LUNAR 4NOMALY

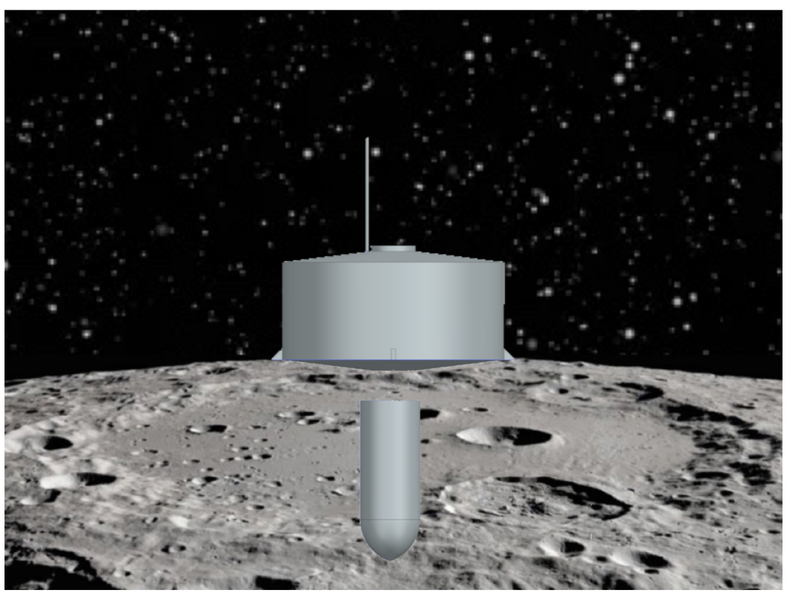
Penetrator Probe

TEAM 40

Preliminary Design Review

NASA L'SPACE Mission Concept Academy

Summer 2021



Colin Gibson, Maikel Heness, Kristen Jingco, Regina Malana, Karl Medel, Aiden Peace, Nannett Perez, Kemal Pulungan, Seemi Zameer

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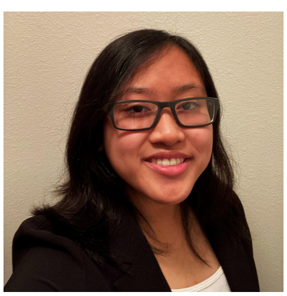
1. Introduction and Summary

1.1 Team Introduction

Colin Gibson
California State Polytechnic University, Pomona, CA
Business Administration Lead
Colin is a Manufacturing Engineering major with an extensive background in precision manufacturing. He is passionate about integrating robotics into manufacturing and quality systems. His past experience working in product development brings a unique problem solving ability to the team.

Maikel Heness
California State University, Northridge, CA
Lead Scientist
Maikel is a recent graduate from CSUN majoring in Mechanical Engineering and working towards a Masters with emphasis on Thermo-fluidic systems. Another strength is working under stress, basically managing to keep a 3.70 GPA along with interning at JPL and volunteering in a research lab. He brings his knowledge in prototyping design and simulation of outer space systems. He excels at communication and teamwork.



Kristen Jingco
California State Polytechnic University, Pomona, CA
Deputy Project Manager; Science Team
Kristen is a fifth year aerospace engineering major who works as a thermo-fluids analyst for her university's Liquid Rocket Lab. She also holds the office of treasurer for Tau Beta Pi, the engineering honors society. Thanks to her university's hands-on coursework, she brings knowledge of leadership, research, and design to the team. She's also versed in systems, structures, orbital dynamics, and mechanical vibrations.

Regina Malana
University of California, Riverside, Riverside, CA
Mechanical Engineer, Engineering Team
Regina is a rising junior studying mechanical engineering. She is passionate about the design aspect of engineering as well as space and all that it has to offer. She brings her creativity and organization, which have been strengthened through past projects and mentorships.

Karl Medel

Los Angeles City College, Los Angeles, CA

Business Administration, Business Team

Karl is an Applied Mathematics major at Los Angeles City College. He has two semesters of C++ experience as well as being familiar with python and mathematica. Having participated in CASGC he brings his research and organization skills to the team as well as his love for problem solving.

Aiden Peace

Saddleback College, Mission Viejo, CA

Engineering Lead

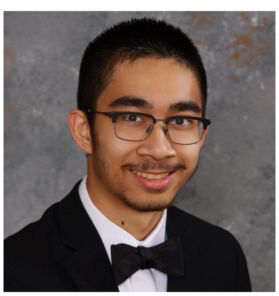
Aiden is a Computer Science major and is passionate about space exploration, engineering design and programming. He has a strong background in C++, HTML, CSS, Python, and Java. He brings creativity, problem solving, communication, CAD/NX design and soft managerial skills.

Nannett Perez

California State University Long Beach, Long Beach, CA

Aerospace Engineer, Engineering Team

Nannett is an Aerospace Engineering student with an emphasis on astronautical engineering. She is involved in the NASA Proposal Writing and Evaluation Experience, where her team is continuing their work for thermal insulation for aerospace applications. She brings her research and design skills through previous leadership experiences.



Kemal Pulungan

California Institute of Technology, Pasadena, CA

Astronautics/Trajectory Planning

Kemal is a Mechanical Engineering major with a great deal of interest in spaceflight. He brings plenty of experience working in teams and solving problems, such as developing electronics as a part of his college AIAA team's entry to NASA's competition to deal with lunar dust.

Seemi Zameer

Chaffey College, Rancho Cucamonga, CA

Project Manager; Business Team

Seemi is a Mechanical Engineering major and is passionate about jet propulsion and engineering design systems. She brings her passion for space exploration along with her project management and research skills through previous leadership experiences.

1.2 Mission Overview

1.2.1 Mission Statement

Lunar Anomaly's objective is to penetrate the moon's surface and analyze the surrounding regolith to determine how much water-ice lays in the top 1 m of a permanently shadowed region (PSR) on the moon's South Pole Region. This mission should give a better understanding of how much ice-water is on the moon. Once the ice-water has been properly measured and mapped human explorers can have a better idea of where to extract water-ice, in order to purify and convert it to oxygen and hydrogen for future uses such as rocket propellant, and drinking water. Water-ice is a crucial resource of which knowledge is much needed before attempting to inhabit the moon for human use, due to its vitality to spaceflight. In order to achieve these goals the penetrator is equipped with the scientific instruments to collect data on the abundance of the water-ice with a measurement accuracy of at least $\pm 1\%$ to send back to Earth. These instruments include devices to detect the molecular makeup of the surrounding surface of the probe.

1.2.2 Mission Requirements

The mission requirements were determined through the team's collective preference towards using a penetrator mission concept along with a set of defined constraints. As a result of the team's decision, the team is required to start the mission at an altitude of 10km after being transported by a primary lunar orbiting spacecraft. The remaining constraints consist of a maximum mass of 180 kg, a maximum volume of 60.1 cm by 71.1 cm by 96.5 cm, and a budget of $200M.

1.2.3 Mission Success Criteria

The mission will be considered successful with the completion of the following criteria:

- Successful EDL procedure, landing within 20 km of the planned landing site
- Successful functionality and calibration of primary on-board instruments
- Collection of data of ice-water composition of lunar surface
- Penetrating 1 m deep in the regolith
- Determining the abundance of ice with a measurement accuracy of at least $\pm 1\%$
- Transmit 75% of data back to Earth

1.2.4. Concept of Operations (COO)

The operation of the mission includes a launch from earth. Proceeding is the Penetrator-Orbiter Separation (Primary Secondary payload seperation). Once completion of separation from the orbiter the penetrator will approach and begin descent on the moon. Collection of data commences on completion of impact. Figure 1 demonstrates the process of the mission.

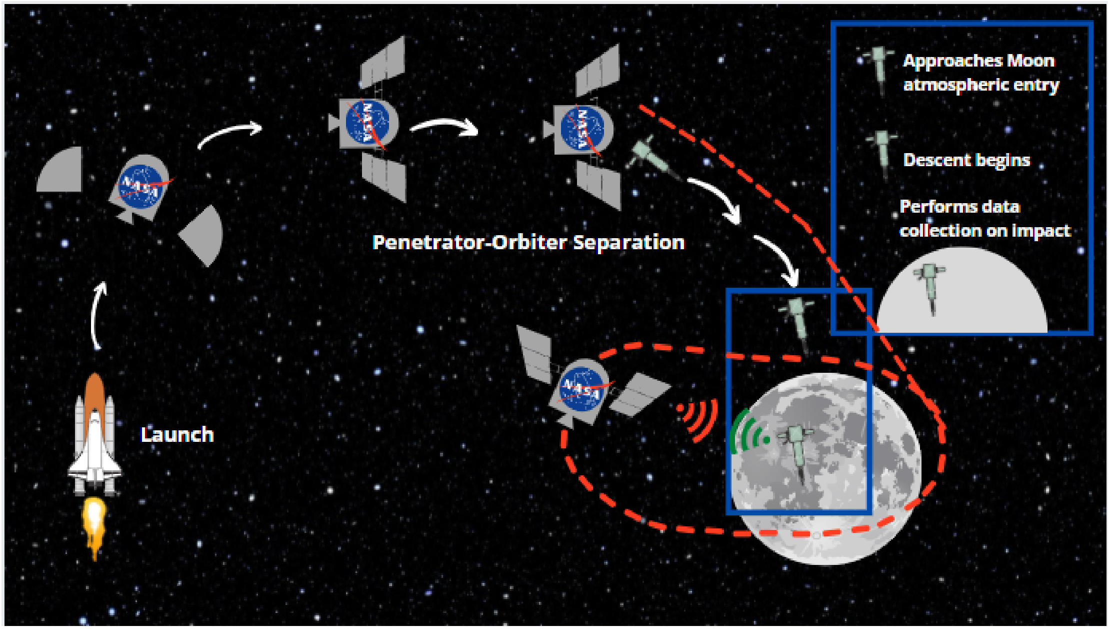


Figure 1: Concept of Operations Graphic for Mission

The penetrator is a secondary payload from the orbiter. It will approach the moon and begin a descent upon atmospheric entry. Once the penetrator has successfully crashed on the moon's surface, it will commence an analysis on the surrounding environment inspecting the water-ice. The data information gathered will be relayed to the orbiter orbiting the moon.

1.2.5 Major Milestones Schedule

The figure below illustrates the project's working major milestone schedule, following the NASA Mission Lifecycle Phases, which span from mission conception through operations, finalized with the mission end point. The duration of the project and mission is intended to roughly coincide with Artemis missions, which emphasizes humanity's return to the moon, and the development of moon mission science and engineering operations by the year 2024. Note that due to this, the length of mission operations and data analyses (Phase E) are subject to change, whether shifted by date or approved for longer duration to meet NASA's needs. Dates can also be altered due to design and/or instrumentation constraints.

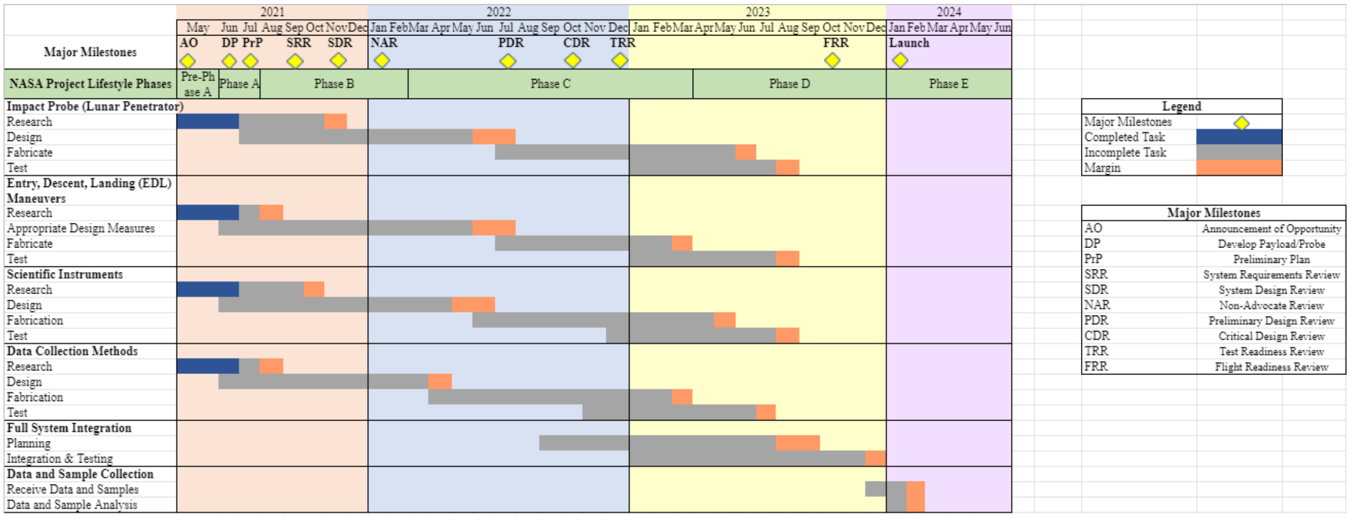


Figure 2: Major Milestones Schedule

1.3 Descent Maneuver and Vehicle Design Summary

The Entry and Descent maneuver will involve the penetrator and orbiting spacecraft beginning at 10 kilometers above the landing site on the surface of the moon, with negligible forward velocity. It will descend into the lunar surface, and as it impacts, bury itself into the lunar surface.

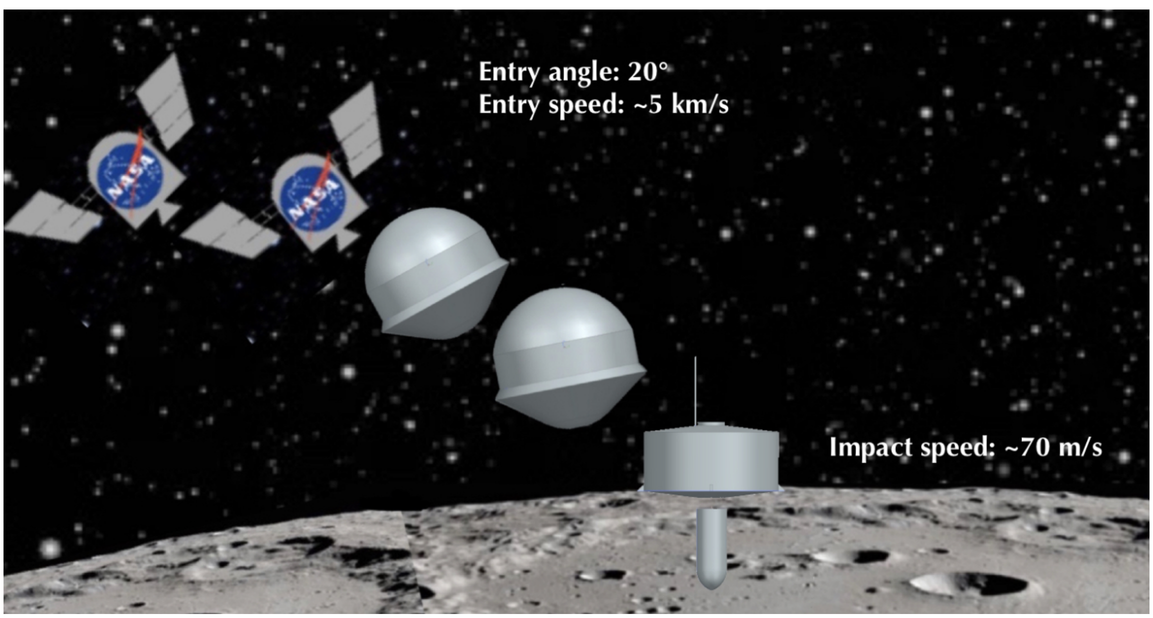


Figure 3: Entry, Descent, and Landing

The working structure of the vehicle included below will include an antenna to transmit data collected throughout the mission. The impact probe that will penetrate the surface upon impact will include a sample collector, spectrometer, drill motor, sensor, and neutron detectors all within the probe. Other components that will also be included are the batteries inside and sensor on top of the spacecraft. To comply with the mission requirements, the penetrator will be less than 180 kilograms, and not exceed a volume of 60.1 cm by 71.1 cm by 96.5 cm. It will be made of a light but still sturdy material to effectively penetrate the surface. The probe will then determine the lunar water-ice in a meter-long depth of the regolith in the targeted area. The material used for this mission concept is Aluminum 6061.

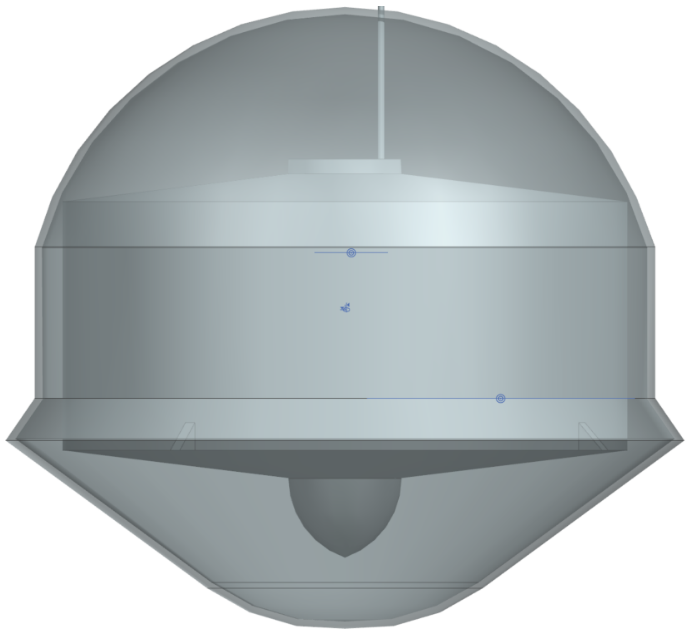


Figure 4: CAD Penetrator Probe Design - Inside Aeroshell

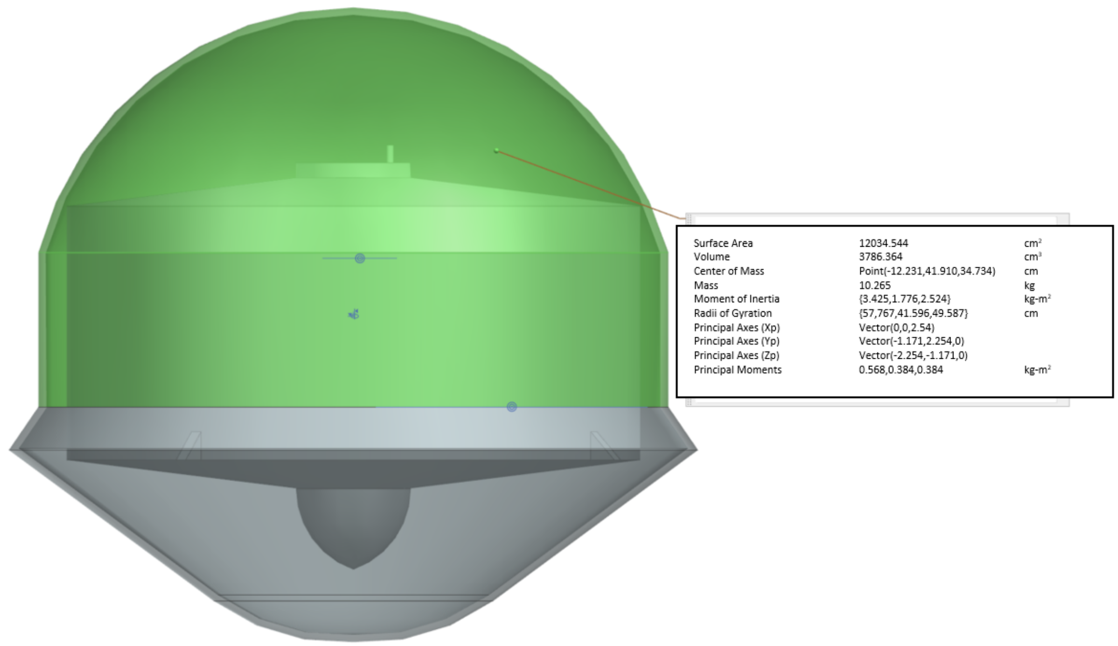


Figure 5: CAD Backshell Design

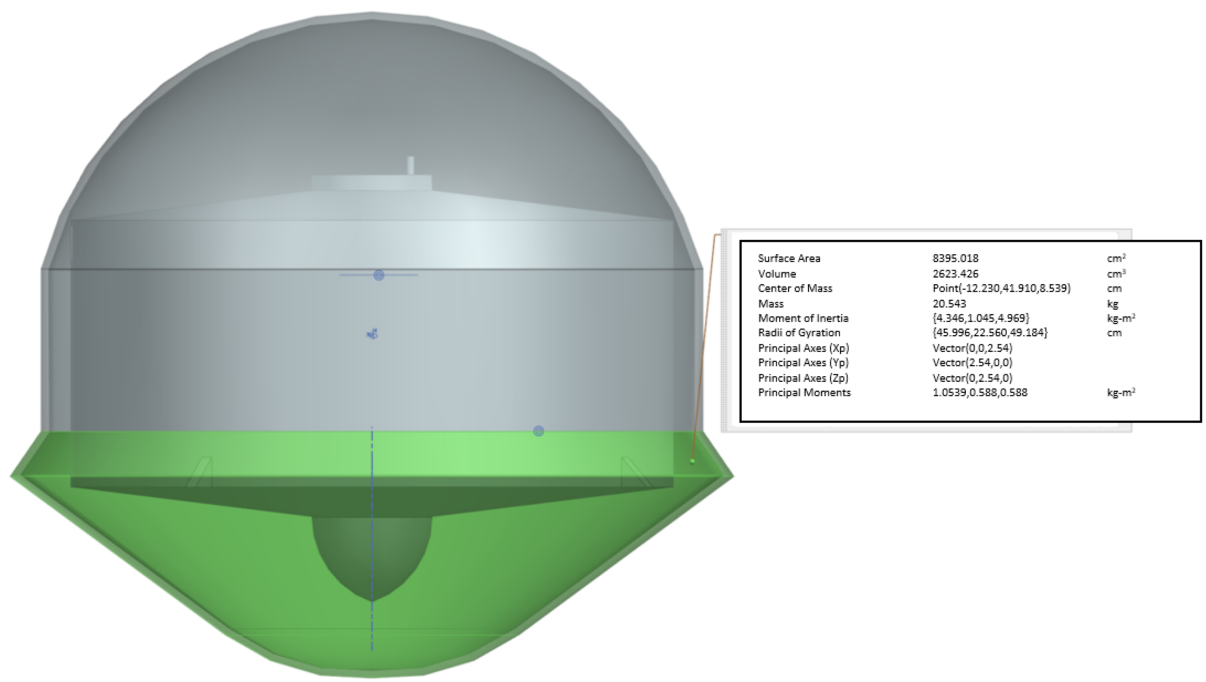


Figure 6: CAD Heat Shield Design

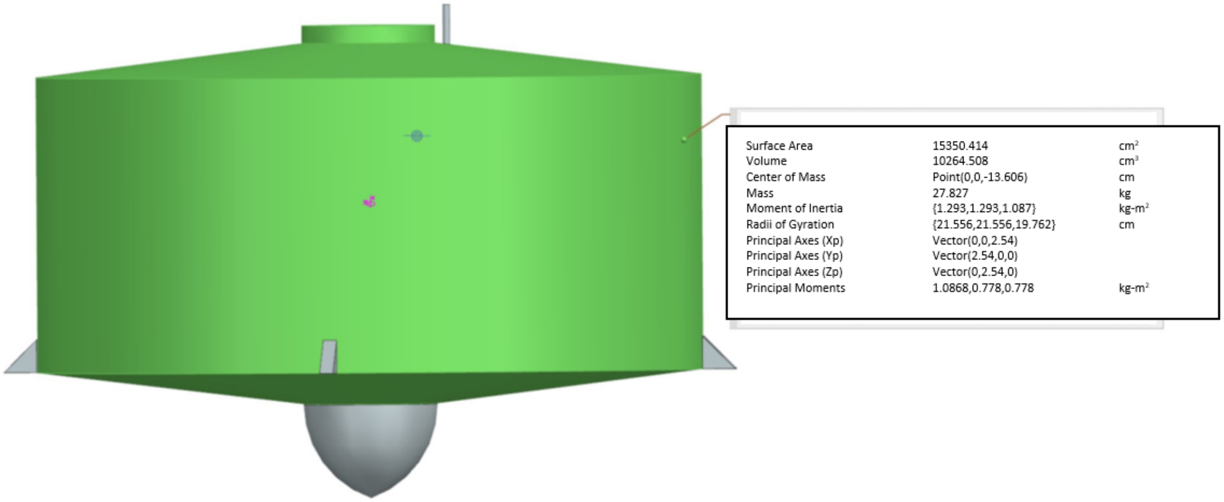


Figure 7: CAD Body Design

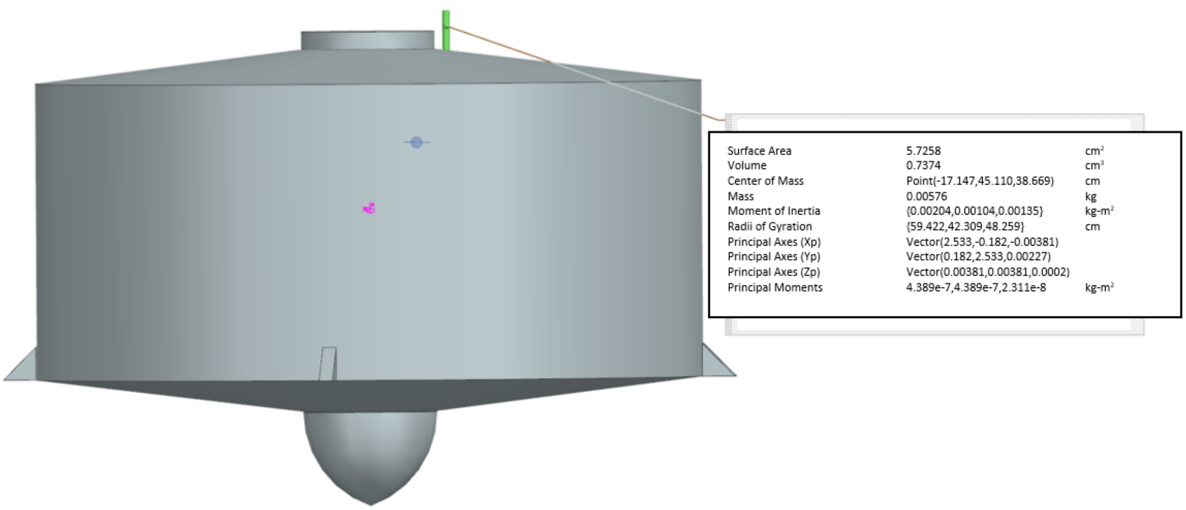


Figure 8: CAD Antenna Design

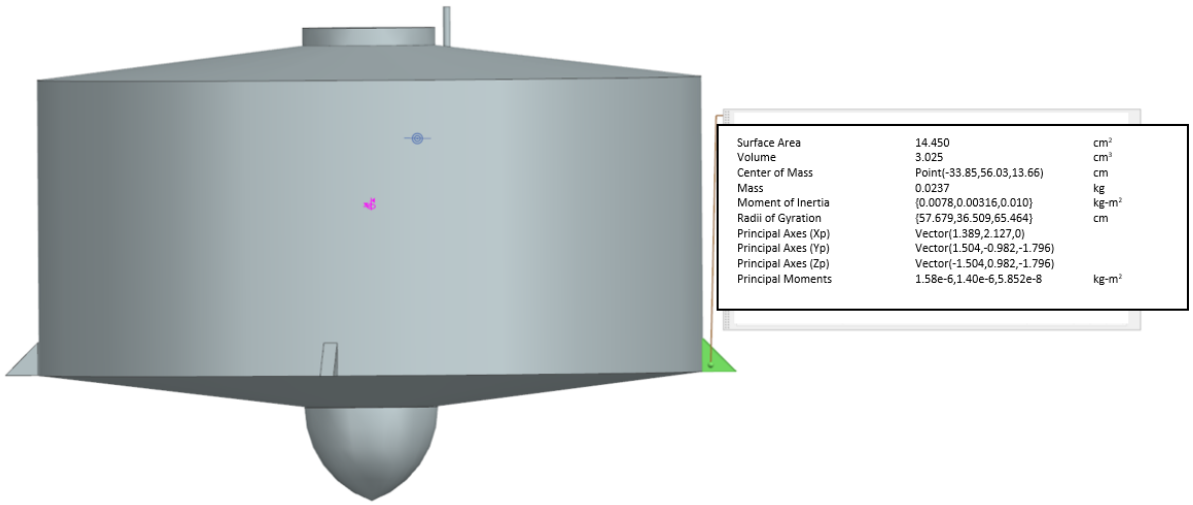


Figure 9: CAD Stand (x4) Design

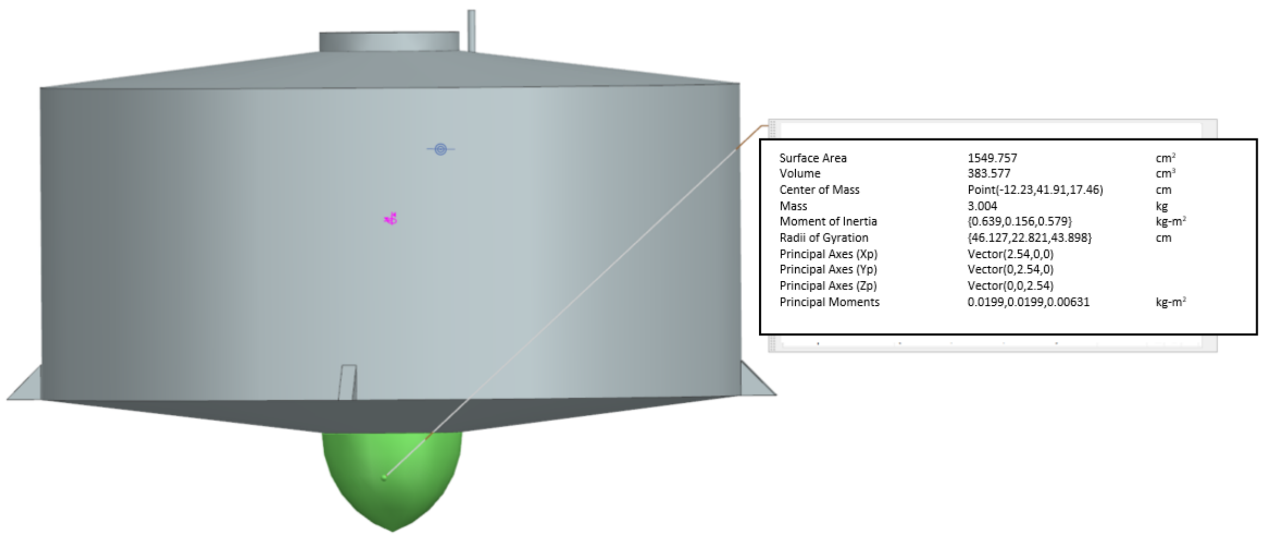


Figure 10: CAD Probe Design

Table 1: CAD Penetrator Design Totals

Penetrator Part	Volume (cm^3)	Mass (kg)
Body	10264.5078	27.827
Antenna*	0.7374	0.00576
Stand (x4)	3.025 (x4)	0.023678 (x4)
Probe	383.5769	3.00364
TOTAL	**10660.922**	**30.931**

*Antenna is retractable, default length is at 2.54 centimeters from surface of penetrator body

Table 2: CAD Aeroshell Design Totals

Aeroshell Part	Volume (cm^3)	Mass (kg)
Backshell	3786.3639	10.2648
Heat Shield	2623.426	20.543
TOTAL	**6409.790**	**30.8079**

1.4 Payload and Science Instrumentation Summary

1.4.1 Science Payload Overview

The impact penetrator probe shall be equipped with a tunable diode laser spectrometer as well as a sample acquisition system. The laser spectrometer is the better option as opposed to a mass spectrometer for the team's mission concept due to its durability and compact design. Several neutron detectors shall be utilized, with the numbers variable due to the working diameter of the probe and the brand of the detector. So far, these instruments shall be the payload for the project, specifically for the probe body of the craft, and will be used primarily for ice detection.

The tunable diode laser spectrometer offers opportunities for measuring the moon's volatiles, even in low abundances. A key advantage for this instrument is its ability to determine the isotopic composition of such volatiles. Testing performed on previous mission concepts has shown that mass spectrometers specifically can survive up to a 1000g loading (and possibly more) while remaining functional. A laser spectrometer may survive an even higher loading (≥ 1000g), and provides a compact option for the penetrator probe. Neutron detectors will be used to measure the hydrogen abundance in the collected volatiles, although a major weakness of these detectors is the inability to determine the chemical state of hydrogen atoms. The other instruments intended for the probe make up for this deficiency.

The rest of the payload craft, not consisting of the penetrator probe body itself, will be equipped with a patch antenna to communicate with the orbiter, a temperature sensor, and a lithium-ion cell battery.

1.4.2 Science Instrument Placement

Regarding the impact probe design, the sample collector shall be located at the top end of the probe, furthest away from the penetrating nose cone. The laser spectrometer will be located on one of the sides of the probe, situated before the nose cone. Several neutron detectors will line the interior diameter of the penetrator probe for the probe’s inner structural integrity and for efficient sample analysis. The current configuration for the probe’s scientific instruments is illustrated in *Figure 5* below. A more complete structure for the entire craft is present in Section 1.3.

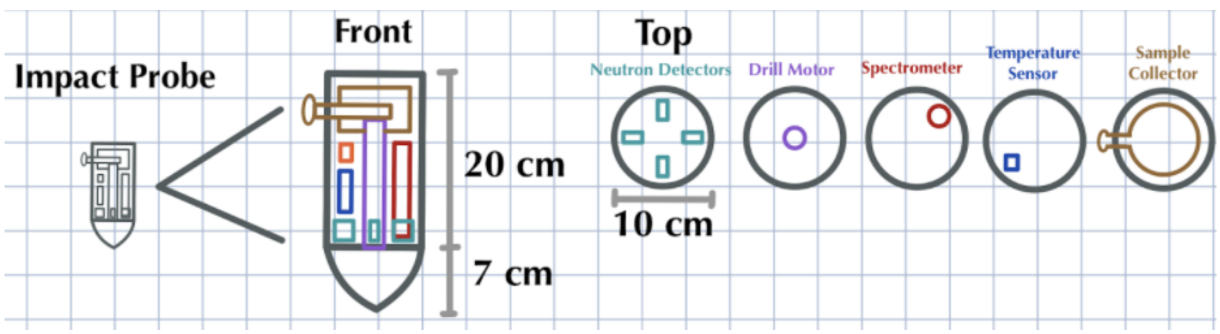


Figure 11: Instrument Placement on the Probe

2. Evolution of Project

2.1 Evolution of Mission Experiment Plan

During the initial stages of planning and development of the mission there was the obstacle of what space vehicle to choose. The team ended up opting for the design of a penetrator probe that, upon extensive research, seemed to be the most optimal choice to fit the constraints that were proposed in the mission document. From here choosing the materials and instrumentation were taken into account as a penetrator probe would be more probable of damaging the payload upon impact on the moon's surface, so choosing materials that would protect the payload was imperative. The science objectives remained constant or largely the same as the mission was still to explore the moon for signs of potential sources of water that could be utilized for human exploration during the mission to the moon. The mission was to have the penetrator probe impact the moon and analyze the surrounding terrain relaying the information to the main orbiter.

2.2 Evolution of Descent Maneuver and Vehicle Design

Descent Maneuver

The initial descent began with the separation of the orbiter from the spacecraft before the orbit around the moon. However, this changed to the separation occurring during the orbit of the moon.

Vehicle Design: First Iteration

The first design iteration involved a placement of scientific instrumentation in scattered positions around the impact probe. The neutron detectors were initially placed on only one side and above the “sensors,” which were not specified until later in the process.

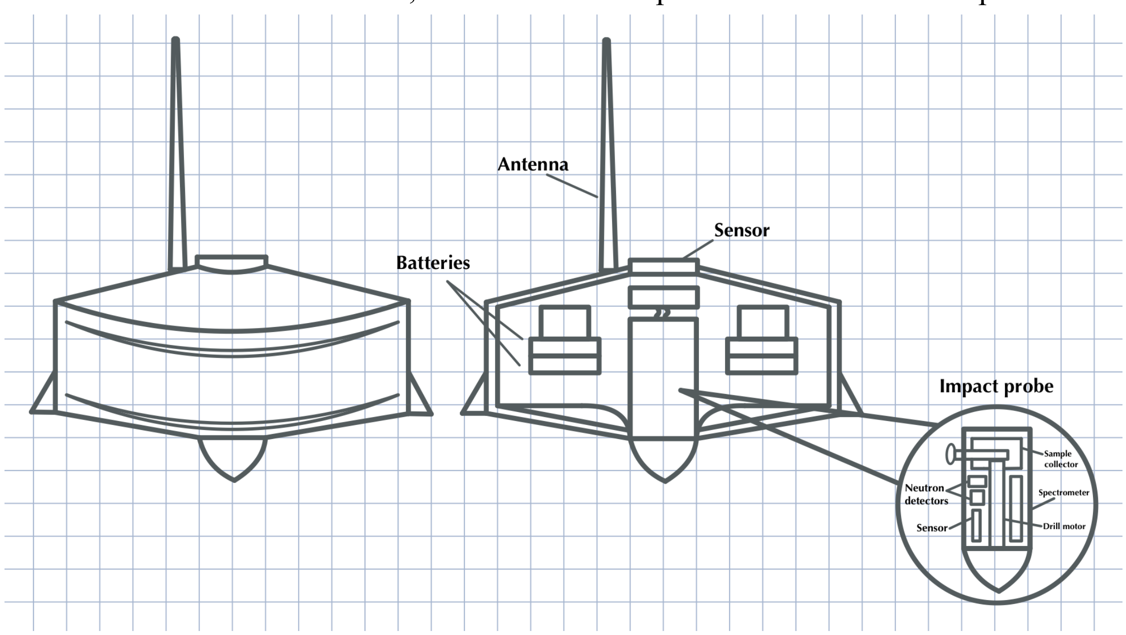


Figure 12: First Iteration Penetrator Probe and Impact Probe Design

Second Iteration

The second iteration of the vehicle design consisted of the neutron detectors lining the inner perimeter of the impact probe, and below the temperature sensor. This change in the placement of the neutron detectors served to improve the structural balance as well as the efficiency of sample analysis of the impact probe. However, this design’s flaws lay in the shape of the aeroshell, which fit the mission requirements but were too wide for an efficient entry and descent.

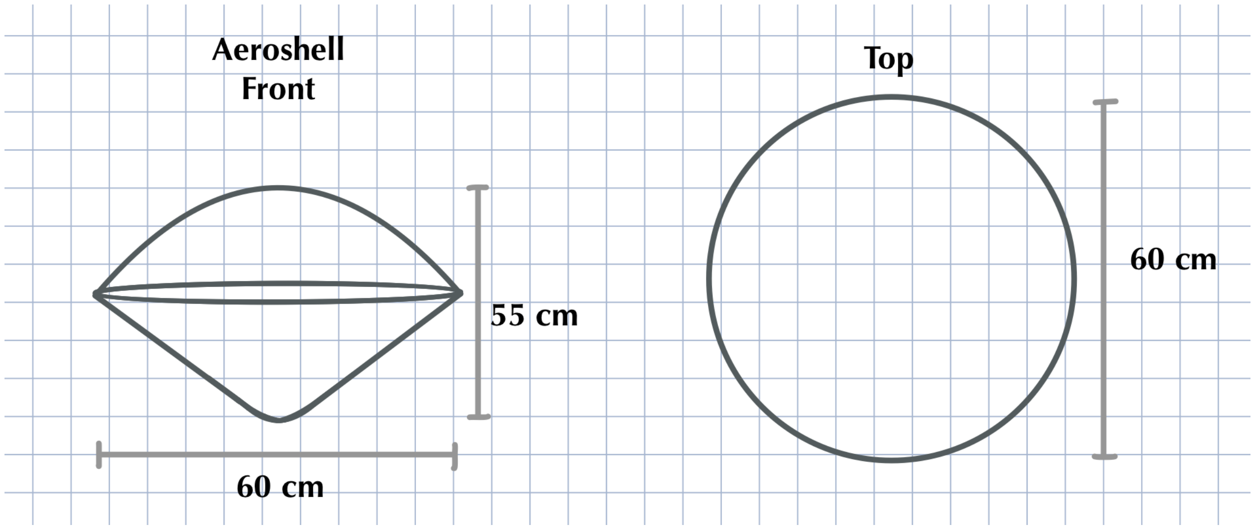


Figure 13: Second Iteration 2

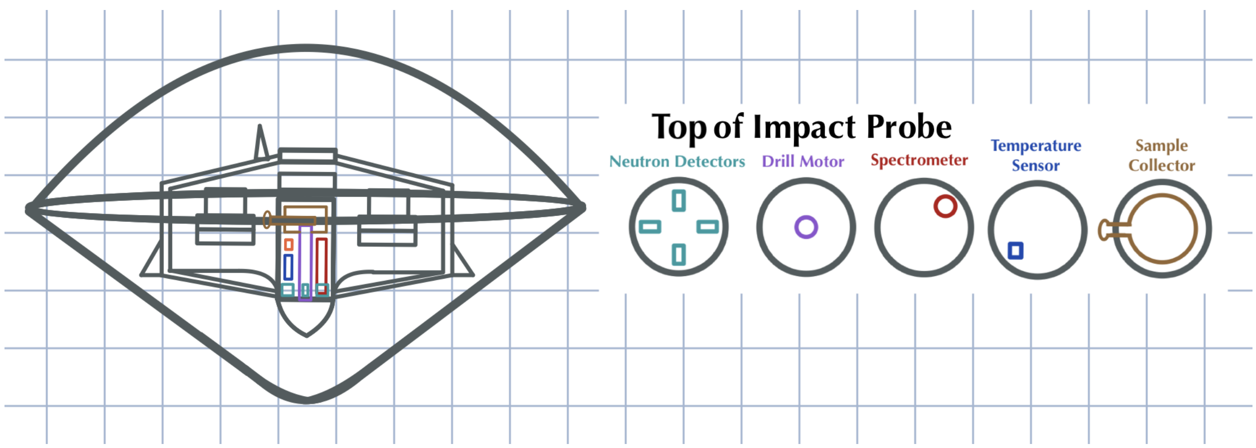


Figure 14: Second Iteration Mission Concept Design with Aeroshell, Penetrator Body, and Impact Probe with Instrument Placement

Third Iteration

The third and final design included changes to the overall shape of the aeroshell. The final aeroshell fits the shape of the penetrator body in a more efficient way and its narrower yet taller backshell allows for a smoother entry and descent into the lunar atmosphere. These changes were on top of the improved design of the impact probe components that were revised in the second design.

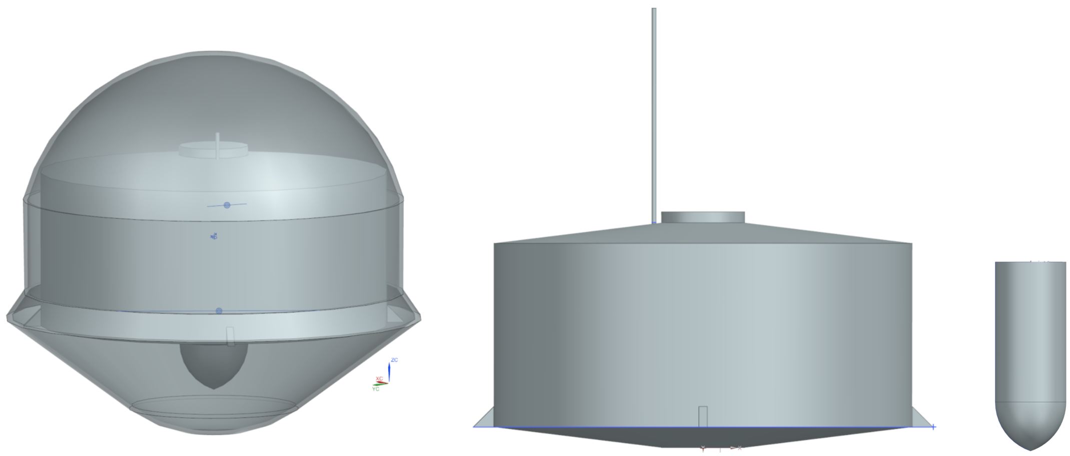


Figure 15: Third Iteration Mission Concept Design with Aeroshell, Penetrator Body, and Impact Probe

2.3 Evolution of Payload and Science Instrumentation

First Iteration

The initial payload design for this mission concept involved a number of science instrumentation located within the impact probe (as mentioned previously) with the main focus of determining the concentration of hydrogen, oxygen, and carbon in order to distinguish water-ice from the Moon regolith. These instruments included neutron detectors, a spectrometer, and sample collector. However, it was not yet known which type of spectrometer should be utilized. The options narrowed down to either a mass spectrometer or tunable diode laser spectrometer, also known as a tunable laser spectrometer, or simply TLS. An example image of a mini mass-spectrometer, which was designed and utilized by NASA's Jet Propulsion Laboratory (JPL) for space application, is shown below. The usage of neutron detectors was also debated, as these instruments fail to determine the chemical state of hydrogen atoms. At this point during the design phase, a sample collector was included along with a sensor. It was still unsure which type of acquisition system was to be placed on the probe, or what type of power source would be fit onto the descending vehicle.

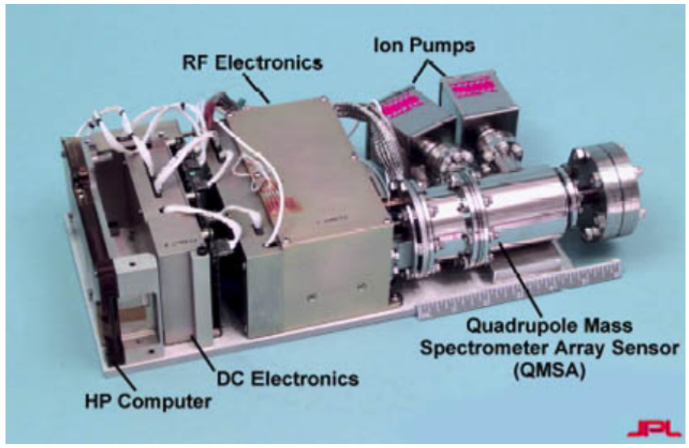


Figure 16: Mini-mass Spectrometer, 2001 Laboratory Network

Second Iteration

The next design iteration involved similar aspects with its predecessor, with determinations made for the instrumentation. It was decided to include the neutron detectors along with the TLS so that each instrument type could make up for each others' weaknesses, and so that additional composition data may be collected for each sample. The image below depicts a TLS which was used for NASA's Curiosity Mars Rover. The following image shows an example of what a neutron detector looks like, although these instruments can vary in appearance slightly due to brand.

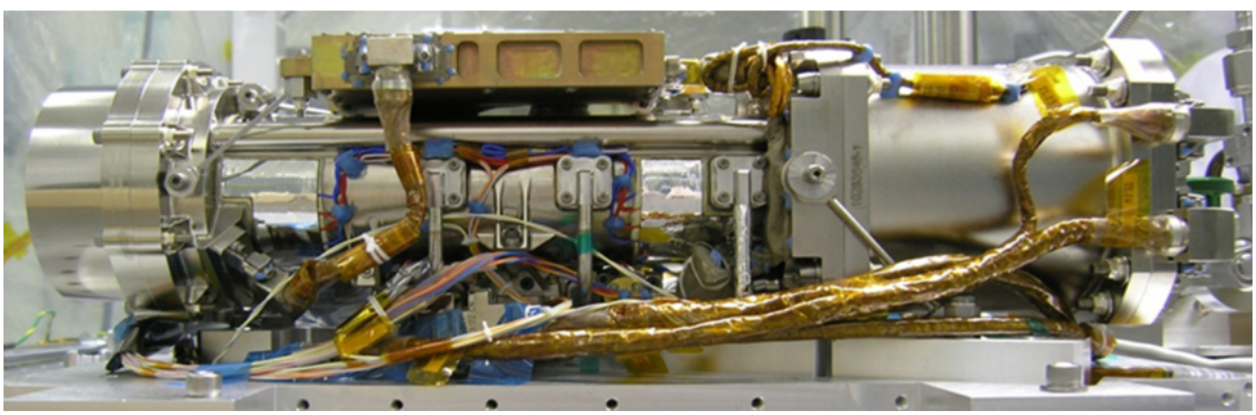


Figure 17: Tunable Laser Spectrometer, 2017 NASA

Figure 18: Neutron Detector, VF Nuclear

The implementation of a power drill was added into the sample acquisition system, along with a sample collection cup. It was also decided that an antenna be placed on the vehicle body which holds the probe in order to send back mission information and data to the main orbiter.

Third Iteration

The spectrometer instrument was reevaluated and it was decided to use a tunable laser spectrometer setup closer to the Deep Space 2 one, as both the one for Deep Space 2 and this mission were to detect "Subsurface Sample Water." Furthermore, the size of this spectrometer is designed to fit into the compact space that the probe holds. It has the drill to collect the sample, a heater to turn volatiles into vapor for the laser to detect.

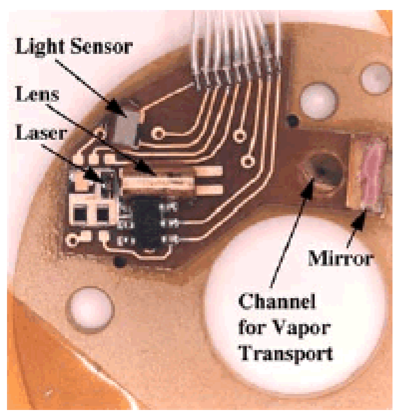


Figure 19: Laser Spectrometer, 1999 J. Geophys. Res.

The communication system was further refined to be a patch antenna, as any deployables risk not functioning properly due to the extremely low temperatures of PSRs on the moon. A battery needed to be able to run the experiments for long enough to obtain the needed data was determined to be one with at least 40 Wh of capacity.

3. Descent Maneuver and Vehicle Design

3.1 Selection, Design, and Verification

3.1.1 System Overview

The descent of the penetrator will follow the entry of the primary lunar orbiting spacecraft. At an angle of 20 degrees and an altitude of approximately 10 kilometers above the moon's surface, the probe will land on the lunar terrain with a balloon that is discharged to decelerate its impact velocity to approximately 70 meters per second. The probe will be encased in an aeroshell that will provide a heat shield to protect the probe from extreme heat conditions upon entry. The aeroshell itself consists of a backshell and heatshield.

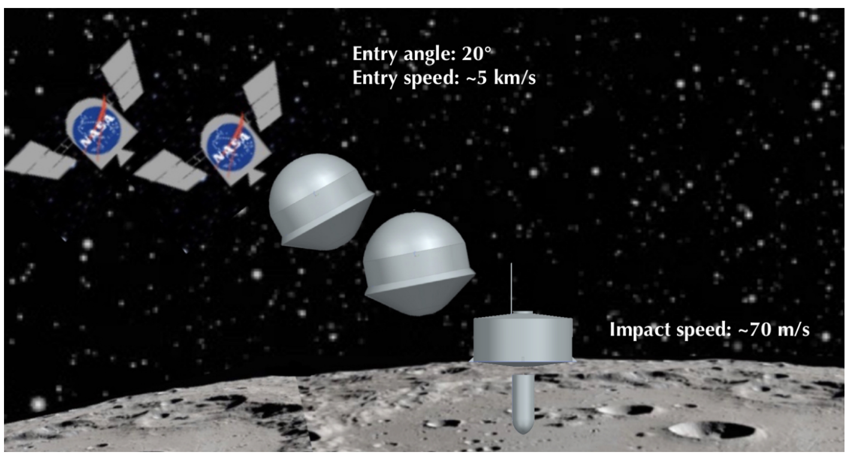


Figure 20: Entry, Descent, and Landing Procedure

3.1.2 Subsystem Overview

- **Penetrator Body**

The penetrator body will be about 55 cm in length and 30 cm in height, with an antenna that will extend about 45 cm. It will have a body diameter of about 50 cm; however, with the addition of four fins that are approximately 2.5 cm each, it will run an overall circumference of 55 cm. Additionally, in order to keep the impact probe in place, it will have an inner diameter of about 10 cm. It will contain batteries across both sides of the cavity of the impact probe, a radio transceiver above one side, and an accelerometer above the other side. The craft will be able to withstand a significant impact while still transmitting data about the lunar surface.

- **Impact Probe**

The probe will be assembled and inserted into the penetrator body. It will have a circumference of 10 cm, and an overall height of 27 cm. The probe is separated into a few components. The drill nose-cone will be approximately 7 cm in height, and the body enclosing instrumentation will be about 20 cm. This body will house the instrumentation needed to drill into the lunar surface. It consists of neutron detectors, drill motor, laser spectrometer, temperature sensor, and sample collector. There will be four neutron detectors, and their role is to detect if a region contains water ice deposits. Additionally, the drill motor is designed to extract the lunar surface for placement of the probe.
The spectrometer is meant to comprehend physical properties of components over a given range. The temperature sensor works hand in hand with the neutron detector to contribute to the understanding of the nucleus' physical properties. Lastly, the sample collector is to store the processed water-ice from the lunar south pole's surfaces.

- **Aeroshell**

The aeroshell is designed to encapsulate the payload, such as the penetrator, probe and any additional equipment needed to support a safe landing. It will have a height of about 55 cm and a diameter of 60 cm, equivalent to a length of 60 cm. It is made up of two primary components, which are the heat shield and the backshell,they will both be Aluminum-6061 The heat shield is designed in a half-cone shape to protect the probe from harsh environments, such as the intense heat it is to be subjected to upon entry. The backshell is designed in a dome shape to protect and support the payload within it. Together, these components serve to encapsulate and thermally protect it upon the descent phases.

An inflatable balloon parachute will act as a decelerator that reduces the penetrator's velocity on impact. The parachute inflates to a 2 meter diameter and will provide enough drag force to slow the landing of the penetrator to 70 m/s, an impact velocity that will mitigate damage of the penetrator but also provide enough speed to collect a 1 meter deep sample of the targeted regolith upon impact.

3.1.3. Dimensioned CAD Drawing of Entire Assembly

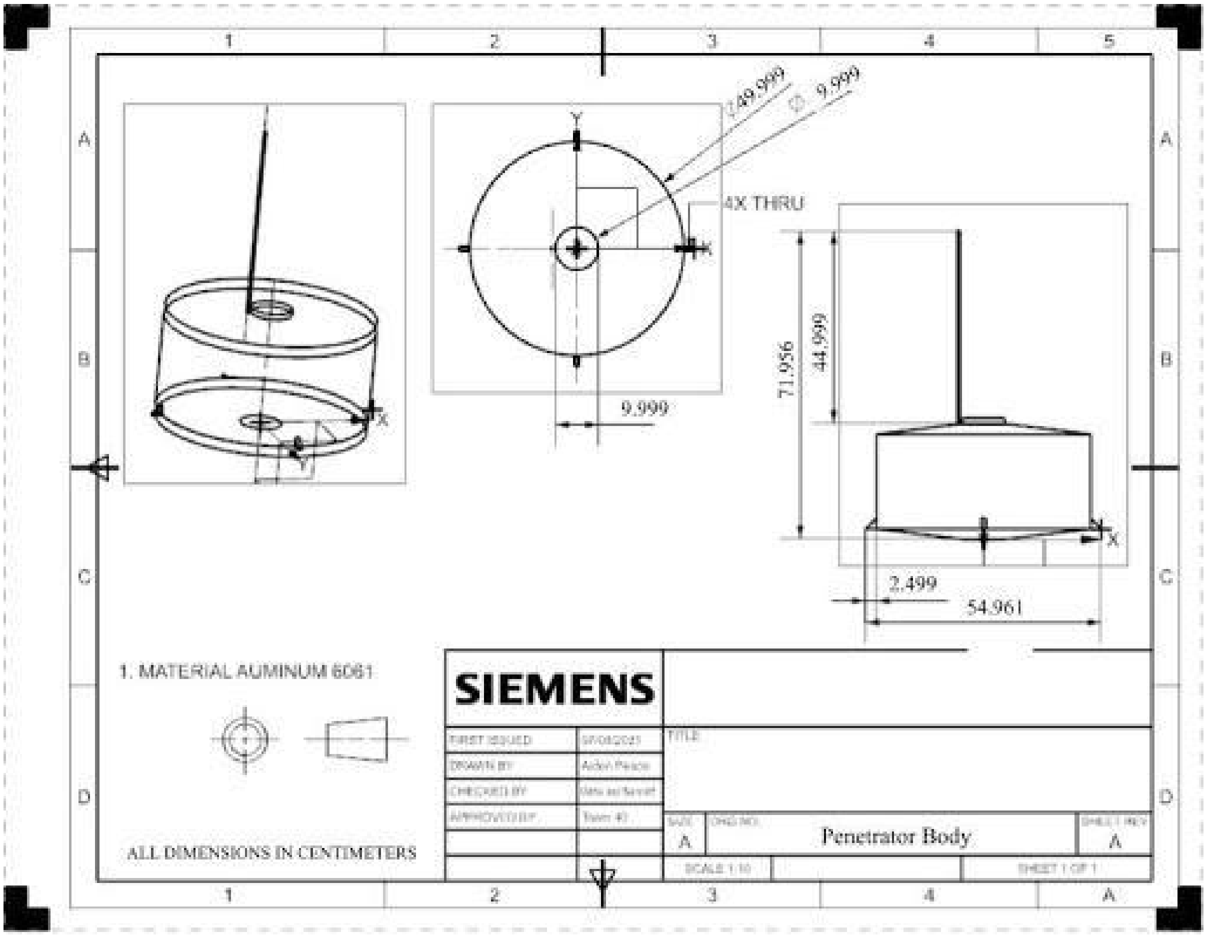


Figure 21: CAD Drawing of Penetrator Body

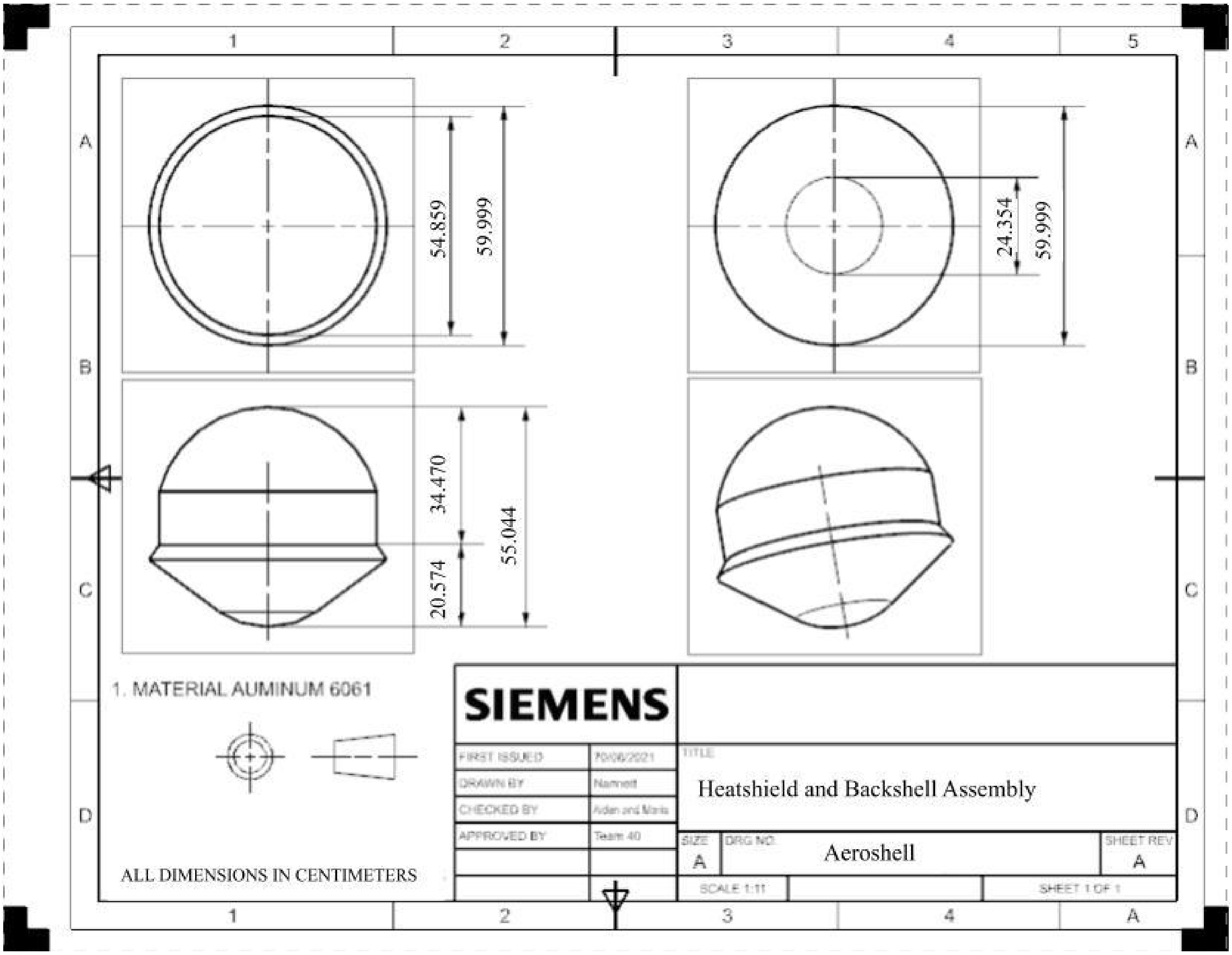


Figure 22: CAD Drawing of the Aeroshell

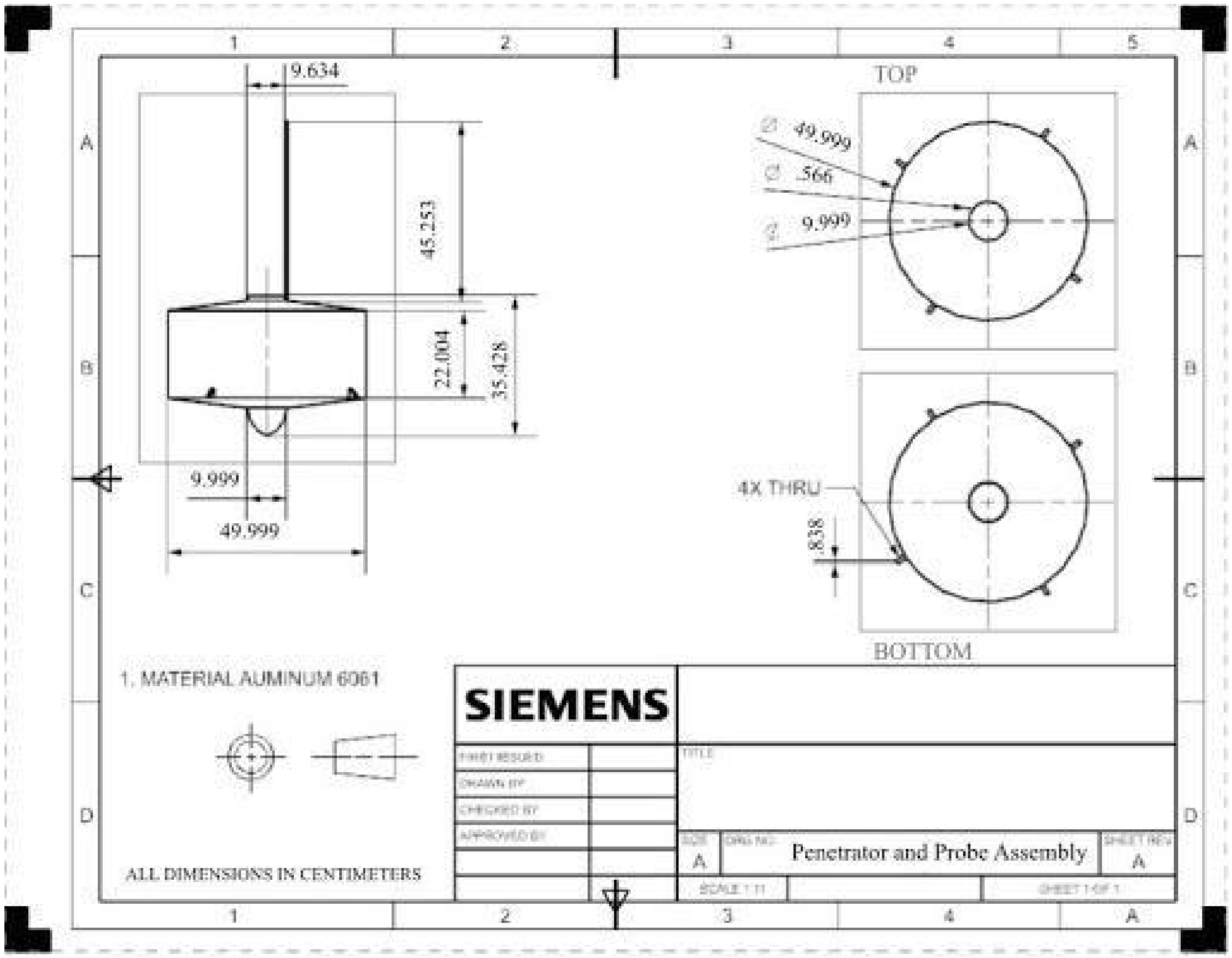


Figure 23: CAD Drawing of the Penetrator and Probe Assembly

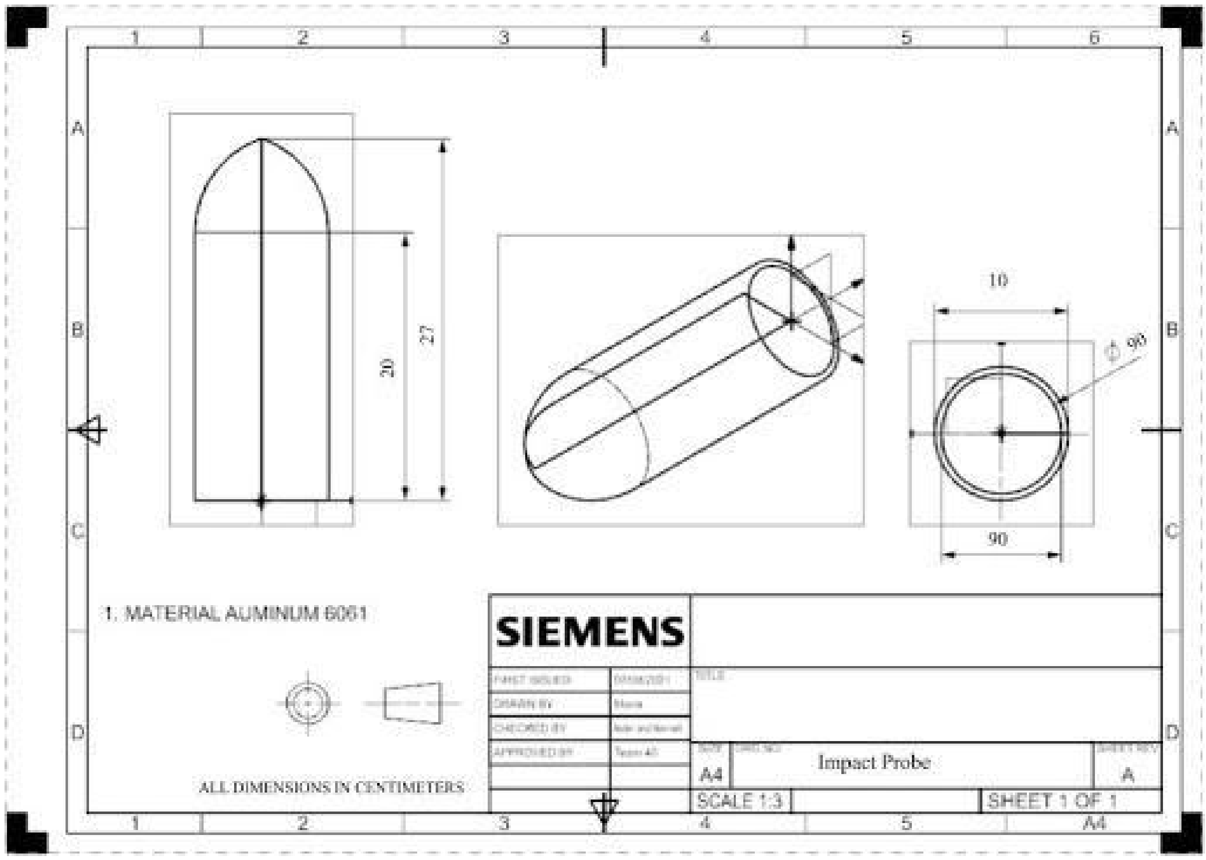


Figure 24: CAD Drawing of the Impact Probe

3.1.4 Manufacturing and Integration Plans

The plan for this mission is to design a mission concept capable of mining lunar water-ice. This is set to be done through the utilization of a penetrator that will house an impact probe to mine for water. In order for this to be achieved, the penetrator probe body is set to take about four months, and undergo testing for two. While the impactor body is set to take about five months, with less than two months of testing. The integration of the system in its entirety is subjected to continuous change as data collection is reviewed. From planning to testing the integration of the entire system takes about ten months to achieve. Overall, the manufacturing of such a system will be done in a facility and take into account the material and instrumentation needed to be used to achieve such tasks. The antenna and power source will be outsourced to ensure that they perform to their full capabilities. These components will be purchased from credible sources with good reputations to enforce that they are able to perform efficiently and effectively.

3.1.5 Verification and Validation Plans

The validation and verification of the design runs concurrently with the manufacture of the parts. Simulations will be performed alongside the development of the parts to verify that they meet the mission requirements. These simulations will involve scientific instrumentation in a controlled environment to predict and prevent failures.

Table 3: Verification and Validation Plans

Analysis	The analysis of the system involves the engineering model or prototype in order to verify the design's suitability. The system must be modeled and simulated with the use of mathematical models and techniques to attain data regarding the system's compliance to the requirements.
Demonstration	The system will be verified through the demonstration of a prototype or model of the system in an environment much like that of the moon's permanently shadowed regions (PSRs). Rather than collect detailed data, this process of verification serves to verify the design's capability through repeated demonstrations of trial and error from a flying aircraft such as a helicopter onto rough terrain.
Inspection	The verification of the overall physical design of the system will be performed through inspection. Using a detailed checklist, the finalized design will be inspected for each component and subsystem so that they are confirmed to meet the requirements.
Test	This process will produce the most detailed data to validate the efficiency and compliance of the vehicle in its targeted location. The system will be tested for its acquisition of regolith composition, the effectiveness of the laser spectrometer, the neutron detectors, and the electric drill.

3.1.6 FMEA and Risk Mitigation

The purpose of a FMEA is to identify any potential flaws that can exist within a product and cause failure. Identifying these flaws is essential to make sure that plans do not become delayed at the day of launch. Ranking the flaws in severity scale will aid in determining which problems should be taken care of. The most severe flaws will be attended to first. Severity will be measured from a scale of zero thru ten. Zero being no severity detected and ten needing immediate attention. The figure below provides a description of some of the potential flaws that may occur.

Table 4: Failure Mode and Effects Analysis Chart

Risk #	Function(s)	Failure Mode(s)	Effect(s)	Sev	Cause(s)	Occ	Controls Prevention	Det	RPN	Recommended Action
1	Parachute	Parachute does not deploy	High velocity impact with lunar surface	8	Parachute entanglement	2	Performance testing and modeling to ensure correct deployment initiation	2	32	Ensure that the Parachute is assembled correctly
2	Communications	Lost of communication	Unable to communicate with penetrator probe	7	Signal lost/jam or damaged antenna	2	Flat-sat testing and testing with penetrator probe	2	28	Making sure that the chosen materials protect the antenna to prevent any lost/jam communication
3	Payload	Payload could be damaged upon impact	Internal payload damaged	9	Chosen material unable to withstand impact	3	Protective housing of payload through aeroshell and performance testing upon impact	2	54	Demo tests with penetrator testing different materials to make sure payload survives impacts on surfaces similar to the moons
4	Power/Battery	Incorrect battery selection	Not choosing the correct battery could shorten the mission lifespan	6	Not enough power is provided to support mission,	2	Ensure adequate battery is chosen	3	36	Extensive research for selection of the correct battery for the mission and backup battery supplies
5	Trajectory	Loss of control resulting in incorrect trajectory	Probe does not land at its designated trajectory	7	Miscalculations and Delayed deployment of secondary payload	2	Performance testing	2	28	Run simulations ensuring no loss of control or miscalculations are detected
6	Penetrator	Penetrator does	May not	9	Systems not	3	Performance	2	54	Guarantee that

		not deploy	land in the desired coordinates		responding		testing			systems are responding accurately during tests. Preventing likelihood of malfunctions once probe is in space.
7	Entry	Thermal Insulation	System overheats on entry	4	Chosen material unable to withstand intensive heats on entry	2	Performance (Heat shield) testing	3	24	Ensure that the material or coating can withstand the heats of entry and descent

		Consequence		
		Low	Med	High
Likelihood	High			
	Med			
	Low		4,7	1,2,3,5, 6,

Critically	Trend	Approach
High	Decreasing (Improving ↓)	M - Mitigate W - Watch
Med	Increasing (Worsening ↑)	A - Accept R - Research
Low	Unchanged (→)	

Figure 25: Risk Matrix with Trend and Approach Information

Table 5: Risk Consequences, Likelihood, Trend, and Approach

Risk #	Critically	Trend	Approach
1	Consequence: High Likelihood: Low	↓	M
2	Consequence: High Likelihood: Low	↓	M/R
3	Consequence: High Likelihood: Low	↓	M
4	Consequence: High Likelihood: Medium	↓	R
5	Consequence: High Likelihood: Low	↓	M
6	Consequence: High Likelihood: Low	↓	M
7	Consequence: High Likelihood: Medium	↓	M/R

3.1.7 Performance Characteristics and Predictions

Team 40's mission is predicted to succeed on the Lunar terrain with its carefully planned entry, descent, and landing. The mission is deemed successful when the following occurs: successful EDL procedure, successful functionality and calibration of primary on-board instruments, collection of data of ice-water at a scale of few kilometres of the PSR, penetrating 1 m deep in the regolith, determining the abundance of ice with a measurement accuracy of at least ±1%, and transmit 75% of data back to Earth.

Through the antenna of the vehicle, data collection is accessible throughout the mission by transmitting data back to Earth. It is to be mounted to the top of the penetrator body and expected to uphold a 75% threshold.

3.1.8 Confidence and Maturity of Design

Throughout the process of ensuring the confidence in the designed prototypes and models, components will be updated and improved progressively. By undergoing analysis, demonstrations, inspections, and tests, members are able to identify flaws to improve upon. Team 40's system maximized its resources in creating a design to successfully meet the mission requirements. The structure of the penetrator was designed to withstand lunar conditions and its entry, descent, and landing makes use of the most reliable techniques verified by past missions. Initially, the penetrator was designed to have no parachute or balloon to decelerate its impact velocity. However, the design of the mission entry evolved to have a balloon parachute to act as a decelerator. This decision came along with the consideration of the high risk that the penetrator would break at a very high impact velocity of around 200 m/s.

3.2 Recovery/Redundancy System

Despite verification and validation planning for all instrumentation; unexpected failures are possibilities that need to be accounted for. As a result, it is essential to identify and establish a mitigation process if any were to occur. To mitigate the effects of lunar dust and weathering in the lunar environment, the scientific instruments are encased in a durable cylinder of the impact probe. These instruments will be protected during the mission so that they can successfully acquire the data on the lunar surface. The penetrator body is equipped with multiple lithium batteries that will power the instrumentation throughout the mission and also withstand the impact. There are also redundant neutron detectors lining the inside of the impact probe to ensure that data collection of hydrogen abundance in the samples in case a detector is obstructed or ineffective upon landing. The entirety of the penetrator is inside a larger body of the spacecraft that will protect its contents through the impact upon landing. The penetrator is also protected by the backshell and heat shield of the aeroshell through the descent of the vehicle. These parts are made of aluminum and are built to withstand the extreme conditions to ensure a stable and protected landing.

3.3 Payload Integration

The penetrator body holds the lithium batteries made to sustain the high impact the penetrator will encounter upon landing. These batteries surround the impact probe housed inside the body of the penetrator and serve to power the scientific instruments needed to collect the data on the mission. The radio transceiver atop the batteries will transmit communications and calibrations performed on the regolith of the targeted surface. The accelerometer will measure data during the descent of the penetrator, from entry to landing, ensuring that the velocity obtained complies with mission criteria.

The sample acquisition system, which consists of an electric drill sample collector and sample cup is located at the top end of the impact probe, away from the body's nose cone. The drill motor for this collector is located in the middle of the probe, and spans most of its height. This instrument makes up most of the probe body, and because so, the motor is placed so that there is adequate room available for the other instruments. The laser spectrometer is situated close to the side of the probe body, and also spans most of its height, although it is shorter. There are 4 neutron detectors spread apart equidistant from each other lining the inner diameter of the probe. These are positioned closest to the nose cone, and their orientation helps to keep the probe balanced. A temperature sensor is also equipped, and is located above the detectors. The temperature sensor is across from the laser spectrometer for balance and space reasons.

4. Payload Design and Science Instrumentation

4.1 Selection, Design, and Verification

4.1.1 System Overview

The penetrator system consists of the data acquisition, power system, communications, and thermal control. The temperature control of the system is powered by the power system of the batteries housed in the penetrator body, through the wire extending from the impact probe once penetrated into the regolith, and connected to the main system. The communication system is also reliant on the power from the batteries in the penetrator body, and supplies the data acquisition of the system with live signals. The data acquisition system runs commands with the radio transceiver, temperature sensor and neutron detectors.

Payload: Scientific Instruments	Operation commands	Raw data sent to orbiter and mission control		
System procedures	**Data Handling and Acquisition**	Transmission commands		
	Transmission acknowledgements	**Communications**		
Power supplied to scientific instruments	Power supplied to process and handle data	Power supplied to antenna	**Power System**	Power supplied to thermal sensor
	Thermal data collected	Thermal data communicated back to orbiter and mission control		**Thermal System**

Figure 26: N2 Chart for the Mission Overview

4.1.2 Subsystem Overview

The temperature of the system is regulated by the temperature sensor across from the spectrometer on the inside of the impact probe. The communication system includes the radio transceiver in the penetrator body, accelerometer, and temperature sensor. The accelerometer sits atop the batteries in the body of the penetrator, and collects data during the descent of the probe into the targeted area. The drill motor works with the sample collector and runs the length of the impact probe and into the top end, while the sample neutron detectors line the diameter of the inner impact probe.

4.1.3 Manufacturing Plan

The manufacturing of the body of the penetrator is planned to span approximately five months. Seven months of testing at the NASA Jet Propulsion Laboratory (JPL) will begin in the final phases of manufacturing, overlapping by three months. The impact probe, though smaller in overall dimensions, consists of more subparts, so it will take 6 months of manufacturing. The testing for this part will take seven months as well. The overall timeline of planning and testing will take about 10 months. This will be performed at JPL using engineers and machinists on site.

4.1.4 Verification and Validation Plan

Table 6:Verification and Validation Plan

Analysis	The analysis of the system involves the engineering model or prototype in order to verify the design's suitability. The system must be modeled and simulated with the use of mathematical models and techniques to attain data regarding the system's compliance to the requirements.
Demonstration	The system will be verified through the demonstration of a prototype or model of the system in an environment much like that of the moon's permanently shadowed regions (PSRs). Rather than collect detailed data, this process of verification serves to verify the design's capability through repeated demonstrations of trial and error from a flying aircraft such as a helicopter onto rough terrain.
Inspection	The verification of the overall physical design of the system will be performed through inspection. Using a detailed checklist, the finalized design will be inspected for each component and subsystem so that they are confirmed to meet the requirements.
Test	This process will produce the most detailed data to validate the efficiency and compliance of the vehicle in its targeted location. The system will be tested for its acquisition of regolith composition, the effectiveness of the laser spectrometer, the neutron detectors, and the electric drill.

4.1.5 FMEA and Risk Mitigation

Table 7: Failure Mode and Effects Analysis Chart Revised

Risk #	Function(s)	Failure Mode(s)	Effect(s)	Sev	Cause(s)	Occ	Controls Prevention	Det	RPN	Recommended Action
1	Parachute	Parachute does not deploy	High velocity impact with lunar surface	8	Parachute entanglement	2	Performance testing and modeling to ensure correct deployment initiation	2	32	Ensure that the Parachute is assembled correctly
2	Communications	Lost of communication	Unable to communicate with penetrator	7	Signal lost/jam or damaged antenna	2	Flat-sat testing and testing with penetrator	2	28	Making sure that the chosen materials protect the

			probe				probe			antenna to prevent any lost/jam communication
3	Payload	Payload could be damaged upon impact	Internal payload damaged	9	Chosen material unable to withstand impact	3	Protective housing of payload through aeroshell and performance testing upon impact	2	54	Demo tests with penetrator testing different materials to make sure payload survives impacts on surfaces similar to the moons
4	Power/Battery	Incorrect battery selection	Not choosing the correct battery could shorten the mission lifespan	6	Not enough power is provided to support mission,	2	Ensure adequate battery is chosen	3	36	Extensive research for selection of the correct battery for the mission and backup battery supplies
5	Trajectory	Loss of control resulting in incorrect trajectory	Probe does not land at its designated trajectory	7	Miscalculations and Delayed deployment of secondary payload	2	Performance testing	2	28	Run simulations ensuring no loss of control or miscalculations are detected
6	Penetrator	Penetrator does not deploy	May not land in the desired coordinates	9	Systems not responding	3	Performance testing	2	54	Guarantee that systems are responding accurately during tests. Preventing likelihood of malfunctions once probe is in space.
7	Entry	Thermal Insulation	System overheats on entry	4	Chosen material unable to withstand intensive heats on entry	2	Performance (Heat shield) testing	3	24	Ensure that the material or coating can withstand the heats of entry and descent

4.1.6 Performance Characteristics

The success of the mission is dependent on the performance of the penetrator in the expected conditions on the lunar surface. The endurance and stability of the science instrumentation (spectrometer, neutron detectors, drill, etc.) will result in a successful

EDL procedure, functionality and calibration of primary on-board instruments, collection of data of ice-water at a scale of few kilometres of the PSR, penetration 1 m deep in the regolith, determining the abundance of ice with a measurement accuracy of at least ±1%, and transmission of 75% of data back to Earth.

4.2 Science Value

4.2.1 Science Payload Objectives

The basis of the mission is that the penetrator probe containing the science payload will impact 1m deep in the regolith, determine the abundance of ice with a measurement accuracy of at least ±1%, and transmit 75% of the data gathered to Earth by first transmitting key data to the main orbiter, then to mission control. These are the main science objectives for the mission concept. Additionally, the science payload of the team's lunar penetrator probe shall have a successful entry, descent, and landing (EDL) procedure, with successful functionality and calibration of its primary on-board instruments. These instruments include a tunable laser spectrometer, 4 neutron detectors, a sample acquisition system, and a sensor for communication with the main orbiter, which the team's craft originated from prior to entry. The sample acquisition system shall be responsible for obtaining lunar regolith samples, while the laser spectrometer and neutron detectors will determine the regolith's composition.

By acquiring the composition of regolith in one of the many permanently shadowed regions (PSRs) of the lunar south pole to a ±1% accuracy, the water-ice content of the top 1m in at least that singular location (the landing site), can be determined. Thus, the mission concept, acting as a technology demonstration, shall test for a suitable method for mapping water-ice. In tandem with similar projects and orbiting spatial missions over the next few years, collective efforts will result in determining the total abundance of water-ice throughout the lunar south pole. This information is vital to future moon missions, including habitation efforts, as water can be utilized to produce rocket fuel, alongside other various uses.

4.2.2 Creativity/Originality and Significance

The team's mission concept shall be the first instance of a complete utilization of a penetrator probe on an extraterrestrial surface, particularly the Earth's moon. This is aside from Deep Space 2, an earlier NASA mission, also known as the "Mars Microprobe", which launched in January of 1999. This is the one of the few recorded instances of using a penetrator probe outside of Earth, and was intended to conduct research to derive the atmospheric density, pressure, and temperature of Mars upon descent using accelerometers and a meteorological sensor. On landing and deployment of the probe, this mission also intended to characterize the hardness of the Martian soil, and determine whether ice is present on subsurface soil. The largest goal of the Deep Space 2 however, was to prove the efficacy of space penetrator probes. Unfortunately, this mission was rendered a failure due to the loss in communications upon impact on Mars. Lunar Anomaly's probe shall surpass the efforts and design of this predecessor and will provide scientists with water-ice data from one of the Moon's PSRs. The team's design will incorporate a few different scientific instruments, previously mentioned in sections such as 1.4 and 4.2.1. The unique design offered in section 3 shall mitigate the risks of craft and instrument failures upon impact on the lunar surface.

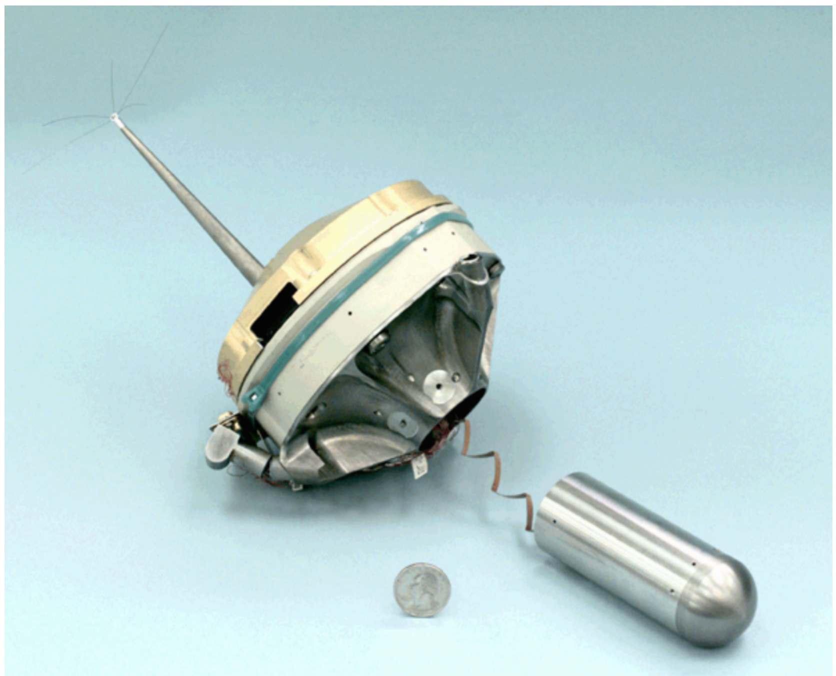


Figure 27: Deep Space 2 Probe, 1999 J. Geophys. Res.

The landing site was determined to need to be in a permanently shadowed region to find ice water, on flat terrain to ensure that the impactor stays in the ground and that future, larger, crewed expeditions can safely go there to make use of the water. Furthermore, a site that isn't too hard to access by ground from an illuminated region was desired in order to make sure that future missions can make easier use of that water, as they can have easier access to energy. Using JMARS, an area that fits them best is an area on the western side of Shoemaker crater at the southern polar region of the moon.

The following images below, in order, show the slope, illumination, both slope and illumination combined, and the LROC WAC imaging.

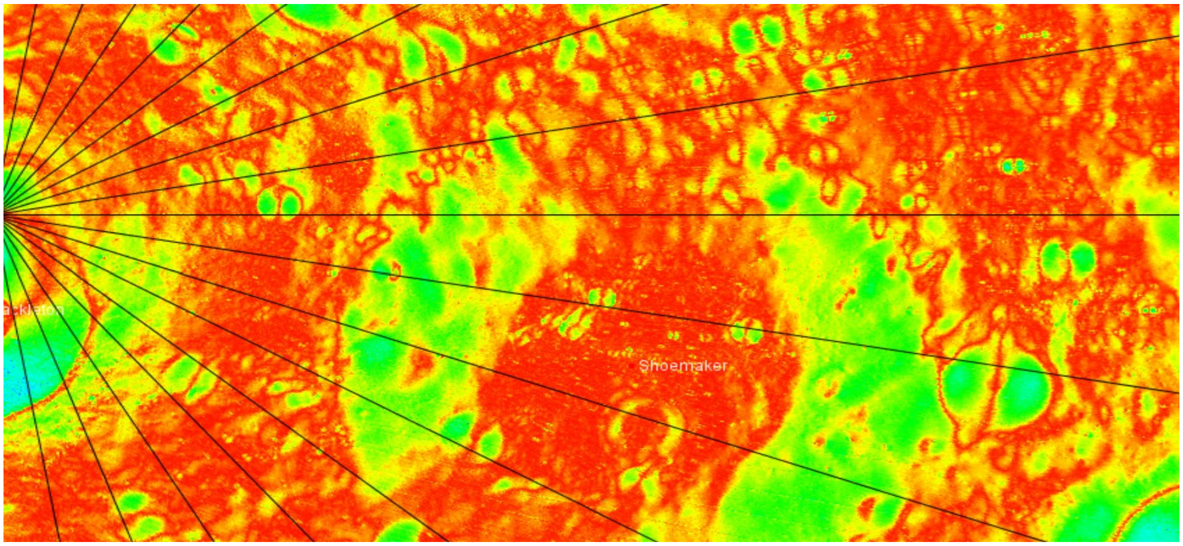


Figure 28: Landing Site Slope

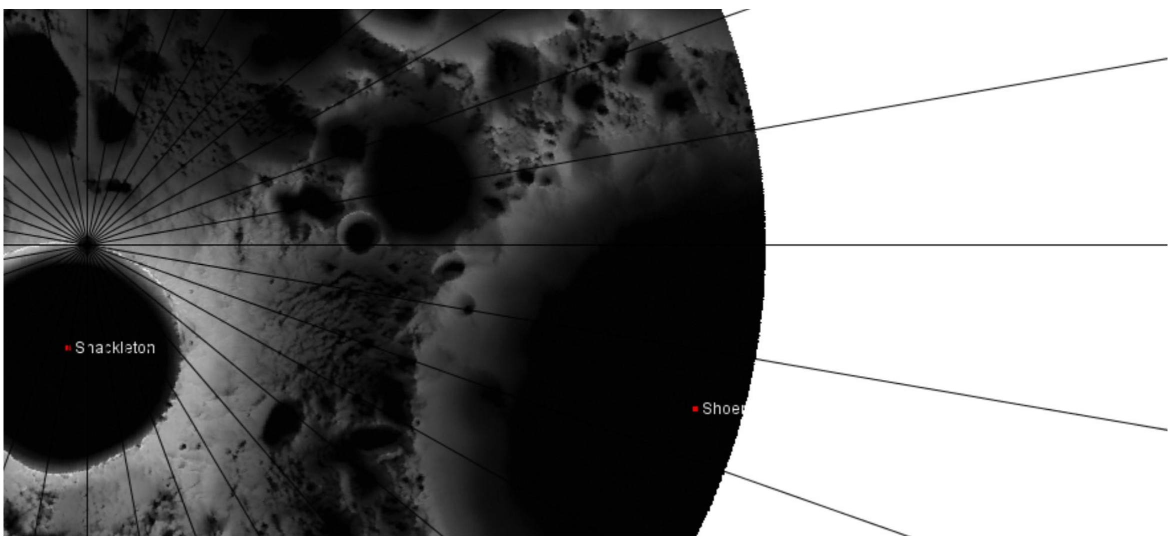


Figure 29: Landing Site Illumination

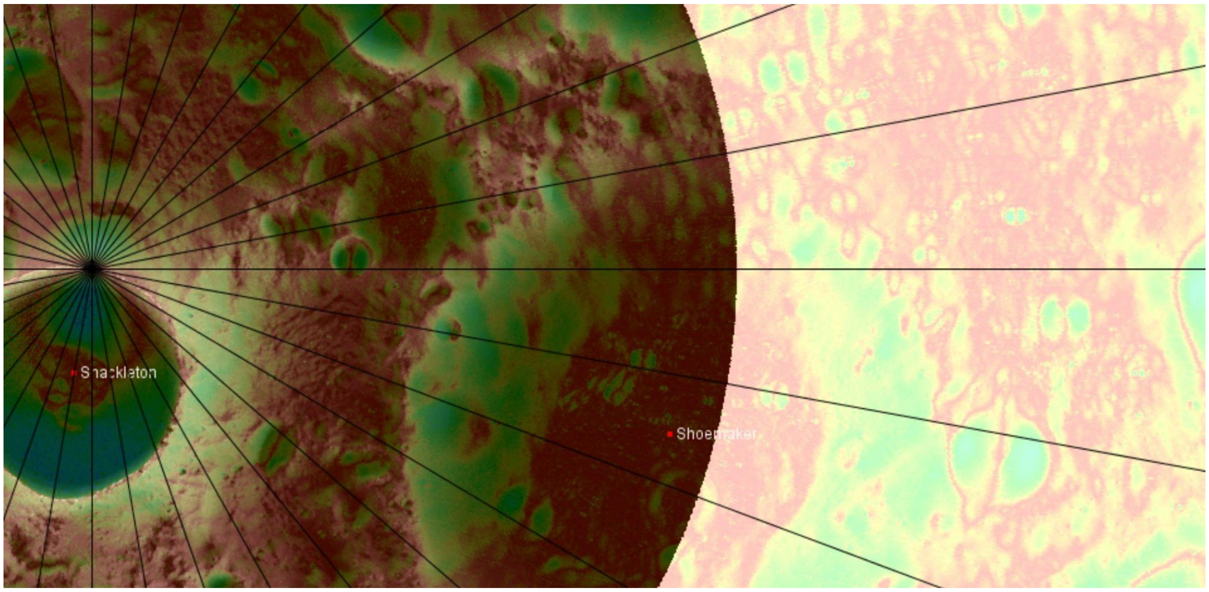


Figure 30: Landing Site Slope and Illumination

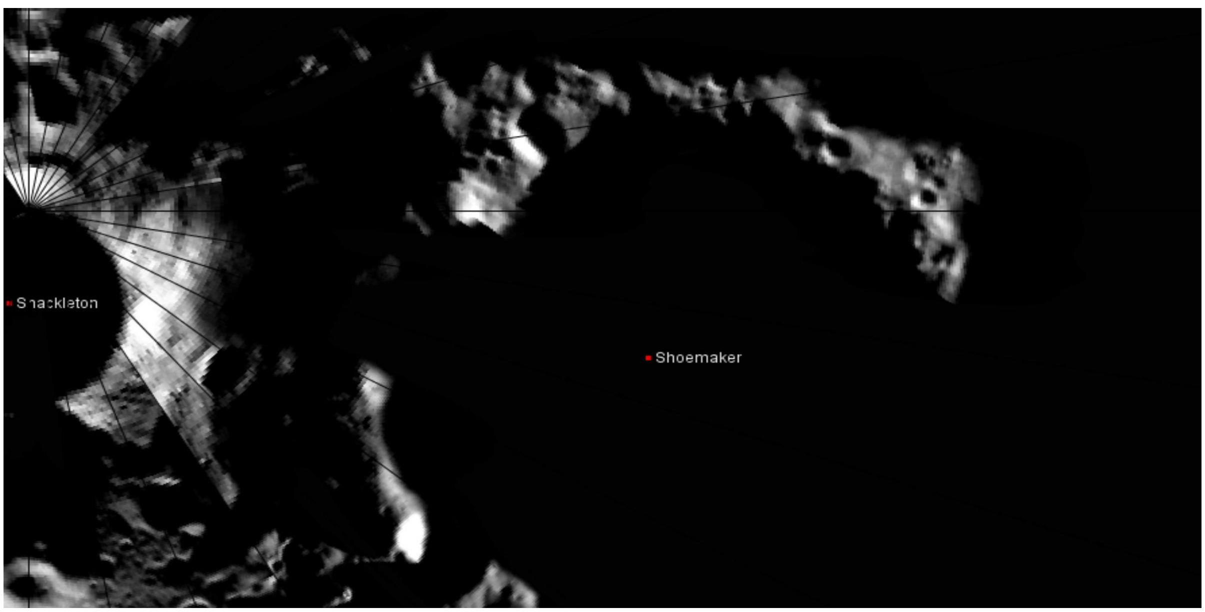


Figure 31: Landing Site LROC WAC Imaging

4.2.3 Payload Success Criteria

The payload success criteria is dependent on the mission's science objectives, mentioned previously in section 4.2.1. The scientific instruments, which are included in the payload, correlate to these goals, as well as to the overall mission objectives stated in section 1.2.3. The following instruments making up the science payload, along with their functionality requirements, are meant to cooperate in order to quantify the abundance of water-ice in the PSR through physical and chemical analyses, assessed to at least 1m down in lunar regolith.

Data from the TLS shall provide measurements for the moon's volatiles, regardless of abundance. The tunable laser spectrometer will measure the hydrogen (H) and oxygen (O) isotope ratios in any water (H_2O) present in the collected samples (in per mil). This instrument will also be responsible for collecting other isotope data, perhaps carbon (C), for complete data purposes which will aid in the differentiation between present water-ice and regolith.

The neutron detectors lined along the inner body of the penetrator probe are responsible for measuring the hydrogen abundance through neutron count regardless of its molecular state. Similar to the purpose of the laser spectrometer, the neutron detectors will also help in determining regolith composition, with the aim of distinguishing water-ice from other substances.

At this point in the mission concept, the sample acquisition system will consist of an electric drill mechanism, which will work for approximately 5 minutes upon impact. The drill bit shall extend about 1cm into the regolith and fill the sample holder to its intended volume, 160mL. These samples will be examined by the spectrometer and detector onboard the probe body when rendered ready for analysis.

Due to the Moon's nature, all instruments must survive specific temperatures/temperature fluctuations and radiation levels. Additionally, the instruments must survive the landing of the impactor in order to proceed with data collection and analyses. This is a more difficult task due to the lack of an atmosphere, which would normally aid in decelerating and stabilizing incoming craft. Therefore, the craft and most of its components must tolerate high velocities using a unique method of orbiting through onboard propulsion systems. Drop heights for the impactor body should be less than 30km, and impact velocities must be less than 300m/s if the scientific instruments are to undergo less than 10,000g loads. Meeting these requirements assures instrument functionality upon landing.

4.2.4 Experimental Logic, Approach, and Method of Investigation

The following graphic illustrates a simple breakdown for data collection. All instruments on the science payload are responsible for determining the composition of water-ice on the landing site; the area west of Shoemaker crater.

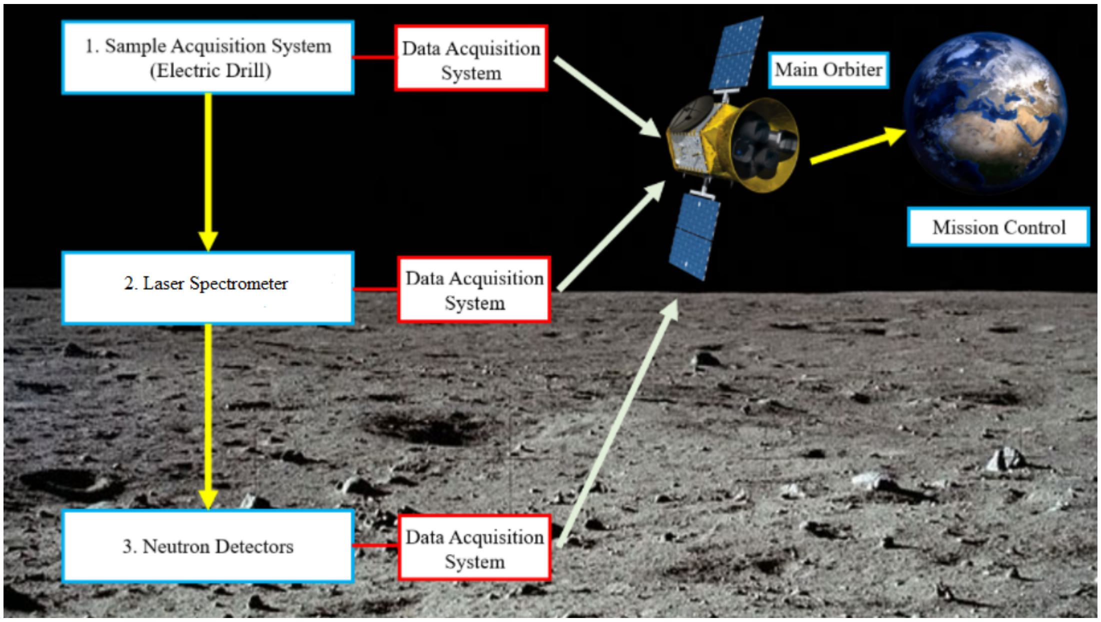


Figure 32: Approach and Investigation Method Summary

After the impactor reaches the lunar surface and deploys the penetrator probe, upon mission control's approval based on system functionality following landing, the sample acquisition system may begin taking samples. The onboard electric drill mechanism shall release the drillbit using an equipped motor, and will begin operation. The duration of sample collection is expected to be 5 minutes. The extended 1cm drill bit proceeds into the lunar soil and collects regolith samples into a 160mL sample cup. Working alongside the electric drill is a data acquisition system which sends information to the main orbiter regarding its functionality. After allowing the system to cool to ambient temperatures, the samples can be analyzed.

The laser spectrometer will work with its own data acquisition system to analyze the obtained sample. This spectrometer measures the absorption of light at certain wavelengths, allowing for the measurement of carbon dioxide and water vapor concentration. For this mission, it is essential that the laser spectrometer measures the hydrogen and oxygen isotope ratios to determine water abundance. Collecting carbon isotope ratio data will help differentiate the regolith from the water-ice. Similar to the electric drill, all data acquired shall be sent to the main orbiter before reaching mission control.

The 4 neutron detectors measure the hydrogen abundance through the counting of neutrons. These instruments serve the same purpose as the laser spectrometer, which is to determine the composition of the sample. These detectors also send the data collected from their system to the main orbiter before reaching mission control.

Between transfer between the main mission orbiter and Earth, at least 75% of data from the sample composition analyses shall be obtained, as per one of the mission goals.

4.2.5 Testing and Calibration Measurements

Once the impactor has hit the surface, the instruments will check themselves out, to make sure they survived the journey. If they are all functioning well, the neutron detector and spectrometer will begin recording the instrument covers, whose values are known beforehand through tests on Earth. Testing on Earth would involve testing relative to temperature, in a vacuum, as the condition that likely would vary the most would be that.

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

Generally for spectrometers, calibration is considered inaccurate when wavelength readings are off by 5 nanometers. The precision of a certain spectrometer can vary according to its design and to any modifications made during testing. For this mission concept, the laser spectrometer's accuracy would need to be tuned to detect the certain wavelengths of water. If the tuning of the laser is off by a certain error, it could miscount how much water there is. This is a similar outcome with the neutron detectors, but the error here would be in the number of neutrons it counts.

The neutron detectors will be used to detect how much hydrogen is around the probe, to validate the findings of the laser spectrometer of how much water there is.

If the laser spectrometer, the more complex instrument that reads chemical composition, fails, only the hydrogen sensors would be used to detect water. Non-ice hydrogen would need to be differentiated in the data from that in ice water.

4.2.7 Expected Data & Analysis

The accelerometer is expected to relay data on the acceleration during the descent of the penetrator into the lunar atmosphere. This begins after the discharge of the decelerator and spans the time of the slowing of the impact velocity, which is critical in ensuring a stable and effective landing into the regolith. The temperature sensor will also relay data on the environment's temperatures on the terrain during the span of the mission. The laser spectrometer will collect data on the lunar volatiles in the samples collected in the penetrator probe (focusing on hydrogen, oxygen, and carbon), and the neutron detectors will measure the hydrogen abundance in the samples. These instruments will ultimately reflect data on the abundance of lunar ice-water in the regolith. Examples of the graphs that can be developed through this data collection are shown below.

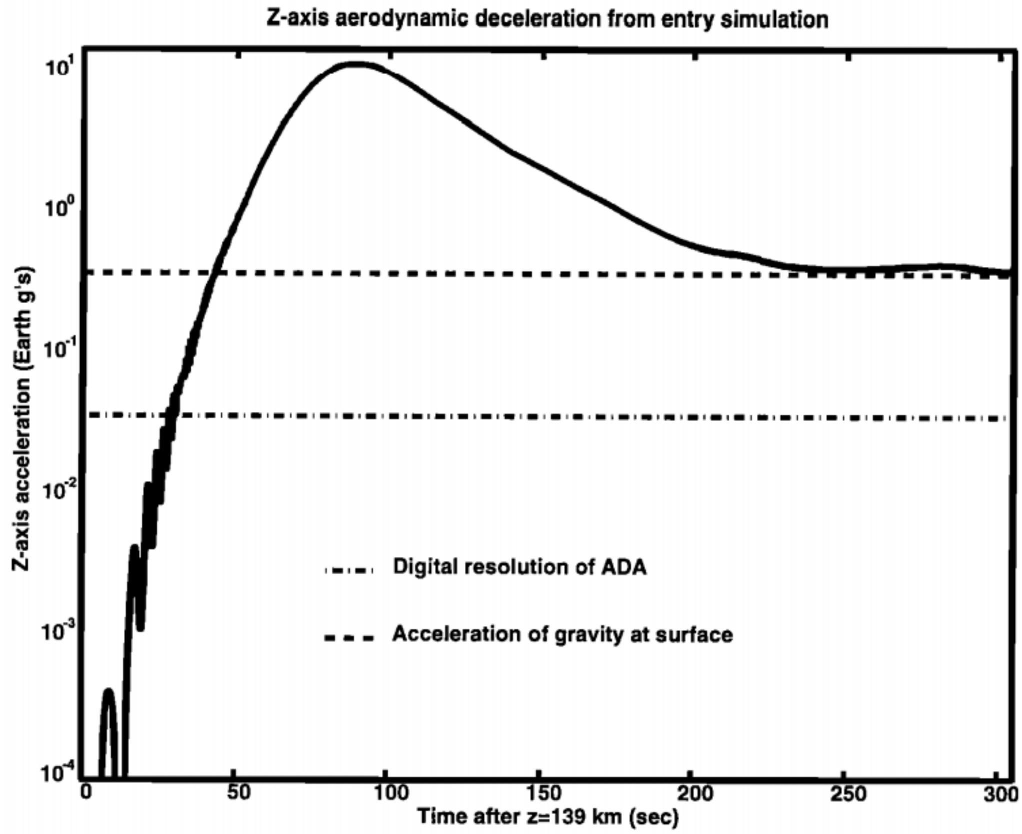


Figure 33: Example Acceleration and Deceleration Data Derived from Previous Probe Simulations, 1999 J. Geophys. Res.

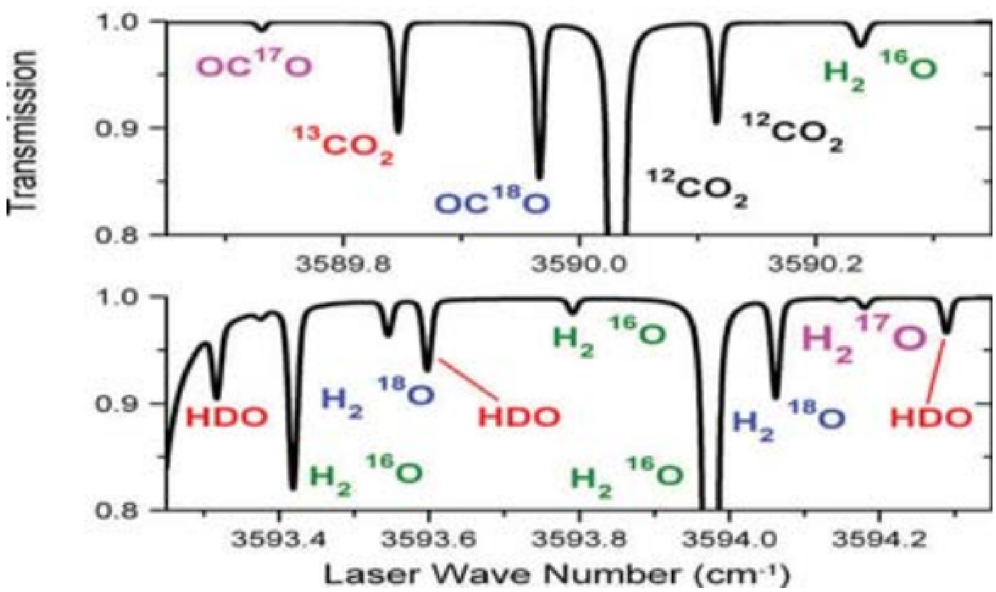


Figure 34: Example Spectrometer Data for Carbon, Oxygen, and Hydrogen, 2013 Webster

5. Safety

5.1 Personnel Safety

5.1.1 Safety Officer

The team has a dedicated Safety Officer whose aim is to identify potential threats and lay specific plans in place so the team can safely and efficiently keep to the schedule. Colin Gibson agreed to fill this role. Through prior experience, research, and team collaboration a system was developed which nearly eliminated the majority of safety threats. This system includes OSHA and local requirements and recommendations, a thoughtfully considered facility layout, consultations of contracted safety engineering firms, and the implementation of machine specific employee training programs.

5.1.2 List of Personnel Hazards

Being aware of the potential hazards that can harm the team in a research facility or lab is significant to avoid any serious injuries along the process of the mission. Injuries can occur in the manufacturing process of building the probe penetrator. There is also potential harm in having too much stress or eye strain that can harm team members.

Here are some potential risks in the manufacturing of the probe:

- Hand or feet injury due to improper handling of tools
- Fire due to electronic short
- Internal or external chemical exposure
- Material shavings becoming lodged in team member’s eyes
- Respiratory harm with chemical or aerosolized materials
- Loose clothing articles and untied long hair getting caught in the machinery
- Muscle strain and fatigue
- Hearing damage
- Forklift or overhead crane related accidents
- Spills

There is also harm in working in an office for extended periods of time:

- Stress
- Eye strain
- Hand arthritis (too much computer typing)
- Mental fatigue
- Indoor air quality

5.1.3 Hazard Mitigation

It is important to prepare in advance for the hazards listed above. To mitigate the hazards in working with the penetrator, the team must follow the following guidelines:

- Wear proper attire, called Personal Protective Equipment (PPE). This protective clothing will ensure that the team avoids injury during the manufacturing process of the onsite parts.
- Have first aid kits at the site to be easily accessed in the case of an injury or emergency.
- Take periodic breaks from work. Local and state laws will be referred to (i.e California law allocates 10 minutes of break per 4 hours worked). This will be a good starting point which will allow workers to rest both physically and mentally to prevent overexertion.
- The team will participate in paid team outings as needed which will counteract fatigue and burn-out.
- Go through training that explains the precautions of the workplace and while operating heavy equipment.
- Loose must be avoided.
- Long hair must be tied back.
- Any hazardous spills should be reported to the Safety Officer immediately.
- Workplaces must be kept clean and organized to avoid any spills or falls.
- All fire extinguishers, sprinklers, and fire alarms must be checked to make sure they are updated.

5.2 Vehicle/Payload Safety

5.2.1 Environmental Hazards

The probe faces many potential hazards when it arrives at the moon. These hazards make carrying out the mission harder, and can even end it entirely. The greatest hazard facing the probe in the permanently shadowed regions is the low temperatures. This can result in batteries depleting faster than expected, and equipment that isn’t rated for those low temperatures breaking. Further hazards can result from space radiation, which can ruin electronic signals, causing the computer to carry out faulty commands.

Lunar dust can damage the mechanisms of the probe. Dust on the moon is sharp and abrasive, increasing the rate of wear and tear. It also is electrically charged, making it stick to surfaces far easier. Other particles that can harm the probe are micrometeoroid impacts. They can punch holes in the spacecraft, and if they hit at the right spot, they can cause malfunction in a component.

5.2.2 Hazard Mitigation

The vehicle and payload design must be able to mitigate the environmental hazards on the Moon. To combat low temperatures, all communication systems and instruments on the craft must be well insulated with appropriate materials and equipped with onboard heaters. As for the craft material itself, aluminum shall be used not only for its lightweight nature, but for its additional properties which allow it to withstand very cold temperatures. Due to this, it is a metal often used in space applications.

For radiation mitigation, appropriate metal materials shall be equipped on the craft to encase and protect essential electronics. Shielding may also be used for any of the other spacecraft components which may be sensitive to the radiation present during spaceflight and on the Moon. Passive radiation shielding materials include Kevlar and polyethylene. Polyethylene has a high hydrogen content which allows it to absorb and disperse radiation. Kevlar works similarly as well, as both of the mentioned shielding materials are highly hydrogenated. In addition to this, the materials act as ballistic shields to prevent impacts while remaining flexible enough to be molded onto spacecraft components.

The penetrator probe mission has a relatively short mission length and will not require complicated methods or systems such as the utilization of electrodynamic dust shields or ultrasonic vibration to mitigate the effects of lunar dust during landing and impact. The priority regarding this hazard is implementing materials and parts on the craft rated for abrasion.

To better ensure that the vehicle and payload design survives and functions successfully throughout its mission, testing shall be conducted for each of the mentioned environmental hazards. Upon CAD rendering, finite element analysis (FEA) may be done to test the forces that each of the applied materials can withstand. Material coupons and prototypes shall be sent out to proper testing facilities for abrasion, radiation, and temperature resistance testing.

6. Activity Plan

6.1 Budget

The mission's budget includes a broad variety of expenses ranging from salary and benefit packages, scientific instrumentation, manufacturing, and launch travel fees. In order to accomodate for unforeseen circumstances which could result in going over the maximum budget of 200 million dollars, initially the budget was capped to about 75%, roughly 150 million dollars. A fairly conservative salary and benefit package was offered to all team members at 80k salary, 100% paid medical, and 2 weeks PTO to start. This equates to well under the recommended 28% ERE, accounting for the average insurance costs in California and other employee related tax costs.

The manufacturing expenses largely come from the tooling and equipment associated with the manufacture and testing of the components and sub assemblies. In order to portion the budget which included a 25% safety margin, roughly half the budget was allocated to the scientific instrumentation of the mission. By working backwards and factoring the known personnel expenses, a reasonable manufacturing budget of roughly 50 million dollars was determined. This accounts for both a manufacturing/office space and an additional testing/assembly space at reasonable local square footage per year rates.

The travel expenses account for the associated team launch travel expenses in January 2024 along with a project leadership trip to Florida in the late Spring/early Summer of 2023. The leadership trip will be to secure various operations requirements which include logistics and science/engineering coordination with the general mission launch team. The travel expenses were determined by General Service Administration (GSA) data. The team set out to be very economical with travel expenditures, as expenses would be spread by, for example, sharing rental cars and hotel rooms between 2 team members. This was critical to maintaining a positive public appearance.

For travel, Team 40 will allocate five days to travel to Florida in the late Spring/early Summer of 2023 for a project leadership trip, as well as five days to travel to Florida for the launching event. For the 2023 trip, stipends are estimated to be around $1500 for airfare ($300 for a single round trip ticket with American Airlines x 5 tickets), $3000 for hotel ($200 for a double bed hotel room x 3 rooms x 5 nights, with 3 male team members share 2 rooms and 2 female team members share 1 room), $530 for transportation cost/rental cars ($43 per car per day x 2 cars x 5 days, along with $20 stipend for gasoline per car per day x 5 days), and lastly $1650 for Per Diem Cost ($66 per person per day x 5 people x 5 days, determined by General Services Administration – GSA). With all of these costs, the total travel costs will be $6680 to cover all 5 team members for a 5-day-travel period.

For the launch event, stipends are estimated to be around $2700 for airfare ($300 for a single round trip ticket with American Airlines x 9 tickets), $6250 for hotel ($200 for a double bed hotel room x 5 rooms x 5 nights, with 5 male team members share 3 rooms and 4 female team members share 2 rooms), $745 for transportation cost/rental cars ($43 per car per day x 3 cars x 5 days, along with $20 stipend for gasoline per car per day x 5 days), and lastly $2970 for Per Diem Cost ($66 per person per day x 9 people x 5 days, determined by General Services Administration – GSA). With all of these costs, the total travel costs will be $12,665 to cover all 9 team members for a 5-day-travel period. The total cost to cover both of the trips will be $19,345.

The budget cap of the entire mission consists of $200 million. The largest portion of the budget will be dedicated to the category of manufacturing the penetrator. This portion will then be distributed in equal parts to engineering and materials and to the purchase of science instruments. There are four primary materials that Team 40 will have to outsource, including the antenna, transmitter, battery and the ISIS On Board Computer. At this time, research is continuous and the team is exploring more about the required materials and supplies cost and equipment cost; these costs will be reported more accurately and precisely as Team 40 moves forward. However, Team 40 estimates that the total materials and supplies cost for our mission would be $3,500,000 ($3.5m) for Fiscal Year 1 and $2,500,000 ($2.5m) for Fiscal Year 2. Similar to total equipment cost, team 40 estimates them to be $3,300,000 ($3.3m) and $2,500,000 ($2.5m) respectively. The manufacturing margin has been determined to be 50% of the sum of the total materials and supplies cost and total equipment cost. Thus, the manufacturing margin for Fiscal Year 1 and Fiscal Year 2 will be $3,400,000 ($3.4m) and $2,500,000 ($2.5m) respectively. Adding all these four costs together (total outsourced instrument cost, total materials, and supplies cost, total equipment cost and manufacturing margin), Team 40 calculated the total direct costs for Fiscal Year 1 and Fiscal Year 2 to be $35,200,000 ($35.2m) and $ 7,500,000 ($7.5m) respectively. After calculating total modified total direct cost (MTDC), facilities and administrative costs (such as Indirect costs or overhead), the total projected cost and total cost margin, our final total project cost for Fiscal Year 1 and Fiscal Year 2 will be $49,855,000 ($49.8m) and $10,335,000 ($10.3m), bringing the final project cost for four years of the mission to be $60,190,000 ($60.2m). This cost is appropriate as it meets our expected goal to keep the final budget to be under $200,000,000 ($200m), as explicitly stated in Section 1 of this PDR.

NASA L'SPACE Mission Concept Academy Summer Budget 2021 - Team 40

Year	Fiscal Year 1 Total	Fiscal Year 2 Total	Fiscal Year 3 Total	Fiscal Year 4 Total	Cumulative Total
PERSONNEL					
Name, Title	Actual Salary	Actual Salary	Actual Salary	Actual Salary	
Seemi Zameer, Project Manager	$80,000	$80,000	$80,000	$80,000	$320,000
Kristen Jingco, Deputy Project Manager	$80,000	$80,000	$80,000	$80,000	$320,000
Aiden Peace, Lead Engineer	$80,000	$80,000	$80,000	$80,000	$320,000
Maikel Heness, Lead Scientist	$80,000	$80,000	$80,000	$80,000	$320,000
Colin Gibson, Lead Business Administration	$80,000	$80,000	$80,000	$80,000	$320,000
Marina Regina Malana, Mechanical Engineer	$80,000	$80,000	$80,000	$80,000	$320,000
Nannett Perez, Aerospace Engineer	$80,000	$80,000	$80,000	$80,000	$320,000
Kemal Pulungan, Astronautical/Trajectory Planner	$80,000	$80,000	$80,000	$80,000	$320,000
Karl Medel, Historian	$80,000	$80,000	$80,000	$80,000	$320,000
Total Salaries	$720,000	$720,000	$720,000	$720,000	$2,880,000
Total ERE	$201,600	$201,600	$201,600	$201,600	$806,400
TOTAL PERSONNEL	$921,600	$921,600	$921,600	$921,600	$3,686,400
TRAVEL					
Total Flights Cost	$ -	$ -	$1,500	$2,700	$4,200
Total Hotel Cost	$ -	$ -	$3,000	$6,250	$9,250
Total Transportation Cost	$ -	$ -	$530	$745	$1,275
Total Per Diem Cost	$ -	$ -	$1,650	$2,970	$7,260
Total travel costs	$ -	$ -	$6,680	$12,665	$19,345
OTHER DIRECT COSTS					
Total Outsourced Instrument Cost	$25,000,000	$	$	$	$25,000,000
Total Materials and Supplies Cost	$3,500,000	$2,500,000	$	$	$6,000,000
Total Equipment Cost	$3,300,000	$2,500,000	$	$	$5,800,000
Manufacturing Margin	$3,400,000	$2,500,000	$	$	$5,900,000
Total Direct Costs	$35,200,000	$7,500,000			$42,700,000
Total MTDC	$31,500,000	$4,500,000			$36,000,000
FINAL COST CALCULATIONS					
Total F&A	$3,150,000	$450,000	$	$	$3,600,000
Total Projected Cost	$38,350,000	$7,950,000	$	$	$46,300,000
Total Cost Margin	$11,505,000	$2,385,000	$	$	$13,890,000
Total Project Cost	$49,855,000	$10,335,000	$	$	$60,190,000

Figure 35: Project Budget

6.2 Schedule

The following figures depict the full mission schedule presented as Gantt charts, including major milestones, from mission conception through operations. The visuals also provide a more in-depth look of the required mission tasks and their duration, as opposed to the rough mission outline provided previously in section 1.2.5. Not only mission concept tasks are listed, but outreach and business related tasks as well, much of what the team considers pertinent to the overall mission.

Each figure presents a different year of the mission schedule. The timeframe for each NASA Project Lifecycle Phase is also shown. Tasks are provided and categorized. Major milestones such as the system design review, preliminary design review, and launch date are shown in bright, light blue. Margins for each task category are provided and highlighted in yellow. Completed tasks on the Gantt charts are highlighted gray.

The optimal launch date for the main orbiter, which shall carry the team's penetrator probe, is January 7, 2024 between 0300 and 0500 hours. Note that the Gantt charts may be subject to change, especially the length of Phase E, mission operations, depending on mission success and stakeholder needs throughout the project.

Lunar Anomaly Penetrator Probe Project Schedule - 2021

Team Number: 40
Project Team Members: Colin Gibson, Maikel Heness, Kristen Jingco, Regina Malana, Karl Medel, Aiden Peace, Nannett Perez, Kemal Pulungan, Seemi Zameer

Project Start: **Tue, 5/18/2021**

NASA PROJECT LIFECYCLE PHASES

TASK	ASSIGNED TO	PROGRESS	START	END	DAYS	Margin
ANNOUNCEMENT OF OPPORTUNITY			5/11/21	5/11/21		
INITIATE TEAM ORGANIZATION			5/18/21	5/21/21	4	0.4
Establish a Solid Means for Communications	All	100%	5/18/21	5/18/21	1	
Introduce and Meet with Team Members to Discuss Project Roles	All	100%	5/19/21	5/21/21	3	
Organize a Dedicated Online Workspace (Drive, Trello, etc.)	Colin, Maikel, Kristen, Aiden, Seemi	100%	5/21/21	5/21/21	1	
RESEARCH AND BRAINSTORM			5/18/21	6/14/21	28	2.8
Acknowledge the Mission Statement/Problem	All	100%	5/18/21	5/19/21	2	
Pinpoint Mission Requirements and Success Criteria	All	100%	5/18/21	5/19/21	2	
Study the Moon's Environment	Maikel, Kristen, Kemal	100%	5/19/21	6/6/21	19	
Investigate the Current SOA to Meet Similar Mission Requirements for Technology Ideas and Reference	Maikel, Kristen, Kemal, Regina, Aiden, Nannett	100%	5/21/21	6/14/21	25	
Research Possible New Technologies or Methods to Meet the Mission Objective	All	100%	6/5/21	6/14/21	10	
Decide on Either an Orbiter or Lander Approach to the Mission	All	100%	6/5/21	6/14/21	10	
Formulate a Rough Mission Vehicle Concept and Design	All	100%	6/5/21	6/14/21	10	
SCIENCE DELIVERABLES			6/8/21	7/16/21	39	3.9
Find Potential Landing Areas/Target Orbits (Location and time)	Maikel, Kristen, Kemal	50%	6/12/21	7/1/21	20	
Select a Candidate Landing Site/Target Orbit	Maikel, Kristen, Kemal	0%	6/21/21	7/16/21	26	
Finalize Scientific Instrument for Payload	Maikel, Kristen, Kemal	24%	6/14/21	7/16/21	33	
DEVELOP PAYLOAD/PROBE (START)			6/5/21	7/16/21		
ENGINEERING DELIVERABLES			6/5/21	7/20/21	46	4.6
Data Acquisition	Aiden, Nannett, Regina	100%	6/5/21	6/14/21	10	
Mission Definition	Aiden, Nannett, Regina	86%	6/15/21	6/21/21	7	
Documentation of Thought and Design Process	Aiden, Nannett, Regina	35%	6/5/21	7/20/21	46	
Mathematical Verification of Technical Criteria	Aiden, Nannett, Regina	0%	6/22/21	6/28/21	7	
Systems Design	Aiden, Nannett, Regina	0%	6/29/21	7/20/21	22	
PRELIMINARY PLAN			7/21/21	7/21/21		
BUSINESS ADMINISTRATION DELIVERABLES			6/9/21	7/21/21	43	4.3
Final Budget Report	All	19%	6/9/21	7/20/21	42	
Instrument/Material Cost Report	Seemi	0%	6/23/21	7/20/21	28	
Salary Report	Seemi	38%	6/9/21	7/10/21	32	
Travel Report	Seemi	38%	6/9/21	7/10/21	32	
Miscellaneous Report	Seemi	38%	6/9/21	7/10/21	32	
Preliminary Budget Report Review	Colin, Karl, Seemi	14%	6/15/21	7/20/21	36	
SYSTEM REQUIREMENTS REVIEW			9/1/21	9/1/21		
Outreach Proposal	All	0%	6/9/21	7/20/21	42	
Public Research	Karl	0%	6/9/21	7/20/21	42	
Simplify the Mission Objective for the Public	Karl	0%	6/9/21	7/20/21	42	
Develop Visuals for Outreach Proposal	Karl	0%	6/9/21	7/20/21	42	
Preliminary Outreach Proposal Review	Colin, Karl, Seemi	0%	6/9/21	7/20/21	42	
Safety Practice Report	All	0%	6/10/21	7/21/21	42	
Safety Document	Colin	0%	6/10/21	7/21/21	42	
Environmental Hazards	Colin	0%	6/10/21	7/21/21	42	
Hazard Prevention Control	Colin	0%	6/10/21	7/21/21	42	
Risk and Risk Mitigation chart	Colin	0%	6/10/21	7/21/21	42	
Preliminary Safety Report Review	Colin, Karl, Seemi	0%	6/10/21	7/21/21	42	
PRELIMINARY DESIGN REVIEW			5/20/21	7/21/21	63	6.3
Subject I Draft (Mission Summary)	All	25%	5/20/21	6/14/21	26	
Subject II (Evolution of Project)	All	0%	5/20/21	7/21/21	63	
Subject III (Descent and Lander Criteria) Draft	Maikel, Kristen, Regina, Aiden, Nannett, Kemal	0%	6/5/21	6/28/21	24	
Subject IV (Payload Criteria) Draft	Maikel, Kristen, Regina, Aiden, Nannett, Kemal	0%	6/5/21	6/28/21	24	
Subject V and VI (Activity Plan and Conclusion) Drafts	Colin, Karl, Seemi	0%	6/5/21	7/5/21	31	
Peer Review	All	5%	5/21/21	7/21/21	62	
Preliminary Design Review Revision	All	~	6/5/21	~		
Further Mission Concept Revision for the SDR	All	0%	7/25/21	11/19/21	118	
SYSTEM DESIGN REVIEW			11/20/21	11/20/21		

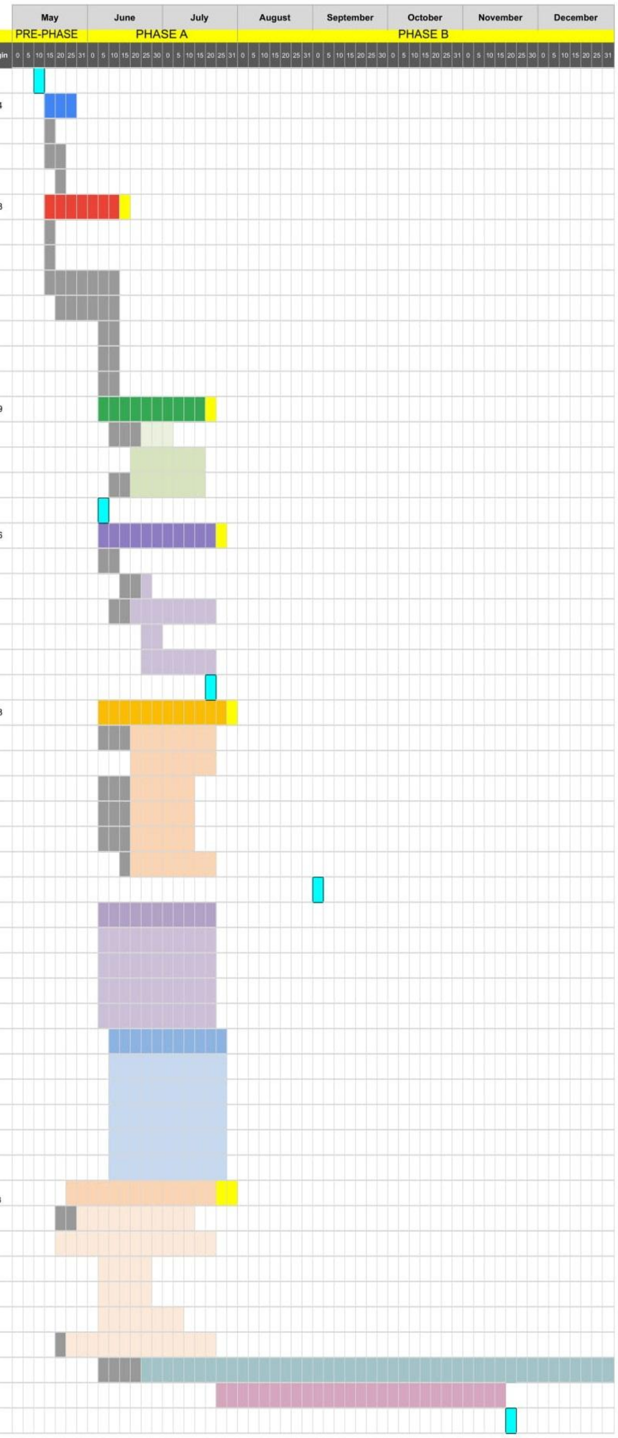
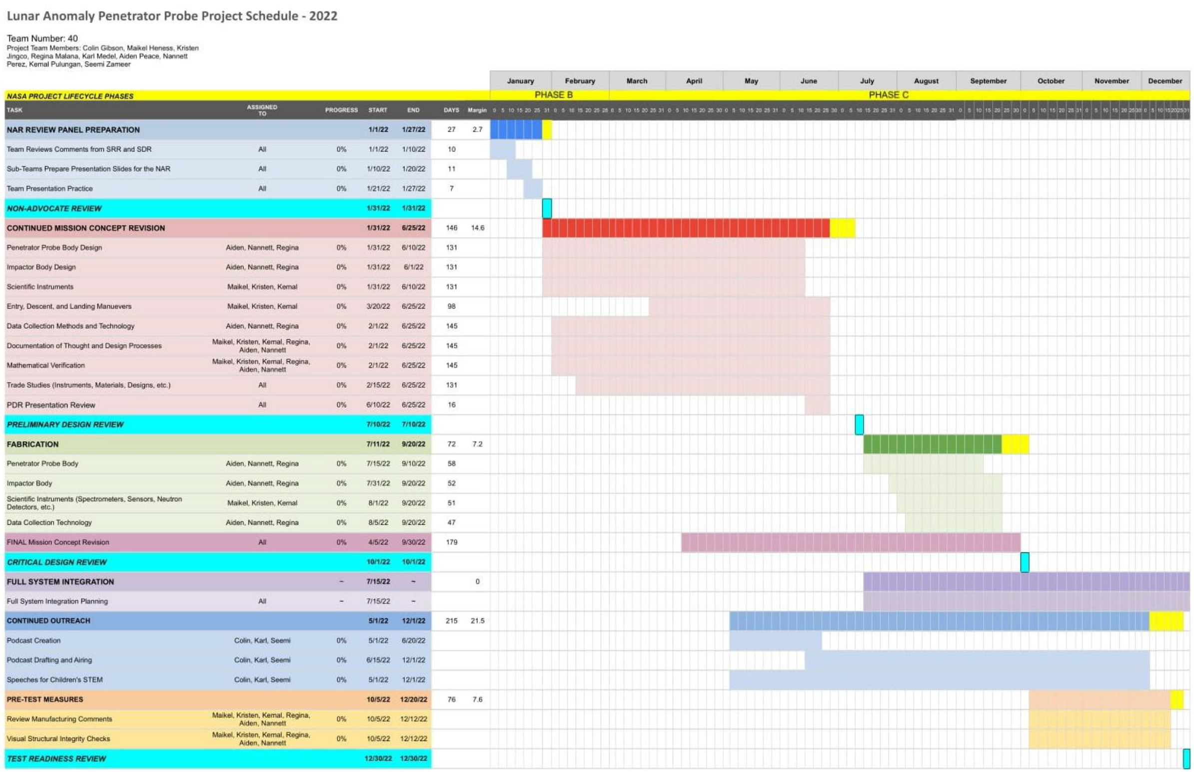


Figure 36: Mission Schedule 2021



Lunar Anomaly Penetrator Probe Project Schedule - 2022

Team Number: 40
Project Team Members: Colin Gibson, Maikel Heness, Kristen Jingco, Regina Malana, Karl Medel, Aiden Peace, Nannett Perez, Kemal Pulungan, Seemi Zameer

NASA PROJECT LIFECYCLE PHASES

TASK	ASSIGNED TO	PROGRESS	START	END	DAYS	Margin
NAR REVIEW PANEL PREPARATION			1/1/22	1/27/22	27	2.7
Team Reviews Comments from SRR and SDR	All	0%	1/1/22	1/10/22	10	
Sub-Teams Prepare Presentation Slides for the NAR	All	0%	1/10/22	1/20/22	11	
Team Presentation Practice	All	0%	1/21/22	1/27/22	7	
NON-ADVOCATE REVIEW			1/31/22	1/31/22		
CONTINUED MISSION CONCEPT REVISION			1/31/22	6/25/22	146	14.6
Penetrator Probe Body Design	Aiden, Nannett, Regina	0%	1/31/22	6/10/22	131	
Impactor Body Design	Aiden, Nannett, Regina	0%	1/31/22	6/1/22	131	
Scientific Instruments	Maikel, Kristen, Kemal	0%	1/31/22	6/10/22	131	
Entry, Descent, and Landing Manuevers	Maikel, Kristen, Kemal	0%	3/20/22	6/25/22	98	
Data Collection Methods and Technology	Aiden, Nannett, Regina	0%	2/1/22	6/25/22	145	
Documentation of Thought and Design Processes	Maikel, Kristen, Kemal, Regina, Aiden, Nannett	0%	2/1/22	6/25/22	145	
Mathematical Verification	Maikel, Kristen, Kemal, Regina, Aiden, Nannett	0%	2/1/22	6/25/22	145	
Trade Studies (Instruments, Materials, Designs, etc.)	All	0%	2/15/22	6/25/22	131	
PDR Presentation Review	All	0%	6/10/22	6/25/22	16	
PRELIMINARY DESIGN REVIEW			7/10/22	7/10/22		
FABRICATION			7/11/22	9/20/22	72	7.2
Penetrator Probe Body	Aiden, Nannett, Regina	0%	7/15/22	9/10/22	58	
Impactor Body	Aiden, Nannett, Regina	0%	7/31/22	9/20/22	52	
Scientific Instruments (Spectrometers, Sensors, Neutron Detectors, etc.)	Maikel, Kristen, Kemal	0%	8/1/22	9/20/22	51	
Data Collection Technology	Aiden, Nannett, Regina	0%	8/5/22	9/20/22	47	
FINAL Mission Concept Revision	All	0%	4/5/22	9/30/22	179	
CRITICAL DESIGN REVIEW			10/1/22	10/1/22		
FULL SYSTEM INTEGRATION		–	7/15/22	–		0
Full System Integration Planning	All	–	7/15/22	–		
CONTINUED OUTREACH			5/1/22	12/1/22	215	21.5
Podcast Creation	Colin, Karl, Seemi	0%	5/1/22	6/20/22		
Podcast Drafting and Airing	Colin, Karl, Seemi	0%	6/15/22	12/1/22		
Speeches for Children's STEM	Colin, Karl, Seemi	0%	5/1/22	12/1/22		
PRE-TEST MEASURES			10/5/22	12/20/22	76	7.6
Review Manufacturing Comments	Maikel, Kristen, Kemal, Regina, Aiden, Nannett	0%	10/5/22	12/12/22		
Visual Structural Integrity Checks	Maikel, Kristen, Kemal, Regina, Aiden, Nannett	0%	10/5/22	12/12/22		
TEST READINESS REVIEW			12/30/22	12/30/22		

Figure 37: Mission Schedule 2022

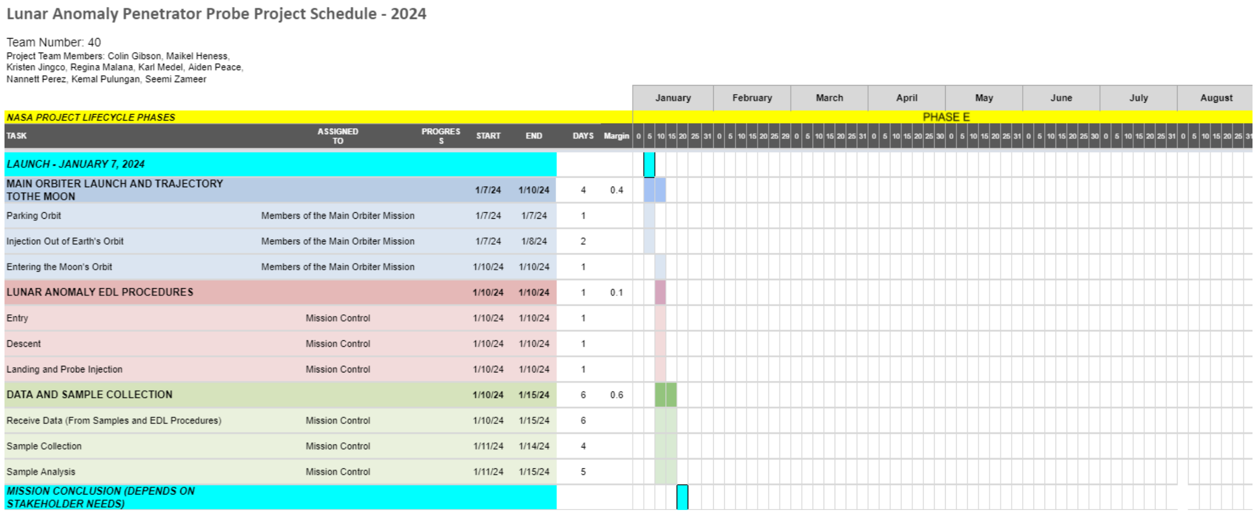
Lunar Anomaly Penetrator Probe Project Schedule - 2023

Team Number: 40
Project Team Members: Colin Gibson, Maikel Heness, Kristen Jingco, Regina Malana, Karl Medel, Aiden Peace, Nannett Perez, Kemal Pulungan, Seemi Zameer

NASA PROJECT LIFECYCLE PHASES

TASK	ASSIGNED TO	PROGRESS	START	END	DAYS	Margin
FINISHING FABRICATION			1/1/23	6/1/23	152	15.2
Penetrator Probe Body	Aiden, Nannett, Regina	0%	1/1/23	4/15/23	105	
Impactor Body	Aiden, Nannett, Regina	0%	1/10/23	5/10/23	121	
Scientific Instruments (Spectrometers, Sensors, Neutron Detectors, etc.)	Maikel, Kristen, Kemal	0%	1/15/23	5/31/23	137	
Data Collection Technology	Aiden, Nannett, Regina	0%	1/5/23	3/31/23	86	
TESTING			1/10/23	8/10/23	213	21.3
Penetrator Probe Body	Aiden, Nannett, Regina	0%	1/10/23	7/31/23	203	
Impactor Body	Aiden, Nannett, Regina	0%	1/20/23	7/31/23	193	
Scientific Instruments (Spectrometers, Sensors, Neutron Detectors, etc.)	Maikel, Kristen, Kemal	0%	1/20/23	8/10/23	203	
Data Collection Technology	Aiden, Nannett, Regina	0%	1/10/23	7/31/23	203	
FULL SYSTEM INTEGRATION			1/1/23	10/3/23	276	27.6
Full System Integration Planning	All	0%	1/1/23	4/3/23	93	
Full System Integration Test	All	0%	4/5/23	10/3/23	182	
CONTINUED OUTREACH			1/1/23	10/3/23	276	
Podcast Episode Drafting and Airing	Colin, Karl, Seemi	0%	1/1/23	10/3/23	276	
Guest Speakers for Children's STEM	Colin, Karl, Seemi	0%	1/1/23	10/3/23	276	
Plans for Children's Hands-On STEM Activities	Colin, Karl, Seemi	0%	1/1/23	10/3/23	276	
FLIGHT READINESS REVIEW			10/25/23	10/25/23		

Figure 38: Mission Schedule 2023


Lunar Anomaly Penetrator Probe Project Schedule - 2024

Team Number: 40
Project Team Members: Colin Gibson, Maikel Heness, Kristen Jingco, Regina Malana, Karl Medel, Aiden Peace, Nannett Perez, Kemal Pulungan, Seemi Zameer

NASA PROJECT LIFECYCLE PHASES

TASK	ASSIGNED TO	PROGRESS	START	END	DAYS	Margin
LAUNCH - JANUARY 7, 2024						
MAIN ORBITER LAUNCH AND TRAJECTORY TOTHE MOON			**1/7/24**	**1/10/24**	4	0.4
Parking Orbit	Members of the Main Orbiter Mission		1/7/24	1/7/24	1	
Injection Out of Earth's Orbit	Members of the Main Orbiter Mission		1/7/24	1/8/24	2	
Entering the Moon's Orbit	Members of the Main Orbiter Mission		1/10/24	1/10/24	1	
LUNAR ANOMALY EDL PROCEDURES			**1/10/24**	**1/10/24**	1	0.1
Entry	Mission Control		1/10/24	1/10/24	1	
Descent	Mission Control		1/10/24	1/10/24	1	
Landing and Probe Injection	Mission Control		1/10/24	1/10/24	1	
DATA AND SAMPLE COLLECTION			**1/10/24**	**1/15/24**	6	0.6
Receive Data (From Samples and EDL Procedures)	Mission Control		1/10/24	1/15/24	6	
Sample Collection	Mission Control		1/11/24	1/14/24	4	
Sample Analysis	Mission Control		1/11/24	1/15/24	5	
MISSION CONCLUSION (DEPENDS ON STAKEHOLDER NEEDS)						

Figure 39: Mission Schedule 2024

6.3 Outreach Summary

Team 40 Lunar Anomaly will assist in bringing awareness to STEM by holding talks, having podcasts, through social media, and creating programs that involve working on a small project that demonstrates the applications of stem. This is imperative in demonstrating to the public how STEM is used in everyday lives such as coding an application or studying the elements that compose the universe. The goal of creating project programs is in exposing students or the public in how the applications of stem are utilized. These projects can involve making a small robot using Arduino Boards and programming the boards giving them commands to execute a wanted action. Working with Arduino boards gives exposure to the applications of computer science and the other stem related fields. This will aid students in showing that having an idea one can bring that idea to life by using the skills that stem offers. Having a project come to life is very rewarding and can enhance interest as now the public or students see the applications of stem. Holding talks to the public or in schools can help bring an understanding of the significance of stem. Educating talks can aid teachers in seeing the applications of stem and expose students that learning stem can be useful. In these talks the goal should also be for teaching educators in not only focusing on teaching the theory behind a subject but also how to integrate and connect the lessons to applications and how it is used in peoples' lives. Having STEM taught in this manner can have students see the connection of stem in their lives and in the workforce. Inviting professionals in the stem workforce to give talks about their profession can assist in giving better ideas of how stem is used. Podcasts are a great way of conveying and keeping the public up to date with new upcoming information. Having guest speakers such as scientists that work at NASA or professionals in the workforce of STEM can give more insight in the work and in the applications of stem.

Through the promotion campaign will take tie in what sets this specific mission apart from the array of ambitious upcoming missions. In simple terms the mission will be described as a significant first step that will lay the groundwork for greater human space travel. This understanding can inspire the public through their individual imaginations. It would be very helpful here to include some speculative yet somewhat grounded examples of how lunar water-ice when repurposed into fuel or other critical function purpose can directly affect their lives. In an even more basic approach, the mission's goals can be utilized to educate the broader, less scientifically illiterate population. Simplified concepts and terminology that will likely be seen in future missions can be incorporated. This can facilitate greater participation and interest overall.

Our objective is also in reaching out to K-12 schools. This is very significant for the team to include school children into the outreach program. In reaching out to K-12 schools this will provide a mutually benefiting exchange that will both teach and inspire these students while cementing the public’s support for space missions. Unlike the greater population, the young students' creativity should be used when they imagine the implications of humans in space. Through talks at various schools, the goal is to stretch some student’s imaginations to emphasize the adventurous spirit of humanity, science, and engineering.

6.4 Program Management Approach

Team 40 consists of nine members, where each member is assigned a designated role within three subgroups identified as: engineering, science, and business administration team. These subgroups consist of leadership positions as well as roles ranging from a mechanical engineer, trajectory planner, and financial planner. The leadership positions that managed and organized most of the communication of the team were led by both the project manager and the deputy project manager. As for the subgroups, the leads performed similar tasks for their prospective groups. To approach the problem, the entire team met at least once a week to discuss each objective that needed to be met, as well as what was accomplished in the week prior. The corresponding subteams then discussed and assigned roles to ensure that each week’s deliverables were met. Several components of the mission required collaboration between more than one subteam, and this required the team’s leadership to assign specific tasks to each subteam so that the work could be done effectively. Overall, the team was able to promote a collaborative environment for each member to discuss their ideas and work together. When issues arose, it was essential to the team that they were discussed and resolved. To reduce possible problems, weekly meetings were set so that issues can be mitigated in an effective and efficient manner.

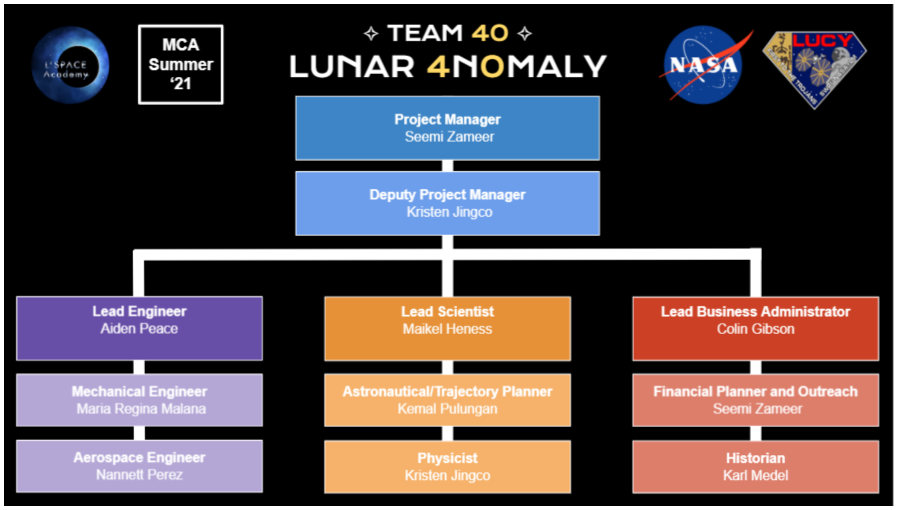


Figure 40: Organization Chart

7. Conclusion

The purpose of the mission is based on the Lunar Water-Ice Strategic Science Investigation. The goal consists of demonstrating the technology necessary to map out areas containing water-ice and to efficiently extract/purify the ice before human arrival on the Moon. The defined objectives of this investigation are to map out the PSR's at a scale of a few kilometers for water-ice and analyze the ice content in the top 1 m of regolith of at least one location. This mission concept specifically covers the requirements involved in the later objective: analyzing the water-ice in the top 1m of regolith in a PSR. The western side of Shoemaker crater was chosen as the landing and investigation site. It is to note that the team's mission concept meets this certain goal, although a full Lunar Water-Ice Strategic Science Investigation could involve many duplicate vehicles of the team's concept and/or accompanying projects.

The team decided on the utilization of a penetrator probe to achieve this, which will descend from a main orbiter mission to the Moon. Within the given mass and size restraints, which are to be no greater than 180 kg and to have a volume no greater than 60.1 cm by 71.1 cm by 96.5 cm, the penetrator probe consists of three main parts: the penetrator body (which holds the penetrator probe), the aeroshell, and the penetrator probe itself. This vehicle consists of a cylindrical body holding an antenna at its top while housing the probe on its underside. The body is supported by four equidistant stands. These parts are contained within the aeroshell, consisting of a top backshell and bottom heat shield. This design utilizes 6061 aluminum alloy as the material due to its relatively high strength, corrosion resistance, and previous usage in space applications. The total volume of this concept is 17070.712 cm^3 and the total mass is approximately 61.739 kg. Without the aeroshell (backshell and heat shield components), the volume is 10660.922 cm^3 and the mass is 30.931 kg, meeting the design restraints.

The content of the lunar surface will be analyzed with laser spectrometry and neutron detection. A tunable laser spectrometer allows for an accurate determination of what is in a sample of material, important to making sure that water is being detected, not hydroxyls. A small sample will be gathered by a drill to be analyzed by spectroscopy. Neutron detectors complement the capabilities of the spectrometer by detecting hydrogen atoms right outside of the probe, regardless of molecular status of the hydrogen.

The team is to continue detailing and validating the penetrator design, maturing technologies, and increasing risk reduction. Capabilities documents may be implemented to ensure that the design can meet all operational requirements needed to render a successful mission. Given more time, more material analyses, trade studies, and mathematical verification (such as for the vehicle's landing procedure) for appropriate aspects of the mission concept would be researched, reviewed, and consolidated. This work, along with the beginning of some fabrication and testing, is essential for the Critical Design Review (CDR) stage of the project.

8. References

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