accompanying risk matrix in Figure 4.2. The team will perform careful monitoring in order to help mitigate risks.

Table 4.6 - Potential risks and the steps taken to mitigate them

Rank	**Trend**	**Approach**	**Risk Title**	**Likelihood**	**Consequence**
1	unchanged	M	Rover gets stuck or unable to travel trajectory	3	4
2	unchanged	M	Instrument failure	2	4
3	unchanged	M	Data loss or transmission problems	2	4
4	unchanged	M	Power loss to rover	3	3
5	unchanged	A	Poor characterization of the lunar environment	2	2

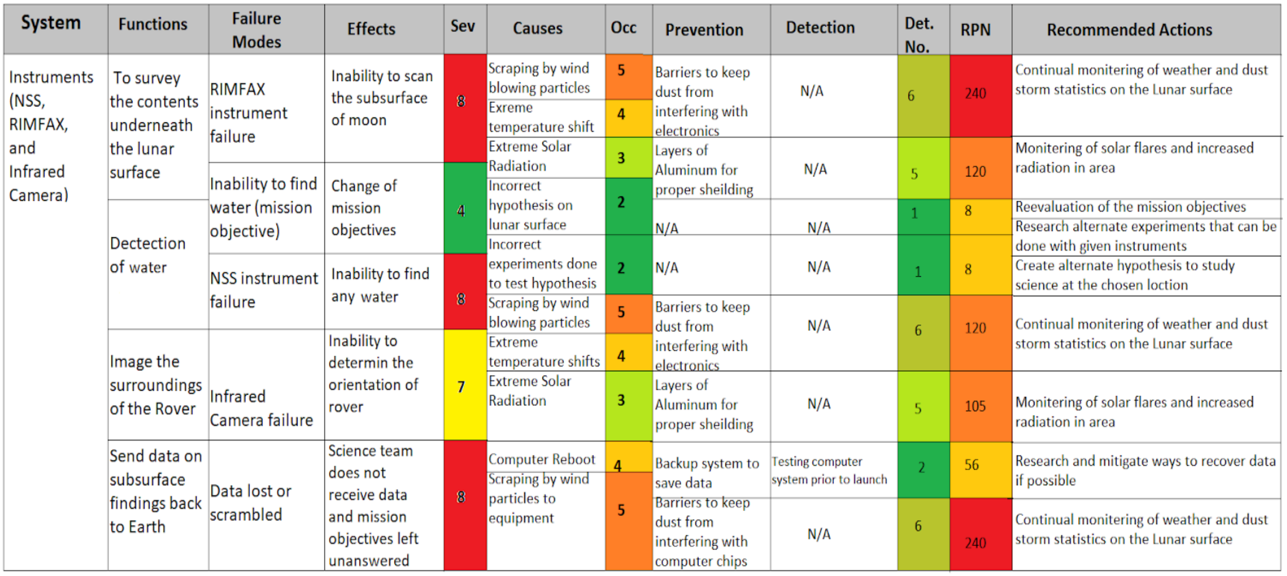


Likelihood					
5	🟩	🟨	🟥	🟥	🟥
4	🟩	🟨	🟨	🟥	🟥
3	🟩	🟨	🟨 4	🟨 1	🟥
2	🟩	🟩 5	🟩	🟨 2,3	🟨
1	🟩	🟩	🟩	🟩	🟨
	1	2	3	4	5
			Consequences		

Figure 4.2 - Risk Matrix with associated risks found in Risk Management Table

A Failure Mode and Effects Analysis (FMEA) was created to list and provide a detailed explanation of potential failures that may exist within the design and implementation of the payload and scientific experimentation. For each system with potential risk the function, failure modes, effects, severity, causes, occurrences, prevention design, detection designs, detection number, risk priority number (RPN), and recommended actions that the team will take were listed in Table 4.7.

Table 4.7 - FMEA for Mission's Payload and Scientific Instruments



System	Functions	Failure Modes	Effects	Sev	Causes	Occ	Prevention	Detection	Det. No.	RPN	Recommended Actions
Instruments (NSS, RIMFAX, and Infrared Camera)	To survey the contents underneath the lunar surface	RIMFAX instrument failure	Inability to scan the subsurface of moon	8	Scraping by wind blowing particles	5	Barriers to keep dust from interfering with electronics	N/A	6	240	Continual monitering of weather and dust storm statistics on the Lunar surface
					Exreme temperature shift	4					
					Extreme Solar Radiation	3	Layers of Aluminum for proper sheilding	N/A	5	120	Monitering of solar flares and increased radiation in area
	Dectection of water	Inability to find water (mission objective)	Change of mission objectives	4	Incorrect hypothesis on lunar surface	2	N/A	N/A	1	8	Reevaluation of the mission objectives
		NSS instrument failure	Inability to find any water	8	Incorrect experiments done to test hypothesis	2	N/A	N/A	1	8	Research alternate experiments that can be done with given instruments Create alternate hypothesis to study science at the chosen loction
					Scraping by wind blowing particles	5	Barriers to keep dust from interfering with electronics	N/A	6	120	Continual monitering of weather and dust storm statistics on the Lunar surface
	Image the surroundings of the Rover	Infrared Camera failure	Inability to determin the orientation of rover	7	Extreme temperature shifts	4					
					Extreme Solar Radiation	3	Layers of Aluminum for proper sheilding	N/A	5	105	Monitering of solar flares and increased radiation in area
	Send data on subsurface findings back to Earth	Data lost or scrambled	Science team does not receive data and mission objectives left unanswered	8	Computer Reboot	4	Backup system to save data	Testing computer system prior to launch	2	56	Research and mitigate ways to recover data if possible
					Scraping by wind particles to equipment	5	Barriers to keep dust from interfering with computer chips	N/A	6	240	Continual monitering of weather and dust storm statistics on the Lunar surface

The severity number is based on a scale from 1-10, where 1 is when there is no detectable effect on the rover, and 10 is where there is a failure to meet safety requirements. The occurrence number is the likelihood of the system failing to meet the standard from 1, where failure is abolished through preventative control, to a 10, where the likelihood of the failure is high due to the new and untested technology. Likewise, the detection number is based on the likelihood of detection before or during the launch on a scale from 1-10. Finally, RPN is the multiplication of the severity, occurrence, and the detection number in order to rank the risks based on priority.

The important thing to note in the FMEA is that the design controls, prevention, and detection are based on pre launch trials; therefore, a majority of the payload and scientific experiment risks will not be noticeable until after having arrived at the moon. The most essential risk mitigation steps for the mission payload and scientific experiments are careful monitoring and control of the listed risks. This includes proactive and innovative preventive measures which will help prevent problems before they become uncontrollable.

4.1.6 Performance Characteristics

The strength of the rover and its payload must be proven prior to the mission to minimize the possibility of hardware failure at any point during the mission. The failure of any single part of the equipment would jeopardize the success of the entire mission. Therefore, every component must be stress tested to resist the extreme conditions of the lunar surface. The rover's components must additionally be able to resist the brutal strains associated with space flight, i.e, extreme acceleration, deacceleration, pressure change, vibration, low temperatures, cosmic rays, solar energetic particles, fine dust, high winds, low atmospheric pressure and magnetospheric fluctuations. Lunar PSRs are subject to very low temperatures; both the neutron spectrometer and the infrared camera will therefore have to be insulated properly to avoid malfunction or failure.
NSS will be tested in low temperature areas to determine its performance in the PSR of the Moon. Different experiments will be performed on the NSS in simulators to check if it will be able to operate in the dry and dusty environment of the Moon.

GPR technology such as RIMFAX, developed over the course of the past 25 years, has proven its capabilities through its extensive stress testing under extreme conditions. Testing in the Arctic, Antarctic, and in the four field seasons in the ice and permafrost of Svalbard have shown its low temperature performance reliability [34]. The dry, dusty environment present on the moon was simulated through testing at Lon Mesa and Coral Pink Sand Dunes in Utah. These tests also allowed the system's penetration and subsequent analysis of subsurface features to be tested in conditions not dissimilar from the lunar regolith [35]. Testing performed in the Mojave Desert further ensured favorable material penetration.

The communication system antenna, designed for space flight, has been radiation tested. The data from manufacturers prove the component functionality under severe conditions, but more testing after all slight modifications to all components must be done to assure their operating functionality as a unit.

4.2 Science Value

4.2.1 Science Payload Objectives

Being able to map the abundance of near surface water in a Permanently Shadowed Region (PSR) of the lunar south pole is essential among the mission's scientific objectives. The supplementary scientific objectives which will allow this to be accomplished are the detection, identification, and analysis of water-ice on a PSR. The scientific payload's instruments will work to detect water by its hydrogen composition and to map its depth distribution at a high definition, in order to determine the feasibility of in-situ resource extraction of water-ice. For the mission to succeed, the payload's instruments must map the abundance of water in the top 1 meter of the lunar regolith at an accuracy of ~ ±1% and, if this can be ensured, at a spatial sampling of ~ 100 meters.

The chosen objectives will contribute strategic science for NASA's plans to achieve a sustained presence on the moon by the end of the decade. Having a detailed map of the water-ice in a PSR will allow mining operations to process the ice into O_2 and H_2 which are crucial for the support of life. Understanding better the water distribution in the lunar pole could also become an asset for planning human exploration missions on the Moon, seeing as H_2 and O_2 can be utilized to oxidize fuel, allowing spacecrafts to decrease the mass dedicated to storing water and oxygen.

4.2.2 Creativity/Originality and Significance

The team chose to perform the mission in Shoemaker crater to most successfully complete the proposed mission. Shoemaker crater is located in a permanently shadowed region (PSR) on the south pole of the moon. Traces of near surface ice have been found in this crater by different NASA studies conducted via earth based radars. Currently, no mission has actually been sent to this crater to further investigate the presence of near surface water. Shoemaker crater is centered at -88.173° N, 45.911° E, and has a diameter of 51 km and depth of 2 km [36]. It contains a flat and partially smooth illuminated surface. It is known that the bottom of Shoemaker crater is a simple plane surface with no central peak, making it a good choice for landing a rover. An image of the crater is shown below.

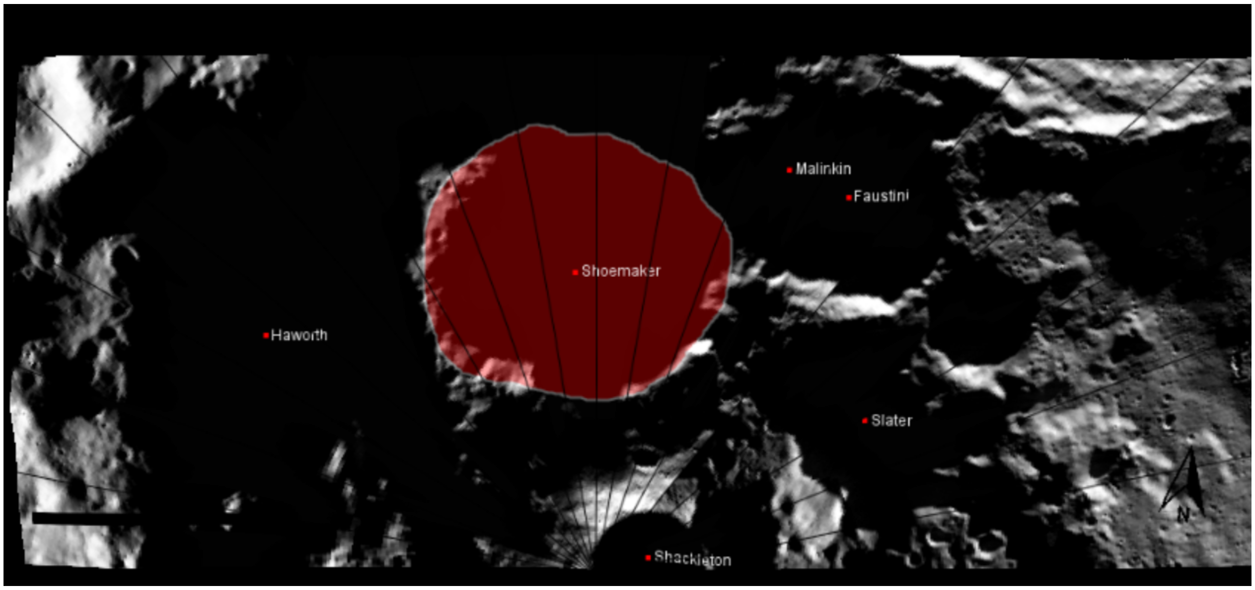


Figure 4.3 - Shoemaker Crater of Moon; Image from JMARS

Previous studies have confirmed an abundance of hydrogen in the crater confirming the possibility of near surface water-ice [36]. Additionally, there is precedent for the use of neutron spectrometers and ground penetrating radars to investigate the presence of water-ice on the moon. Due to the extremely low temperatures encountered in lunar PSRs, the rover's instruments will be insulated to function properly in temperatures of 110 K or lower.

4.2.3 Payload Success Criteria

To fulfill the mission's objectives, the rover must deliver the data collected on the mission back to the earth to be analyzed. For this to happen, each of the scientific payload's instruments must be deployed and functional. Before the rover lands on the selected lunar south pole PSR, the descent system will follow procedure and secure the rover a safe landing, keeping the payload and its components intact. After descent maneuvers, the rover will deploy and start its instruments to collect data before beginning its path of travel. At this point, a mission failure must be declared if the scientific instruments get damaged on landing or fail to deploy and calibrate their measurements. If only the Ground Penetrating Radar fails to deploy, it would also constitute a mission failure due to the loss of reliable data about the depth distribution of water in the top 1 meter of the lunar regolith.

The first instrument that will be used is the Neutron Spectrometer (NS), which will measure spectra derived from the scattering of neutrons due to its interaction with hydrogen after its correct deployment. The NS must provide a measurement of the changes in the flux of neutrons which will provide information about the Hydrogen abundance and its depth distribution in the area of the lunar regolith covered by its range. This process will allow the rover to move close to clusters of hydrogen so that the second instrument can be deployed as a way to fulfill the secondary mission success criteria of taking data at a spatial sampling of ~ 100 meters.

The second instrument, RIMFAX, will be used to collect high-definition data about the depth distribution of ice water in the top 1 meter of the regolith, directly meeting the mission's objectives. RIMFAX has to be deployed such that the ground penetrating radar can take measurements above the regolith uninterrupted. As a minimum success criteria, RIMFAX must be able to collect depth data at an accuracy of ~ ±1% or better.

The use of the NS before the RIMFAX will allow the rover to move to the most promising areas of the crater before taking in-depth measurements with RIMFAX, while also obtaining general Hydrogen distribution from the NS that will allow for a broader mapping beyond the clusters analyzed by RIMFAX. The correct use of both instruments synchronized with the rover's path of travel will allow for the mapping of the PSR

To be able to compute and interpret the data collected by the payload, it must first be sent to the rover's computer so that it can be regularly sent through the comms system back to Earth. Successful receipt of the data by the scientific team will allow an assessment of the underground water-ice of the chosen lunar crater.

4.2.4 Experimental Logic, Approach, and Method of Investigation

The rover will be landed within Shoemaker Crater located at -88.137N, 45.911E on the lunar south pole. Upon landing, the rover's Neutron Spectroscopy System (NSS) will activate and begin to scout the surrounding area for points of interest. The rover will activate its Infrared Navigational Camera (Navcam) to aid Earth based scientists in navigation in the shadowed region toward points of interest or new areas to scan. A point of interest will be classified as an area showing an increased concentration of water or water-ice, 400ppm or more, detected via the

NSS system. They will be classified as such because they exceed the average range of lunar water concentration of ~100-400ppm. The NSS scan pattern will consist of mapping a circle around the rover's location with a radius of 50m. If no points of interest are located within the area, the rover will navigate to the area's point of highest detected water concentration, run a short Ground Penetrating Radar (GPR) scan, collect data, and communicate with Earth to be assigned a new place to scan. The rover's communication with Earth will occur via its antenna based communication system (comm system). If a point of interest is located within the scanned area, the rover will navigate toward it, run a full GPR scan, collect data, and once again communicate with Earth. The rover's GPR scan will be conducted in pulses spaced 10cm apart in a straight line path that penetrate the ground to a depth of up to 10m. Short scans will be conducted over a length of 5m where full scans will be conducted over a length of 20m. The scans will serve to reveal possible pockets of water or water-ice. After the scan data is sent, the Navcam will once again be activated and Earth scientists will navigate the rover to a new area to scan. The whole process will continue to be repeated until the rover's batteries are spent. On Earth, the raw data will be interpreted by scientists who will then mark each point of interest as being sufficiently water bearing or not based on the GPR and NSS scans.

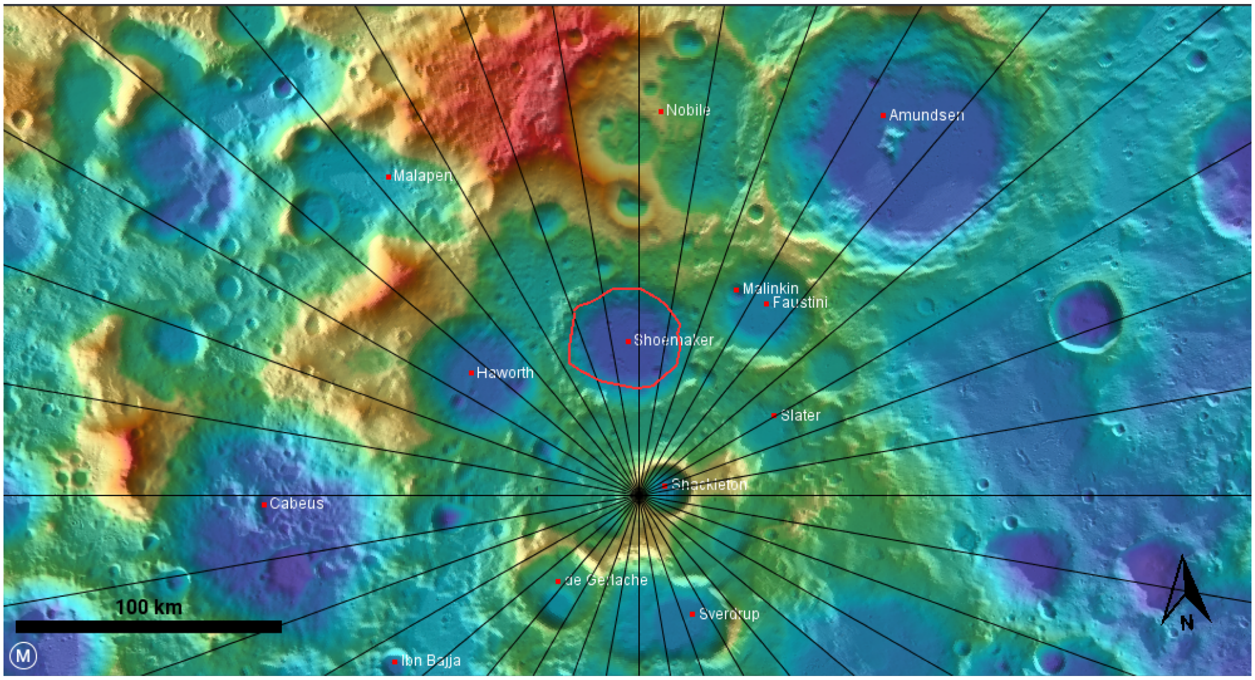


Figure 4.4 - JMARS image of Shoemaker crater and the perimeter of its PSR (shown in red)

4.2.5 Testing and Calibration Measurements

In order to test reliability and create the control variables needed for the mission, the three scientific instruments included in the payload must undergo intensive testing and calibration before and after launch. Before the scientific payload arrives at the moon, the three principal instruments (RIMFAX, NSS, and the Navcam) will be tested to create the control variables.

Even though RIMFAX has undergone past field tests in the extremely cold climates of Svalbard [35], being able to penetrate through ice and permafrost rock, there will be more intensive testing of the payload to ensure that the added components and modifications for lunar travel and rover integration also can withstand the cold temperatures of the lunar south pole. This would mean that temperature has to be one of the control variables during the tests and calibrations. To test the functionality of RIMFAX, an artificial surface with distinct water deposits at different depths (up to 10 meters) will be built, that way the data can be analyzed to ensure that it matches the predicted outcome. While testing, the full range of RIMFAX's frequency band (150 - 1200 MHz) will be utilized. In these tests, the depth and frequency settings of the GPR will be the variables.

The VIPER NSS system has been tailored to work on the moon. Seeing as manufactured insulation will be utilized for this instrument, it has to undergo temperature testing along with the NSS which will also serve the function of ensuring that the NSS signal is going through uninterrupted. In a similar way to the GPR, an artificial surface with different concentrations of Hydrogen will be built to test the NSS results with the expected data. A comparison of both will give the scientists a better understanding of the signals and noise of the system, alongside providing data to perform an error analysis. For this instrument, the hydrogen concentration of the surface measured is a variable

In the case of L-CIRiS, most of the testing and calibration will take place once the camera is fixed to the rover. Before integrating, the camera's navigation capabilities in darkness will be tested through its whole spatial resolution, comparing control images to those taken by the camera at different ranges (from 3.6 to 1000 meters) [38]

After the complete payload has been tested separately, the three principal instruments will undergo a shake test to test their reliability in launch and descent conditions.

Once the rover lands safely on the moon, all the instruments will need to be calibrated. First, the L-CIRiS will use its “end-to-end” calibration through its whole photons-to-bits chain and choose one of its three calibration views which will also adjust to the moon’s temperature [38]. After this initial calibration, L-CIRiS will send pictures back to Earth so that they can be compared to test pictures and to also confirm the landing site in the Shoemaker crater. After calibrating the infrared camera, the rover will begin its travel and start its data collection with the NSS and GPR according to the Method of Investigation. With each signal, a secondary one will be sent in order to calibrate. The first signal reflected will be the desired data while the second will confirm normal functioning of the instruments and its sensing position

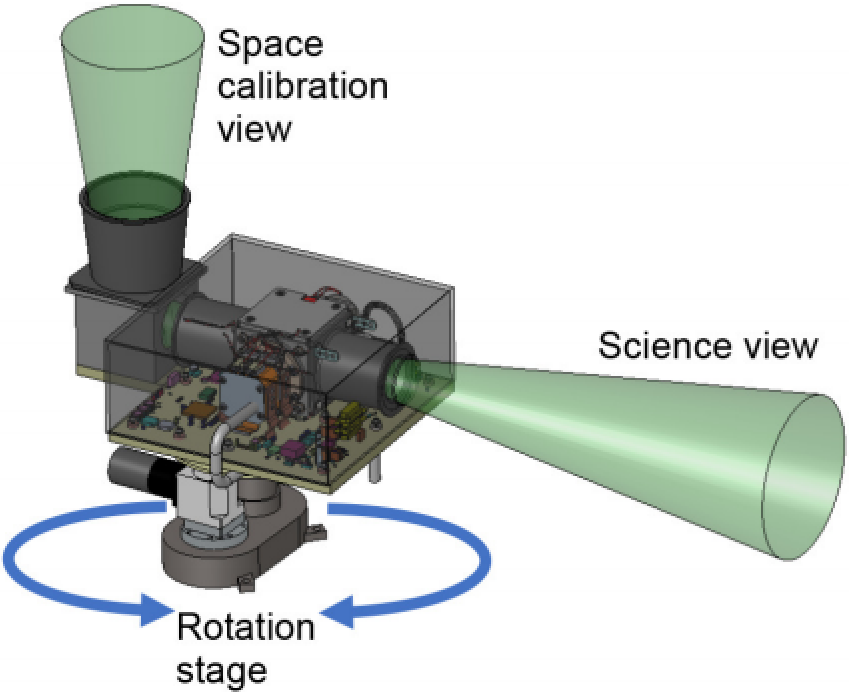


Figure 4.5 - L-CIRiS Calibration View

If any of the calibration tests fails during operations, damage mitigation steps will be needed to ensure that no further errors happen in the mission and to determine possible areas of failure.

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

The RIMFAX scans using radio waves with frequencies ranging from 150 MHz to 1200 MHz. Because different materials can absorb, reflect, or scatter the radar energy, the depth of the RIMFAX's measurements can vary. As explained in 4.2.5, the radar will be tested in different artificial surfaces to generate reference data simulating water ice pockets and will provide an expected accuracy reading for different depth levels. The instrument will image down to a depth of more than 10 meters,with vertical resolution of better than 30cm and a horizontal sampling distance of 10 cm as the rover travels along the surface. When sending a radar pulse into the ground, major losses in received signal quality can happen due to the conductivity of the ground and scattering of the transmitted signal [40]. The time-depth resolution of a Ground Penetrating Radar like RIMFAX is considered equivalent to the radar wave's pulse length, or approximately the inverse of its frequency bandwidth, B. This depth resolution in meters depends on the wave velocity, and is given as:

$$\mathbf{\Delta d = v/2B} \quad [41]$$

In general, the full bandwidth (with effective center frequency of 675 MHz) will be used for shallow imaging down to several meters, and a reduced bandwidth of the lower frequencies (center frequency 375 MHz) will be used for imaging deeper structures. The radar's largest error range should occur at its lowest frequency (150 MHz) as a much reduced bandwidth must be used, which is approximately 3%. In order to maximize resolution and minimize error, RIMFAX will be tuned to utilize the minimum center frequency of 375 MHz while imaging the top 1 meter of the regolith.

L'CIRIS will provide thermal imaging of the moon's surface to assist the rover's navigation. This instrument's thermal images can be tested for correlation with those previously acquired from orbit by LRO Diviner [38], which have a much lower resolution, as a way of testing its accuracy. L'CIRiS includes four spectral bands, three of them can be used to distinguish compositional differences and the fourth is a broad band that measures surface temperatures. This last band is the one that will be chosen for this mission, using a wavelength range of 7.5 to 13.5 um. The calculated emissivity precision of L'CIRiS is < 0.02 for illuminated scene features, enabling identification of silicate minerals. Temperature precision varies from <

10 mK for 300 K targets to < 2 K for 100 K targets. The NavCam's spatial resolution depends on the range that is being used, Table 4.8 illustrates this relationship.

Table 4.8 - L-CIRiS spatial resolution as a function of range.

Range (m)	Spatial Resolution (cm)
3.6	0.7
5.3	1.0
10	3.1
100	40
1000	400

Data from the Neutron Spectrometer System (NSS) will be primarily used for navigation and for identifying clusters of perceived water-ice in a broad range for the radar to investigate, having a much smaller resolution and larger error. Similarly to RIMFAX, the NSS will be tested on different surfaces with varying Hydrogen concentrations to generate reference data and will provide expected accuracy readings for its different ranges which will allow for an error baseline for which the error for the data taken in the moon will be extrapolated.

The onboard computer will process and save the data taken by each of the instruments to later send it through the communications system back to Earth for analysis. In the event of a failure, the corresponding risk mitigation procedure stated in Section 4.1.5 will need to be deployed and, depending on the instruments affected, the mission can continue or will be declared a failure according to the mission's success criteria.

4.2.7 Expected Data & Analysis

The L-CIRiS onboard the rover will be used as the eyes of the mission as it traverses the bottom of Shoemaker crater. Since L-CIRiS has not yet been used on the moon, there is no actual existing photography to show expected data but refer to Fig. 3 to see the expected look of output from L-CIRiS. The data collected by the rover's LCIRiS should look similar if not identical to what is shown in Fig. 3. LCIRiS is capable of panoramic infrared photography which will reveal not only the local terrain, allowing confident and safe navigation of the rover, but also reveal features of the geology such as composition and density of the surrounding material. Given data such as the one in Fig. 3, the team of scientists leading the mission could not only plot a detailed route taking into account obstacles like the large boulder which could pose a risk to the rover. The high resolution of the image would also allow scientists to pick out spots for the rover to scan while carrying out its mission.

The rover's GPR will seek out large pockets of water-ice in the lunar regolith to find sustainable water mining sites in Shoemaker crater. It will be similar to generic GPR technology and especially to RIMFAX, therefore the data can be expected to look very similar to the one output by other GPR systems. Fig. 4 provides a data output from RIMFAX similar to what should be expected from the rover's GPR, with a loose upper layer in the strata and more compacted layers of sediment and/or rock below. The expected data might differ if the rover encounters a large pocket of water or water-ice, in which case there would be a bright white inclusion somewhere within the strata present in the image returned.

The Neutron Spectroscopy instrument will be able to hone in on areas of relatively high water concentration by tracking hydrogen atoms due to the fact that hydrogen atoms scatter neutrons particularly strongly. These areas may provide a gateway to finding near surface water-ice within Shoemaker crater. The data in Fig. 5 represents the detection of hydrogen atoms by an NS system; this detection is made evident by the peaks in the waveform labeled o-H2 vibrations and p-H2 vibrations. If there is hydrogen present in the lunar regolith of Shoemaker, the NSS should show a peak in neutron scattering consistent with the data shown in Fig. 5. Since the scattering and ensuing energy loss in the neutron beam by hydrogen atoms will be the same regardless of what environment an NS device is used in, the data collected will be identical if hydrogen is detected but will otherwise show no peaks in the areas consistent with the hydrogen presence.

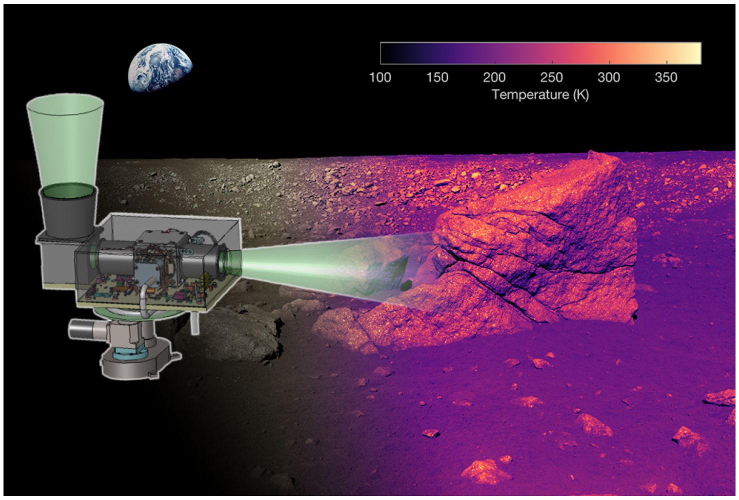


Figure 4.6 - simulation of the level of detail that L-CIRiS's infrared camera will reveal of the moon's surface [28]

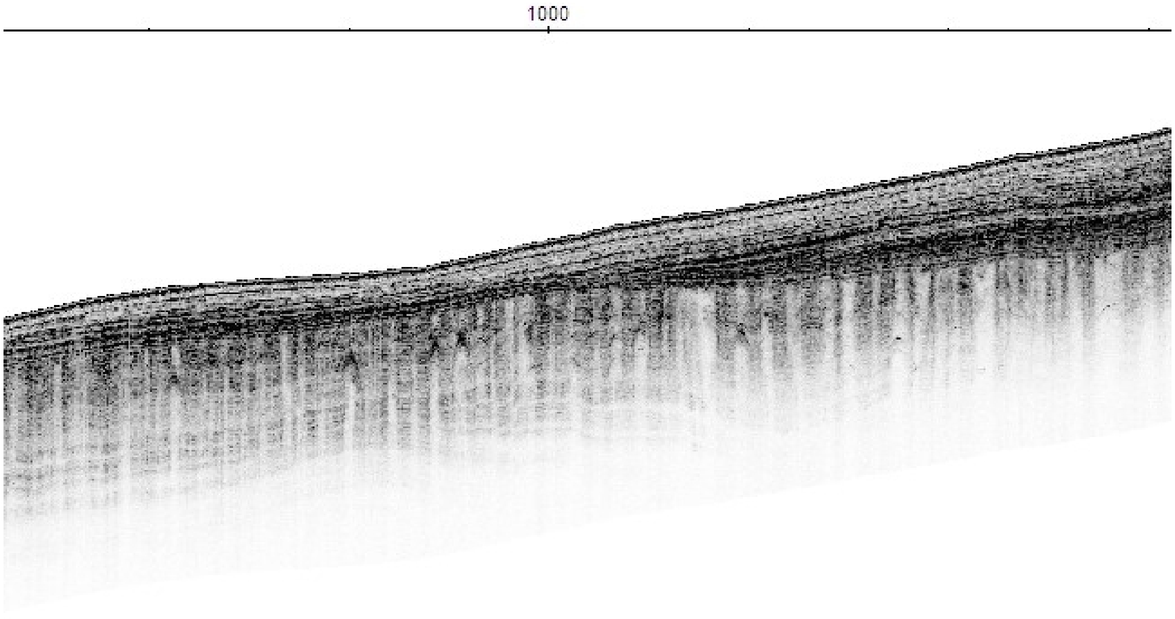


Figure 4.7 - Data output from RIMFAX showing the Martian subsurface [37]

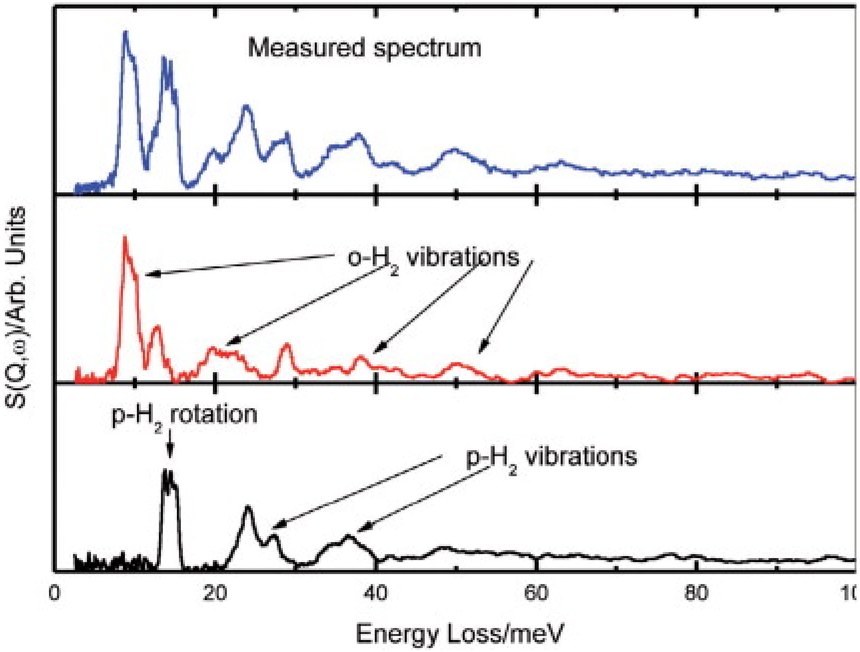


Figure 4.8 - Data output from a Neutron Spectroscopy instrument [39]

5. Safety

5.1 Personnel Safety

5.1.1 Safety Officer

Table 5.1 - Safety Officer

Name	Team / Role	Major	University
Jaya Bannarbie	Deputy Business Safety Officer	Computer Science	South Florida

The designated team safety officer for the project is Jaya Bannarbie. She will be the primary person in charge delegated with the responsibilities of keeping up to date with government and regulatory standards including the state and on-site safety mandates throughout the duration of the mission.

5.1.2 List of Personnel Hazards

Machining / Manufacturing

CNC Router

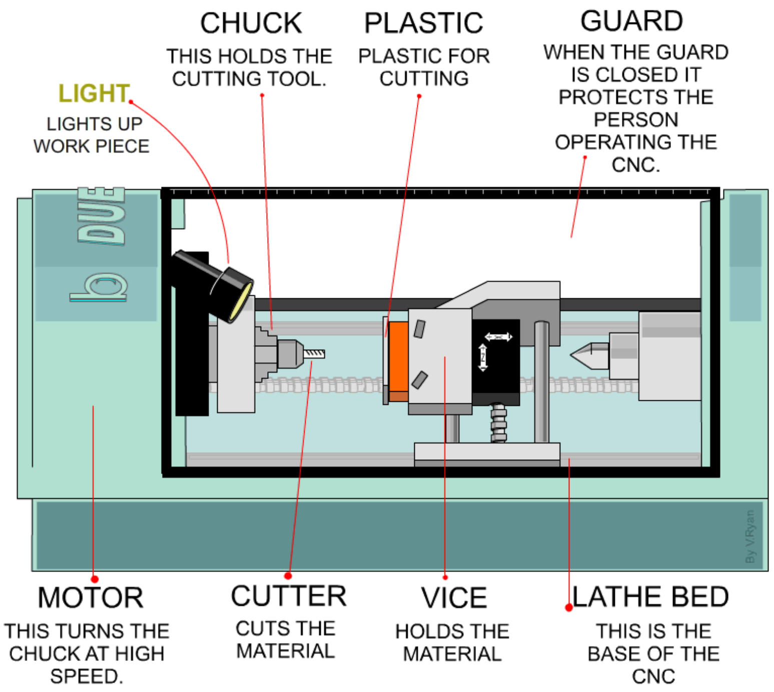


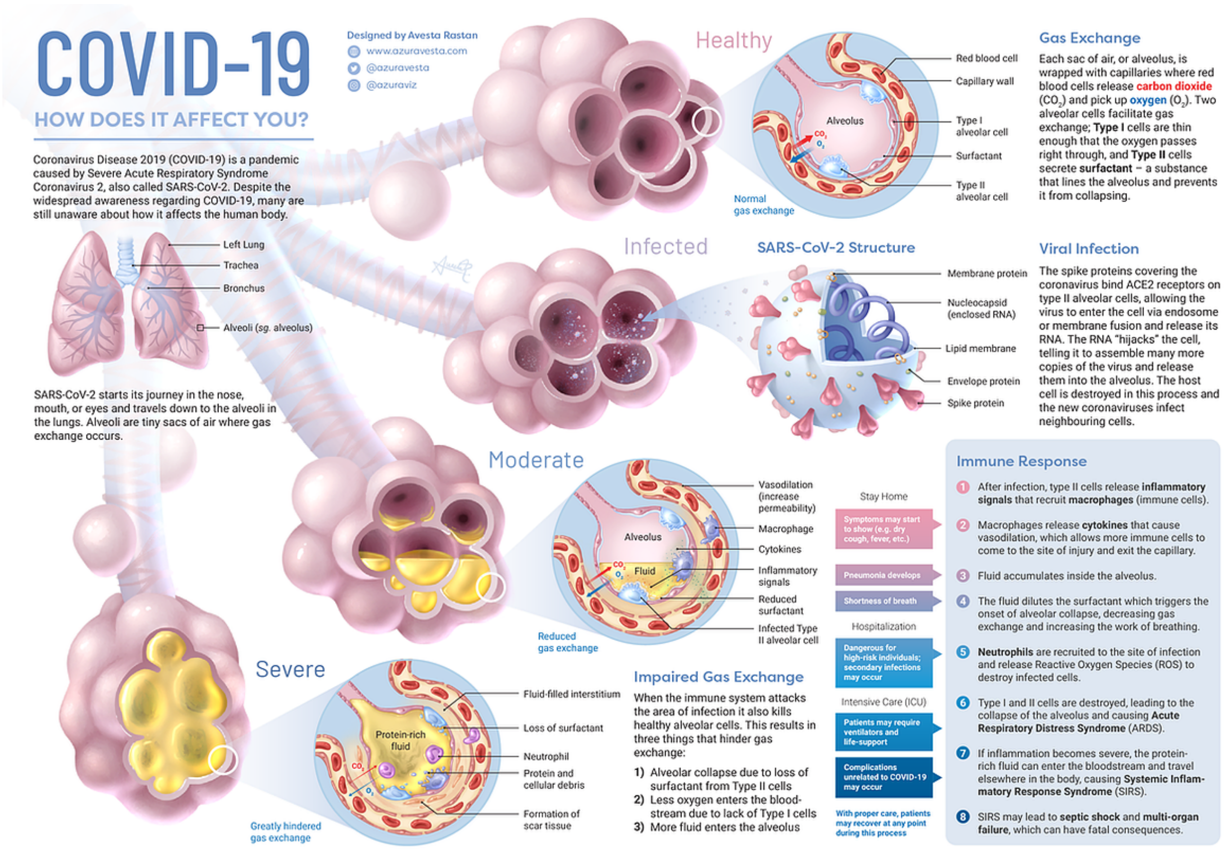
Figure 5.1 - CNC Machine [42]

In order to cut the 6061 aluminum alloy which composes the body of the space rover, a computer numerical control (CNC) router will be utilized to ensure a lack of material waste and error [43]. There are multiple rotating proponents to this machine that all increase mechanical hazards. The shafts, pulleys, and exposed gears can lead to lesions in the hands or arms as well as have parts flying into the operator's skin and eyes. Additionally, the debris from the aluminum can cause respiratory, skin, and eye irritation.

Standard safety practices are necessary in order to avoid excess noise exposure, tripping hazards, and obstructions. Too much loud noise can lead to long term hearing damage and can reduce the clarity of surrounding noises that keep safety in the workplace. Likewise, loose wires and other miscellaneous objects left on the ground can result in an intense injury or potential death.

CoronaVirus (COVID-19)

As the COVID-19 pandemic continues to present health risks throughout the project's duration, the implementation of social distancing and mask wearing is still urgent, especially among those who are not vaccinated.



Coronavirus Disease 2019 (COVID-19) is a pandemic caused by Severe Acute Respiratory Syndrome Coronavirus 2, also called SARS-CoV-2. Despite the widespread awareness regarding COVID-19, many are still unaware about how it affects the human body.

SARS-CoV-2 starts its journey in the nose, mouth, or eyes and travels down to the alveoli in the lungs. Alveoli are tiny sacs of air where gas exchange occurs.

Gas Exchange

Each sac of air, or alveolus, is wrapped with capillaries where red blood cells release **carbon dioxide** (CO_2) and pick up **oxygen** (O_2). Two alveolar cells facilitate gas exchange; **Type I** cells are thin enough that the oxygen passes right through, and **Type II** cells secrete **surfactant** – a substance that lines the alveolus and prevents it from collapsing.

Viral Infection

The spike proteins covering the coronavirus bind ACE2 receptors on type II alveolar cells, allowing the virus to enter the cell via endosome or membrane fusion and release its RNA. The RNA "hijacks" the cell, telling it to assemble many more copies of the virus and release them into the alveolus. The host cell is destroyed in this process and the new coronaviruses infect neighbouring cells.

Impaired Gas Exchange

When the immune system attacks the area of infection it also kills healthy alveolar cells. This results in three things that hinder gas exchange:

1) Alveolar collapse due to loss of surfactant from Type II cells
2) Less oxygen enters the bloodstream due to lack of Type I cells
3) More fluid enters the alveolus

Immune Response

① After infection, type II cells release **inflammatory signals** that recruit **macrophages** (immune cells).

② Macrophages release **cytokines** that cause vasodilation, which allows more immune cells to come to the site of injury and exit the capillary.

③ Fluid accumulates inside the alveolus.

④ The fluid dilutes the surfactant which triggers the onset of alveolar collapse, decreasing gas exchange and increasing the work of breathing.

⑤ **Neutrophils** are recruited to the site of infection and release Reactive Oxygen Species (ROS) to destroy infected cells.

⑥ Type I and II cells are destroyed, leading to the collapse of the alveolus and causing **Acute Respiratory Distress Syndrome** (ARDS).

⑦ If inflammation becomes severe, the protein-rich fluid can enter the bloodstream and travel elsewhere in the body, causing **Systemic Inflammatory Response Syndrome** (SIRS).

⑧ SIRS may lead to **septic shock** and **multi-organ failure**, which can have fatal consequences.

Figure 5.2 - Coronavirus Chart [45]

5.1.3 Hazard Mitigation

These risks will be mitigated by implementing appropriate safety training for all machines and material included in each manufacturing process.

It is essential to be in a well ventilated area with zero skin exposure while handling the aluminum. After handling, it is required to clean the entire work area and dispose of any dust particles. Eating, drinking, and smoking is prohibited in the manufacturing and testing facilities. All non-operational activities must take place in designated areas. Along with this, personal protective equipment (PPE) will be required during all operational procedures. This will include work gloves, goggles, masks, face shields, and earplugs. Upon entering the manufacturing and testing facilities, personnel must wear a hooded coverall along with closed-toed shoes with grip to avoid falls from slippage.

Figure 5.3 - Slippery Floor Sign [46]

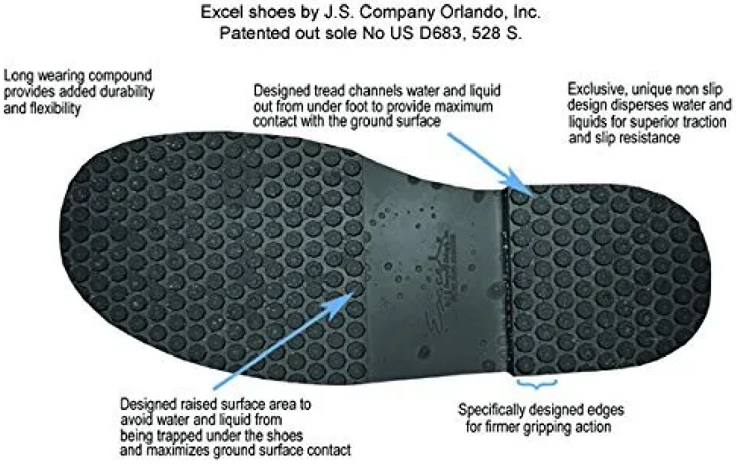


Figure 5.4 - Slip-Resistant Shoes [47]

Safety Training

Operators must go through relevant fire safety training prior to use of machinery or facilities. To implement proper safety controls, in the event of fire, operators should have a nearby Class D fire extinguisher prepared in advance at all times. Similarly, knowing how to read, identify, and place appropriate hazard signs for fire and slippery when wet risks should be elementary. Personnel should be able to recognize relevant icons even without detailed text simply through color codes and symbolic indicators.

5.2 Vehicle/Payload Safety

5.2.1 Environmental Hazards

There are many awaiting hazards present on the moon, including solar winds, uneven regolith, and temperature, each of which all have some potential effect. The greatest of these moon hazards is solar radiation. As the moon does not have its own atmosphere, it is more subjected to such risks. According to a team of Chinese and German scientists, “radiation levels on the Moon’s surface are 200 to 1,000 times more than that on Earth’s surface” [48]. This can have severe effects on space rover electronics including violation of data consistency or reliable network communications. More specifically Solar radiation is when tiny energetic particles zip throughout space, which can wreak havoc if not cautious [49]. Solar radiation can affect electronics in two ways, first is immediate threats, through quick bursts of energy, solar particles or cosmic rays can pierce through a circuit. These immediate threats can “mess up your computers, scrambling your data — in binary code — from 1’s to 0’s”. Then there are the second types that worsen with time, which are charged particles that can collect on a spacecraft’s surface and build up a charge within hours. Known as long-term radiation, these can wear material down, gradually reducing instrument performance the longer they’re in orbit, with even relatively mild radiation can degrade solar panels and circuitry. In addition to solar radiation, the regolith itself presents an environmental surface hazard of unpredictable potholes and collapsible ground spread across the moon’s landscape as well.

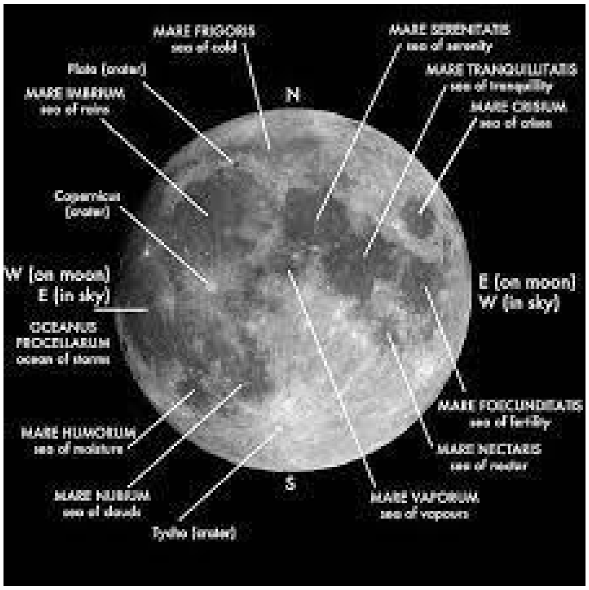


Figure 5.5 - Map of the Moon [50]

Without extremely careful caution, any wrong movement could lead to the rover’s demise, if it were to be unsalvageable from a deep crater. Most think that the moon’s surface is like a desert, but that is wrong, it’s more like an ocean. But a particular danger about the regolith is it’s many contrasts between light and dark that can play tricks on the eyes. For example, “...when Pete Conrad and Alan Bean landed on the moon during the Apollo 12 mission, one of their tasks was to enter the 650-foot-wide Surveyor Crater. But as they skirted its rim, searching for the best path down, they informed Houston that the crater was far too steep. Topographic maps, however, revealed an easy, 21-degree slope. The sharp shadows had fooled the astronauts" [51]. That disaster was prevented with trained human eyes, now imagine trying to spot that through a rover camera, which would be insanely difficult. Not to mention the danger in transit upon launch, crashing into any debris from Earth's satellites and space junk would represent a wave of initial obstacles.

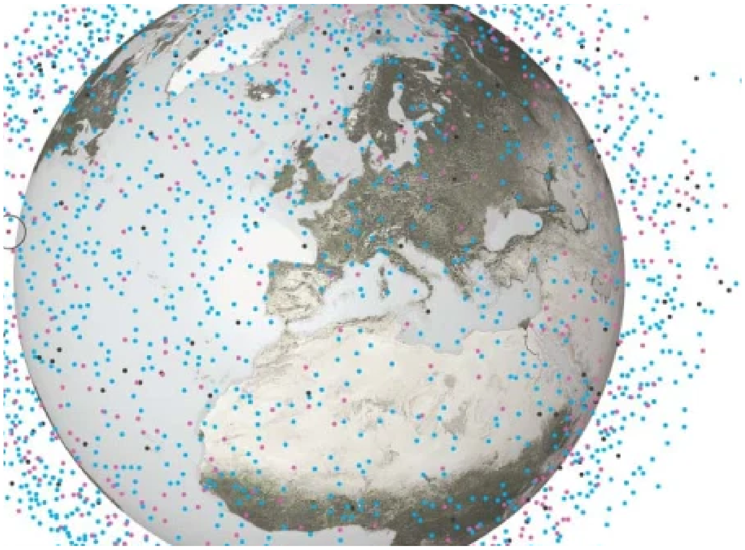
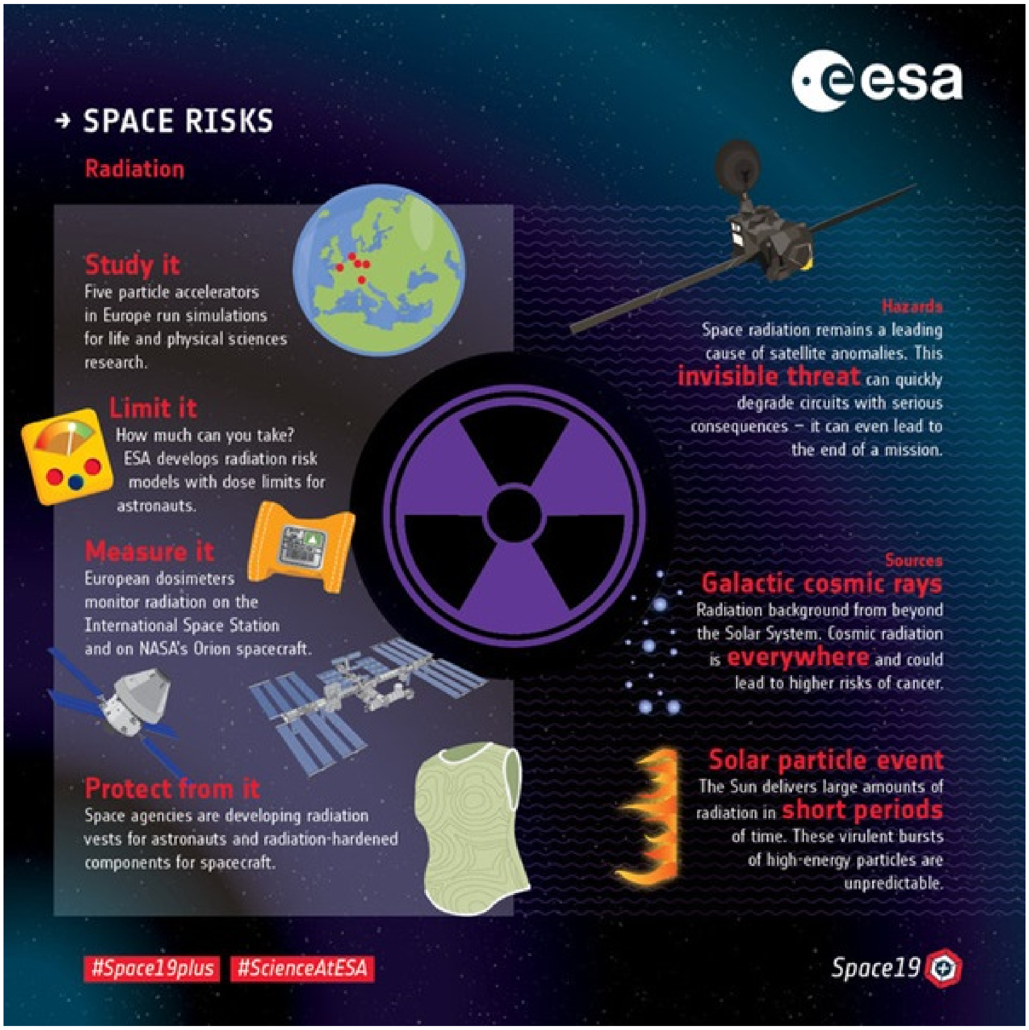


Figure 5.6 - Spatial Debris in Earth's Atmosphere [52]

Additional hazards such as rapid changes in temperature could also drastically affect the rover's internal electronics. For example, temperature from standard locations on the moon could reach as high as 260 F and drop as low as -280 F. In contrast, at the extremities of the South pole, the mission space rover's target destination, temperatures may drop as low as -396 F [53]. Which can prove extremely dangerous, as no material upon the rover can withstand such temperatures for long, the best the team can do is prolong it as long as possible, until the mission is complete. As for the severity of the cold on electronics, it can cause a wide range of problems such as, the wheels and other moving parts, which as the temperature drops, metal contracts making moving parts run under higher load stress which can cause the part to fail.

5.2.2 Hazard Mitigation

As there are many vehicle, payload, and environmental hazards, a safety mitigation control should be established for each.



Five particle accelerators in Europe run simulations for life and physical sciences research.

How much can you take? ESA develops radiation risk models with dose limits for astronauts.

European dosimeters monitor radiation on the International Space Station and on NASA's Orion spacecraft.

Space agencies are developing radiation vests for astronauts and radiation-hardened components for spacecraft.

Space radiation remains a leading cause of satellite anomalies. This invisible threat can quickly degrade circuits with serious consequences – it can even lead to the end of a mission.

Radiation background from beyond the Solar System. Cosmic radiation is everywhere and could lead to higher risks of cancer.

The Sun delivers large amounts of radiation in short periods of time. These virulent bursts of high-energy particles are unpredictable.

Figure 5.7 - Radiation Risks [54]

Solar radiation can be handled by including a protective shell of materials stronger than typical mechanisms for X-Ray protection such as the anti-radiation shield blankets used by dentists.

For data and network communications, the space rover could be monitored for related metrics such as bandwidth and speed rates with tools including an internal system portal and dashboard functionally similar but more user-friendly than WireShark. Data would need to be incrementally backed up and sent back to mission headquarters throughout execution, if such events like crater fall occur.

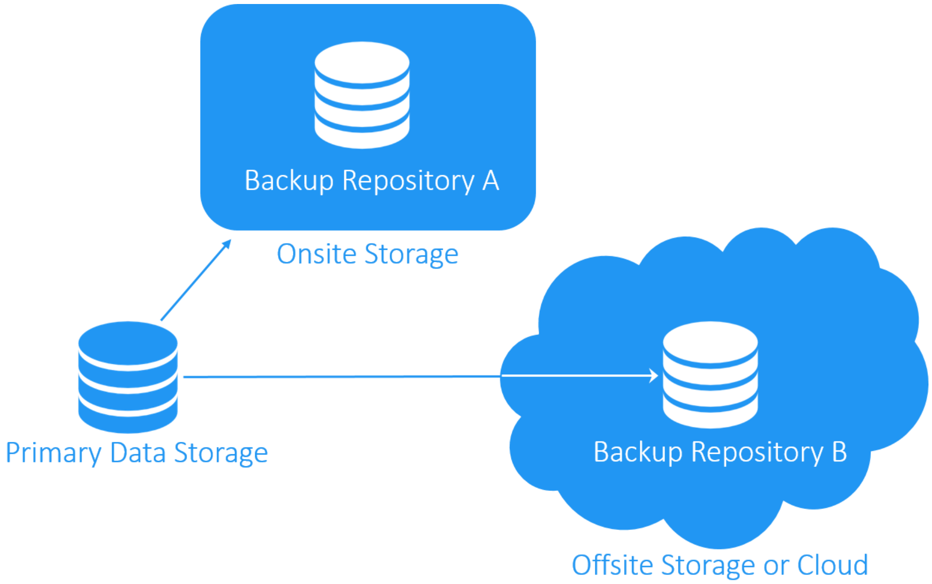


Figure 5.9 - Data Protection [56]

In worst case scenarios such as mission failure, the organization must fall back on any financial protections such as insurance investments.

6. Activity Plan

6.1 Budget Plan

Table 6.1 - Budget Summary

	# People on Team	FTE Year 1	FTE Year 2	FTE Year 3	FTE Year 4	FTE Year 5	FTE Year 6	FTE Year 7
Science Team:	3	1	1	1	1	1	1	1
Engineering Team:	6	1	1	1	1	1	1	1
Administrative Team:	3	1	1	1	1	1	1	1
Annual Salary ($)	100000							
NASA L'SPACE Mission Concept Academy Budget - Team Leviathan								
Year	**Yr 1 Total**	**Yr 2 Total**	**Yr 3 Total**	**Yr 4 Total**	**Yr 5 Total**	**Yr 6 Total**	**Yr 7 Total**	**Cumulative Total**
PERSONNEL								
Science Team	$ 270,000.00	$ 270,000.00	$ 270,000.00	$ 270,000.00	$ 270,000.00	$ 270,000.00	$ 270,000.00	$ 1,890,000.00
Engineering Team	$ 540,000.00	$ 540,000.00	$ 540,000.00	$ 540,000.00	$ 540,000.00	$ 540,000.00	$ 540,000.00	$ 3,780,000.00
Administrative Team	$ 270,000.00	$ 270,000.00	$ 270,000.00	$ 270,000.00	$ 270,000.00	$ 270,000.00	$ 270,000.00	$ 1,890,000.00
Total Salaries	$ 1,080,000.00	$ 1,080,000.00	$ 1,080,000.00	$ 1,080,000.00	$ 1,080,000.00	$ 1,080,000.00	$ 1,080,000.00	$ 3,240,000.00
Total ERE	$ 301,428.00	$ 301,428.00	$ 301,428.00	$ 301,428.00	$ 301,428.00	$ 301,428.00	$ 301,428.00	$ 904,284.00
TOTAL PERSONNEL	$ 1,381,428.00	$ 1,381,428.00	$ 1,381,428.00	$ 1,381,428.00	$ 1,381,428.00	$ 1,381,428.00	$ 1,381,428.00	$ 9,669,996.00

TRAVEL								
Total Flights Cost	**$ 1,913.00**	**$ 1,913.00**	**$ 1,913.00**	**$ 1,913.00**	**$ 1,913.00**	**$ 1,913.00**	**$ 1,913.00**	**$ 13,391.00**
Total Hotel Cost	**$ 7,440.00**	**$ 7,440.00**	**$ 7,440.00**	**$ 7,440.00**	**$ 7,440.00**	**$ 7,440.00**	**$ 7,440.00**	**$ 52,080.00**
Total Transportation Cost	**$ 1,122.15**	**$ 1,122.15**	**$ 1,122.15**	**$ 1,122.15**	**$ 1,122.15**	**$ 1,122.15**	**$ 1,122.15**	**$ 7,855.05**
Total Per Diem Cost	**$ 3,855.00**	**$ 3,855.00**	**$ 3,855.00**	**$ 3,855.00**	**$ 3,855.00**	**$ 3,855.00**	**$ 3,855.00**	**$ 26,985.00**
Total Travel Costs	**$ 14,330.15**	**$ 14,330.15**	**$ 14,330.15**	**$ 14,330.15**	**$ 14,330.15**	**$ 14,330.15**	**$ 14,330.15**	**$ 100,311.05**
OTHER DIRECT COSTS								
Total Outsourced Manufacturing Cost	**$ -**	**$ 29,811,719.00**	**$ 10,000,000.00**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 39,811,719.00**
|> Science Instrumentation	**$ -**	**$ 29,700,000.00**	**$ 10,000,000.00**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 39,700,000.00**
|> Other COTS Components	**$ -**	**$ 111,719.00**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 111,719.00**
Total In-House Manufacturing Cost	**$ -**	**$ -**	**$ 2,636.00**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 2,636.00**
|> Materials and Supplies	**$ -**	**$ -**	**$ 2,636.00**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 2,636.00**
Total Equipment Cost	**$ 4,200,000.00**	**$ 4,200,000.00**	**$ 4,200,000.00**	**$ 4,200,000.00**	**$ 4,200,000.00**	**$ 4,200,000.00**	**$ 4,200,000.00**	**$ 29,400,000.00**
|> Manufacturing Facility Cost	**$ 3,000,000.00**	**$ 3,000,000.00**	**$ 3,000,000.00**	**$ 3,000,000.00**	**$ 3,000,000.00**	**$ 3,000,000.00**	**$ 3,000,000.00**	**$ 21,000,000.00**
|> Test Facility Cost	**$ 1,200,000.00**	**$ 1,200,000.00**	**$ 1,200,000.00**	**$ 1,200,000.00**	**$ 1,200,000.00**	**$ 1,200,000.00**	**$ 1,200,000.00**	**$ 8,400,000.00**
In-House Manufacturing Margin	**$ 2,100,000.00**	**$ 2,100,000.00**	**$ 2,101,318.00**	**$ 2,100,000.00**	**$ 2,100,000.00**	**$ 2,100,000.00**	**$ 2,100,000.00**	**$ 14,701,318.00**

Total Direct Costs	**$ 7,695,758.15**	**$ 37,507,477.15**	**$ 17,699,712.15**	**$ 7,695,758.15**	**$ 7,695,758.15**	**$ 7,695,758.15**	**$ 7,695,758.15**	**$ 29,405,272.00**
Total MTDC	**$ 1,395,758.15**	**$ 31,207,477.15**	**$ 11,399,712.15**	**$ 1,395,758.15**	**$ 1,395,758.15**	**$ 1,395,758.15**	**$ 1,395,758.15**	**$ 5,272.00**
FINAL COSTS								
Total F&A	**$ 139,575.82**	**$ 3,120,747.72**	**$ 1,139,971.22**	**$ 139,575.82**	**$ 139,575.82**	**$ 139,575.82**	**$ 139,575.82**	**$ 4,958,598.01**
Total Projected Cost	**$ 7,835,333.97**	**$ 40,628,224.87**	**$ 18,839,683.37**	**$ 7,835,333.97**	**$ 7,835,333.97**	**$ 7,835,333.97**	**$ 7,835,333.97**	**$ 98,644,578.06**
Total Cost Margin	**$ 2,350,600.19**	**$ 12,188,467.46**	**$ 5,651,905.01**	**$ 2,350,600.19**	**$ 2,350,600.19**	**$ 2,350,600.19**	**$ 2,350,600.19**	**$ 29,593,373.42**
Total Project Cost	**$ 10,185,934.15**	**$ 52,816,692.32**	**$ 24,491,588.37**	**$ 10,185,934.15**	**$ 10,185,934.15**	**$ 10,185,934.15**	**$ 10,185,934.15**	**$ 128,237,951.47**
************ Do not change percentages in the boxes below unless mission concept instructions specify otherwise.**								
F&A %	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	**10%**	
Manufacturing Margin	**50%**	**50%**	**50%**	**50%**	**50%**	**50%**	**50%**	
Total Cost Margin	**30%**	**30%**	**30%**	**30%**	**30%**	**30%**	**30%**	
ERE - Staff	**28%**	**28%**	**28%**	**28%**	**28%**	**28%**	**28%**	

Personnel

Hourly Rate: 100 000 / 2088 = $ 48.07

Annual Compensation

Salary $ 100,000 *Benefits $2,800*

Table 6.2 - Personnel

Section	Name	Role	Base Salary ($)	Benefits (28%)	Bonus (5%)	Insurance (8%)	401K Match (15%)	Total ($)
Engineering	Quintin	*Lead PM*	100000	28000	5150	8000	15000	128000
	Emma	*Lead*	100000	28000	5000	8000	15000	128000
	Grace	*Deputy*	100000	28000	5000	8000	15000	128000
	Alex		100000	28000	4950	8000	15000	128000
	Evan		100000	28000	4950	8000	15000	128000
	Ananya		100000	28000	4950	8000	15000	128000
Size	6	**Sum ($)**	600000	168000	30000	48000	90000	768000
Science	Francisca	*Lead*	100000	28000	5000	8000	15000	128000
	Nicolas	*Deputy*	100000	28000	5000	8000	15000	128000
	Hena		100000	28000	5000	8000	15000	128000
Size	3	**Sum ($)**	300000	84000	15000	24000	45000	384000
Business	Jon	*Deputy PM*	100000	28000	5000	8000	15000	128000
	Kien	*Lead*	100000	28000	5000	8000	15000	128000
	Jaya	*Deputy*	100000	28000	5000	8000	15000	128000
Size	3	**Sum ($)**	300000	84000	15000	24000	45000	384000
Size	12	**Total ($)**	1200000	336000	60000	96000	180000	1536000

Compensation was adjusted by +20K due to extra funds remaining in the budget. Highest leadership positions have slightly larger bonuses.

Travel

Launch Site: Kennedy Space Center

Dates: October 14 - 18, 202

Airline (Commercial Flights)

Table 6.3 - Travel

Personnel			Location			Cost ($)		Itinerary					
								Airport Code	Airline	Arrival		Return	
Name	**Section**	**Role**	**City**	**State**	**Distance (mi)**	**Airfare**	**Efficiency Per Mile**			**Start**	**End**	**Start**	**End**
Fran	Science	Lead Science	Amherst	MA	1218	177	0.15	BDL	Delta	1:00 PM	9:09 PM	7:00 AM	11:52 AM
Quintin	Engineer	Lead PM	Centre County	PA	1059	177	0.17	SCE	Delta	2:00 PM	8:30 PM	6:40 AM	1:45 PM
Emma	Engineer	Lead Engineer	Philadelphia	PA	992	192	0.19	PHL	American	5:10 AM	9:15 AM	5:01 AM	9:46 AM
Kien	Business	Lead BA	Blacksburg	VA	735	177	0.24	ROA	Delta	2:05 PM	8:05 PM	8:00 AM	1:41 PM
Nicolas	Science	Deputy Science	Tallahassee	FL	276	157	0.57	TLH	Delta	3:30 PM	9:09 PM	7:30 AM	1:00 PM
Jon	Business	Deputy PM	Stony Brook	NY	1102	192	0.17	JFK	American	5:00 AM	9:15 AM	5:00 AM	9:15 AM
Grace	Engineer	Deputy Engineer	Cleveland	OH	1057	192	0.18	CLE	American	5:03 AM	9:15 AM	5:01 AM	9:43 AM
Evan	Engineer		Madison	WI	1315	214	0.16	MSN	Delta	12:36 PM	9:33 PM	6:05 AM	12:06 PM
Hena	Science		College Park	MD	864	165	0.19	DCA	American	6:59 AM	9:17 AM	5:01 AM	9:30 AM

Each year, for the duration of the mission, all Leviathan personnel will travel to the Kennedy Space Center for one week in mid October when weather is most temperate in Cape Canaveral. The team will be split into two groups: commercial flights & personal vehicles.

Part of the team will be flying through Delta and the other part through American Airlines, all arriving at the Orlando airport (MCO). The total airfare for roundtrip tickets is $1913, including the $30 baggage check fee for each team member per year.

- Emma travelling from PHL via American
- Arrival Time: 5:10 AM - 9:15 AM
- Departure Time: 5:01 AM- 9:46 AM
- Total Cost: $222
- Jon travelling from JFK via American
- Arrival Time: 5:00 AM - 9:15 AM
- Departure Time: 5:00 AM - 9:15 AM
- Total Cost: $222
- Grace travelling from CLE via American
- Arrival Time: 5:03 AM - 9:15 AM
- Departure Time: 5:01 AM - 9:43 AM
- Total Cost: $ 222
- Hena travelling from DCA via American
- Arrival Time: 6:59 AM - 9:17 AM
- Departure Time: 5:01 AM - 9:30 AM
- Total Cost: $195
- Francisca travelling from BDL via Delta
- Arrival Time: 1:00 PM - 9:09 PM

  - Departure Time: 7:00 AM - 11:52 AM
  - Total Cost: $207
- Quintin travelling from SCE via Delta
  - Arrival Time: 2:00 PM - 8:30 PM
  - Departure Time: 6:40 AM - 1:45 PM
  - Total Cost: $207
- Kien travelling from ROA via Delta
  - Arrival Time: 2:05 PM - 8:05 PM
  - Departure Time: 8:00 AM - 1:41 PM
  - Total Cost: $207
- Nicolas travelling rom TLH via Delta
  - Arrival Time: 3:30 PM - 9:09 PM
  - Departure Time: 7:30 AM - 1:00 PM
  - Total Cost: $187
- Evan travelling from MSN via Delta
  - Arrival Time: 12:36 PM - 9:33 PM
  - Departure TIme: 6:05 PM - 12:06 PM
  - Total Cost: $244

Car Rental

The team will arrive in two groups where one member from each will rent a standard vehicle from Budget Rental for the duration of the 5 day trip at a total cost of $712.55 per year.

Automobile (Privately Owned Vehicles)

Table 6.4 - Automobile Summary

Personnel			Location			Fuel Cost	
Name	**Section**	**Role**	**City**	**State**	**Distance (mi)**	**Actual**	**Reimbursed**
Jaya	Business	Deputy BA	Tampa	FL	130	74.75	72.8
Ananya	Engineer		Gainesville	FL	165	94.875	92.4
Alex	Engineer		Orlando	FL	56	32.2	31.36

Three team members will be independently driving their privately owned vehicles for the entire round trip. The total mileage driven will be 351 mi, totalling to $198 in reimbursement per year.

- Ananya travelling from Gainesville will receive $186 in reimbursement for driving 330 mi
- Alex travelling from Orlando will receive $64 in reimbursement for driving 112 mi
- Jaya travelling from Tampa will receive $146 in reimbursement for driving 260 mi

Meals and Incidentals

Each team member will receive a per diem for meals and incidentals at $319.50.

$71.00 will be received each day aside from the first and last day of travel where they will only receive $53.25.

There will be a total cost of $3,855 for the five day trip per year.

Hotel

Each team member will stay at the Towneplace Suites by Marriott Tiitusville with an allocated hotel per diem of $155. There will be a total cost of $7,440.00 for the four night trip per year.

Manufacturing

Machining (Cut+Weld)

CNC

Table 6.5 - Manufacturing

Instrument	**Power (W)**	**Component**	**Estimate**	**Energy (Wh)**	**Power (W)**
Rimfax	10	Batteries	~40	mAh*V/1000=Wh	
Comm	0.075	Movement	~5 days=120 hr	2736	
NavCam	2.2	Instrument(s)	~5 days=120 hr	1749	
Neutron Spec	2.3	Thrusters	~5min=1/12 hour	12	
Total	14.575	Max	Online 24/7	4497	65.74561404

Outsourced

Table 6.6 - Outsourced

Batteries			**Thrusters**	*Amount (#)*	2		*Amount (#)*	4
Battery (1)	*Voltage (V)*	3.6	**Cold Gas**	*Energy (Wh)*	2	**Monopropellant**	*Energy (Wh)*	10
	Charge (mAh	19000	Source	*Power (W)*	12	Source	*Power (W)*	30
	Energy (Wh)	68.4		*otal Power (W*	24		*Total Power (W)*	120
				Cost Per	$15,000.00		*Cost Per*	$20,000.00
	Min. Amount (#)	65		*Cost Total*	$30,000.00		*Cost Total*	$80,000.00
	Cost Per	$14.99						
	Cost Total	$974.35	**Neutron Spec**	*Amount (#)*	1			
Source				*Cost Per*	$9,200,000.00			
Radio	*Cost*	$220		*Cost Total*	$9,200,000.00		**Total Outsource**	$9,311,194.35

In-House

Table 6.7 - In-House

Main Body				
Source	*Material*	Aluminum-6061		
	Volume (mm^3)	13501666.67		
	Min. Volume (m^3)	0.01350166667		
	Thickness (mm)	35	20	25
	Costs			
	Per Side	$430		
	All Sides	$2,580		
Wheels	*Diameter (mm)*	27		
Source	*Amount (#)*	4		
	Cost Per	$13.99		
	Cost Total	$55.96		

Equipment

Facilities

Kennedy Space Center	**$ 1 200 000**
Manufacturing	**$ 3 000 000**
Total	**$ 4 200 000**

For the manufacturing, there were three categories: outsourced manufacturing, in-house manufacturing, and total equipment cost. For outsourced manufacturing, these costs consisted mainly of instruments that are pre-made, such as batteries, thrusters, and scientific instruments, specifically the spectrometer that added up to **$9,500,000** [57], RimFax up to **$20,000,000,** and Navigation camera up to **$10,000,000,** which all in all came to be a total of **$ 39,811,719.00,** with the scientific instruments taking up the most money. While for the in-house manufacturing, these consisted of the main body and wheels, and this came out to be **$ 2,636.00,** which included the material used which was aluminum.

Equipment on the other hand included manufacturing facilities to assemble the project and testing facilities to work with the project. For the testing facilities, the Kennedy space center was chosen and maintenance on that annual is **$1,200,000** [58], while for manufacturing facilities to create the project, these cost **$3,000,000,** in total equipment would cost **$ 12,600,000.00.** In addition, other equipment included things such as a crane and CNC machine which

6.2 Schedule

Phase A: Preliminary Analysis

- May 11, 2021 - Project start
- June 14th, 2021 - Concept of Operations, preliminary research finalized

Phase B: Definition

- June 21st, 2021 - Budget, Mission Schedule finalized
- June 28th, 2021 - Finalize landing site on Moon, finalize both scientific studies and engineering summary
- July 5th, 2021 - Safety plan finalized

Phase C/D: Design and Development

- July 26th, 2021 - PDR Materials Due, submission
- August 2021 - July 2022 - PDR refining, project maturation
- July 2022 - CDR
- July 2022 - January 2023 - CDR review, feedback, manufacturing setup
- January 2023 - Start Manufacturing
- July 2025 - Finish Manufacturing, System Integrations Review (SIR)
- August 2025 - Integration begins
- February 2026 - Integration end, Testing Readiness Review (TRR)
- March 2026 - Testing begins
- September 2026 - Testing end, Verification Testing start
- January 2027 - Verification Testing end, Validation Testing start
- July 2027 - Validation Testing end, System Acceptance Review (SAR)
- Operational Readiness Review (ORR)
- Flight Readiness Review (FRR)
- Mission Readiness Review (MRR)

Phase E: Operations Phase

- October 2028 - Launch at Cape Canaveral
- November 2028 - Post-Launch Assessment Review

6.3 Outreach

6.3.1 Summary

The team mission is to increase public awareness in the community using STEM education in a variety of ways. Events like hackathons, science fairs, skill workshops, career day seminars, facility tours, and NASA scholarships will enable more community involvement.

The business team will travel to the Brevard Public School District in Cape Canaveral, where they will hold assemblies at multiple elementary schools for 4th-5th graders to showcase the Leviathan Team Mission and promote an essay competition on what the student's would do if they could travel to space. Their teachers will submit their choice of best work and a medium will determine one final winner from each school. Along with this, science fair competitions will be held for 7th and 8th graders where they will each build their own rocket, faux moon crater, and present where they would go and why. The winner from each school will have the opportunity to bring their family to tour the Kennedy Space Center and witness the mission launch. Portable and interactive dioramas at these events will engage children to be more active participants. The goal being to inspire the next generation, all outreach will primarily focus on younger students.

There will also be general public outreach using platforms such as news broadcasts, the Leviathan web page, and social media. There will be constant media updates regarding the launch such as virtual launch notifications and announcements including focused posts on the benefit of green energy from alternative resources outside of the Earth

Aerospace affiliate companies that would be significantly affected by the launch such as SpaceX, Blue Origins, and Virgin Galactics can advertise information to employees, clients, and news outlets in order to raise awareness of the launch for everyone already interested in the aerospace industry.

6.3.2 Promotions

NASA JPL INVITES YOU TO

CODING FOR MARS

Create a video game to simulate exploration of the Red Planet

Aug 3 at 10 AM
Online

More at www.jpl.nasa.gov/edu/learn

Figure 6.1 - Sample I

Let's discover and learn together!

LEVIATHAN SCIENCE FAIR

Be Inspired by the Upcoming Leviathan Launch to the Moon and Show NASA your Innovation

Available to K12 and below

Aug 3 at 10 AM to 6 PM
123 Anywhere St.

Learn more at www.Leviathan.com

Figure 6.2 - Sample II

6.4 Program Management

The team structure and problem approach was organized according to the organizational diagrams via tables and tree charts, while the mission schedule is represented by the Gantt chart and mission milestones. The team worked both asynchronous and synchronous with scheduled team meetings throughout the week. The decisions made about the team structure were based on everyone's major, skill sets, desired roles, and team nominations. Initially, everyone was assigned a role based on their background and then given the opportunity to switch. When asked again in the first team meeting, there were a few who did change. Relevant changes were made before the team organizational structure was finally established.

When issues arose they were solved through group talks, which proved to be highly effective. Everyone would get together at the scheduled team meeting and discuss what issues they had with deliverables. For example, on the organizational chart, there were some issues, but these were resolved by asking each team member's opinion individually on what they think is right and how they would do it. Afterwards a team vote was made to see if the majority agreed the deliverable was good or not. Issues were either resolved this way or through Discord. For information, that was shared either through Discord or Google Drive, but primarily Google Drive.

Organizational Diagram

Tree Hierarchy

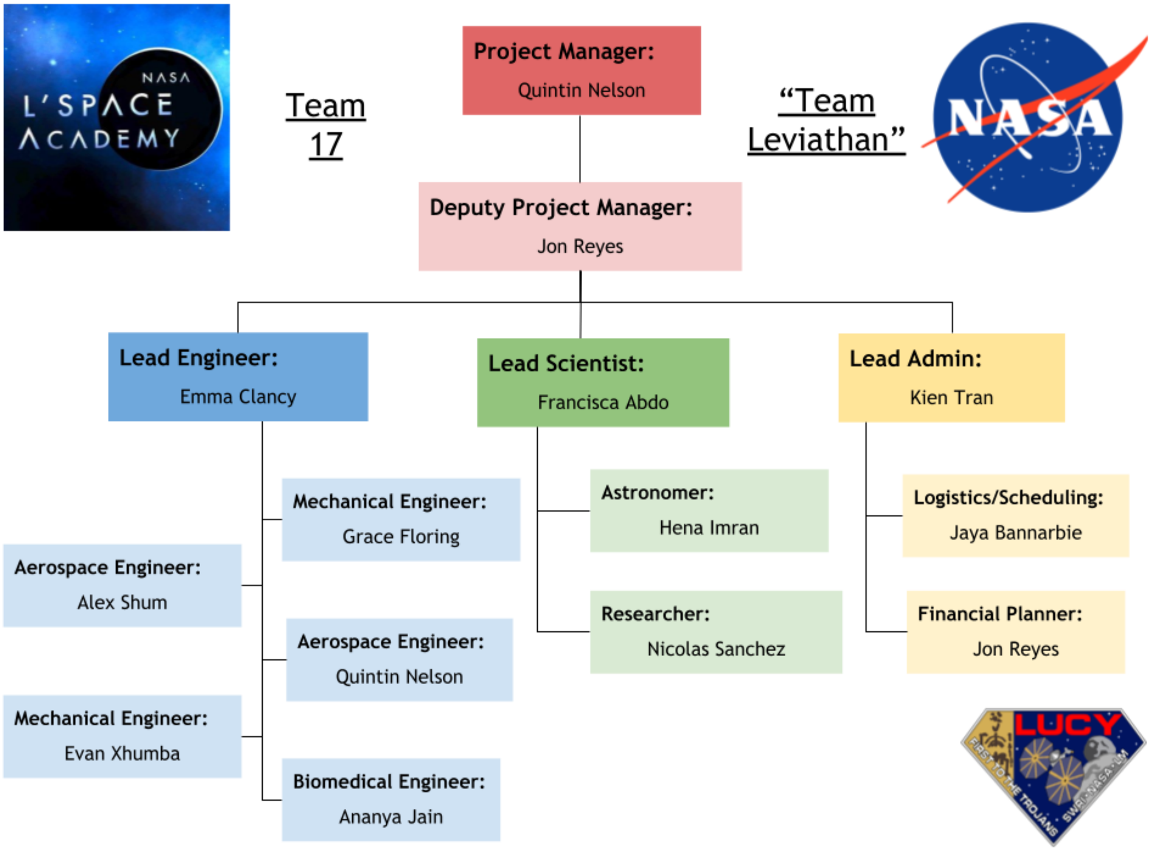


Figure 6.3 -Tree Hierarchy

Simple Group Sets

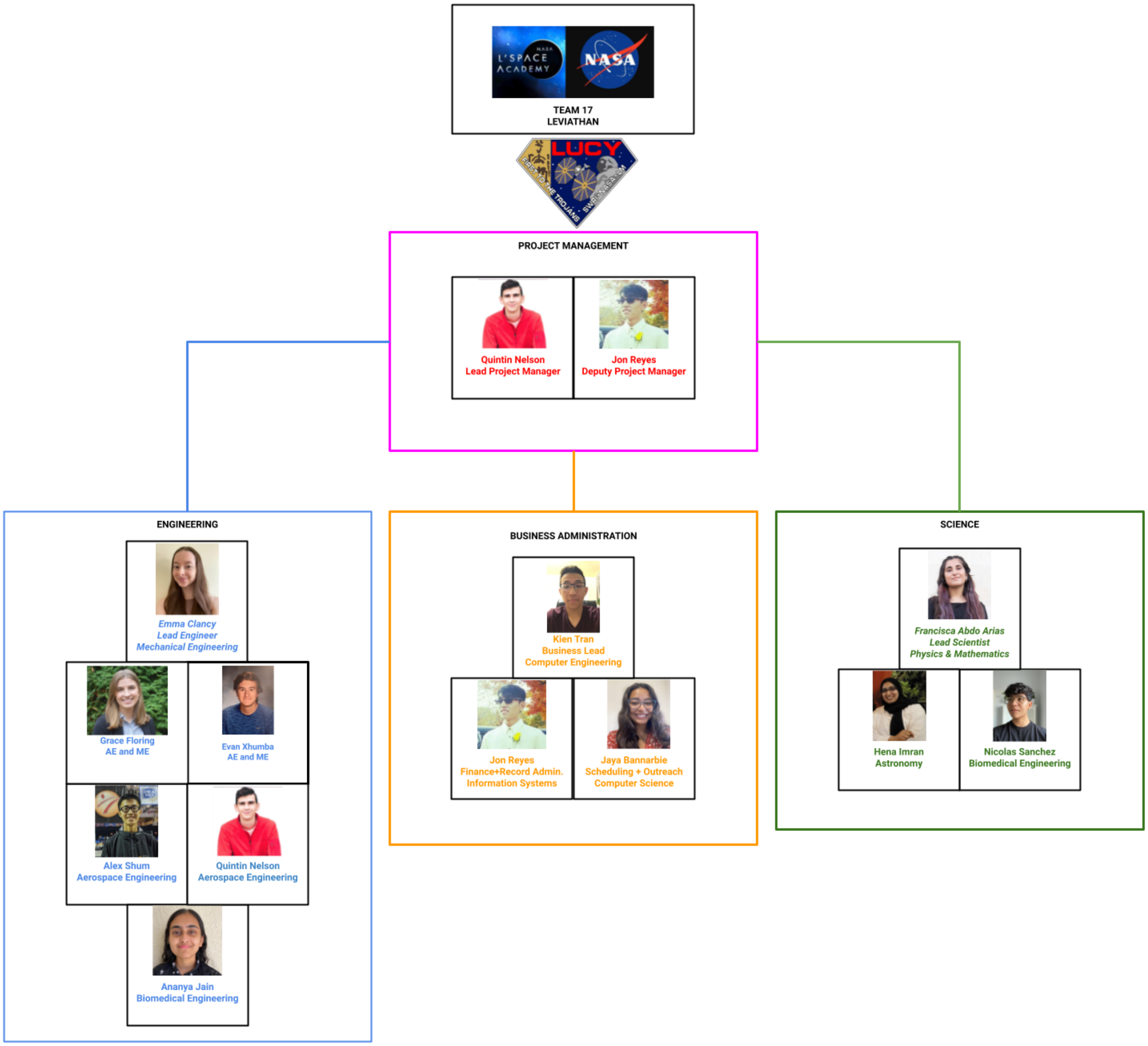


Figure 6.4 - Simple Group Sets

Complex Network

TEAM ROLES

1. Project Management
2. Engineering
3. Science
4. Business Administration

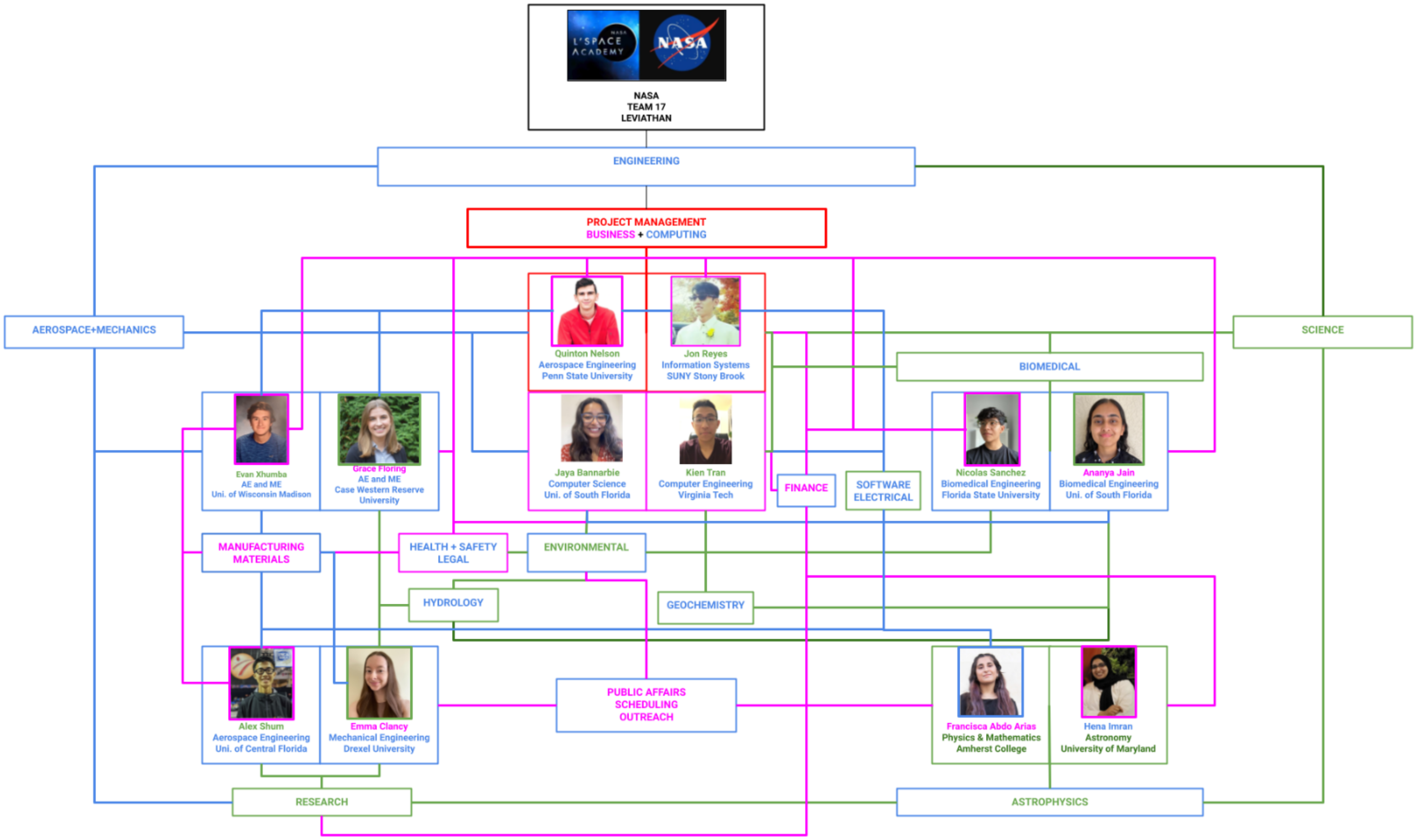


Figure 6.5 - Complex Network

7. Conclusion

The purpose of this mission is to assist with NASA's plans to establish a presence on the moon by researching the abundance of water-ice within the moon's surface. This will be done by finding and measuring near-surface water-ice on the moon's Permanently Shadowed Regions (PSRs) at the Lunar South Pole. The data collected from this mission will allow future NASA plans to use in-site resources to sustain both fuel and air resources. This will, in turn, remove the expense of continuous resupplying of Earth's resources.

This mission will be executed by a land rover. It will be made primarily of 6061 Aluminum (Al) which contains good mechanical properties and can withstand immense amounts of stress. The rover is designed to reduce its volume to allow for easier transport. The volume totals to 732 x 439 x 693 mm when "stowed" aboard the transport rocket. During descent to the moon, it extends to a volume of 892 x 565 x 693 mm. The rover consists of a main body, made of 6061 Aluminum, that houses lithium thionyl chloride (Li-SOCl2) batteries, the RIMFAX radar electronic box, the data processing system, the communication instruments, and the Neutron Spectrometer. The legs, made of aluminum tubing, attached on the side of the housing, are positioned "upward" during launch to allow for a smaller volume and extend during landing to allow a clearance underneath the rover.

The mission will officially start once the rover detaches from the lunar orbiting spacecraft at an altitude of 10km about the lunar surface. Once it lands, it will utilize the scientific instruments on board to collect the mission's data.

The rover will be equipped with a Ground-Penetrating Radar (GPR) based on the Radar Imager for Mars' Subsurface Experiment (RIMFAX). This will gather information on subsurface features, like clusters of water-ice, using radio waves that are transmitted into the subsurface and then reflected into the radar system. A maximum depth of 10 meters can be probed. Since the GPR is only able to reliably distinguish water when it exists in higher concentrations relative to regolith, the rover will also employ a Neutron Spectrometry System (NSS), which will measure changes in the number and energy of neutrons coming from the Moon. The NSS will be used primarily to hone in on possible clusters of water-ice within a radius of about 150 km with a sensitivity of at least 10 ppm of hydrogen, so that the rover may then approach a possible water-ice cluster and confirm its presence with the GPR system.

With such a short span of time between mission introduction and PDR finalization, there are a few things that could be added if more time was given. First and foremost, the thermal control system of the rover has not been developed to the level we wished it could be. The mission will be conducted in a PSR, where temperatures will be extremely low. Due to these low temperatures, we did not add in a heat-shielding system. However, we may need to account for electronic and material issues that could arise in the extreme cold. This was not accounted for in the present version of the design due to time constraints but it will be further developed for the CDR review.

With the finalization of this PDR, the next milestone is the CDR. This will be a more refined and detailed design review to reflect the maturation of the project. In addition to the thermal control system, the rover will undergo more design changes. There will also be more testing, research, and feedback to help mature the mission concept. The CDR is scheduled for review in July of 2022. The next milestones include manufacturing, the SIR, integration, the TRR, and various rounds of testing. The launch is scheduled to occur in October 2028.

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