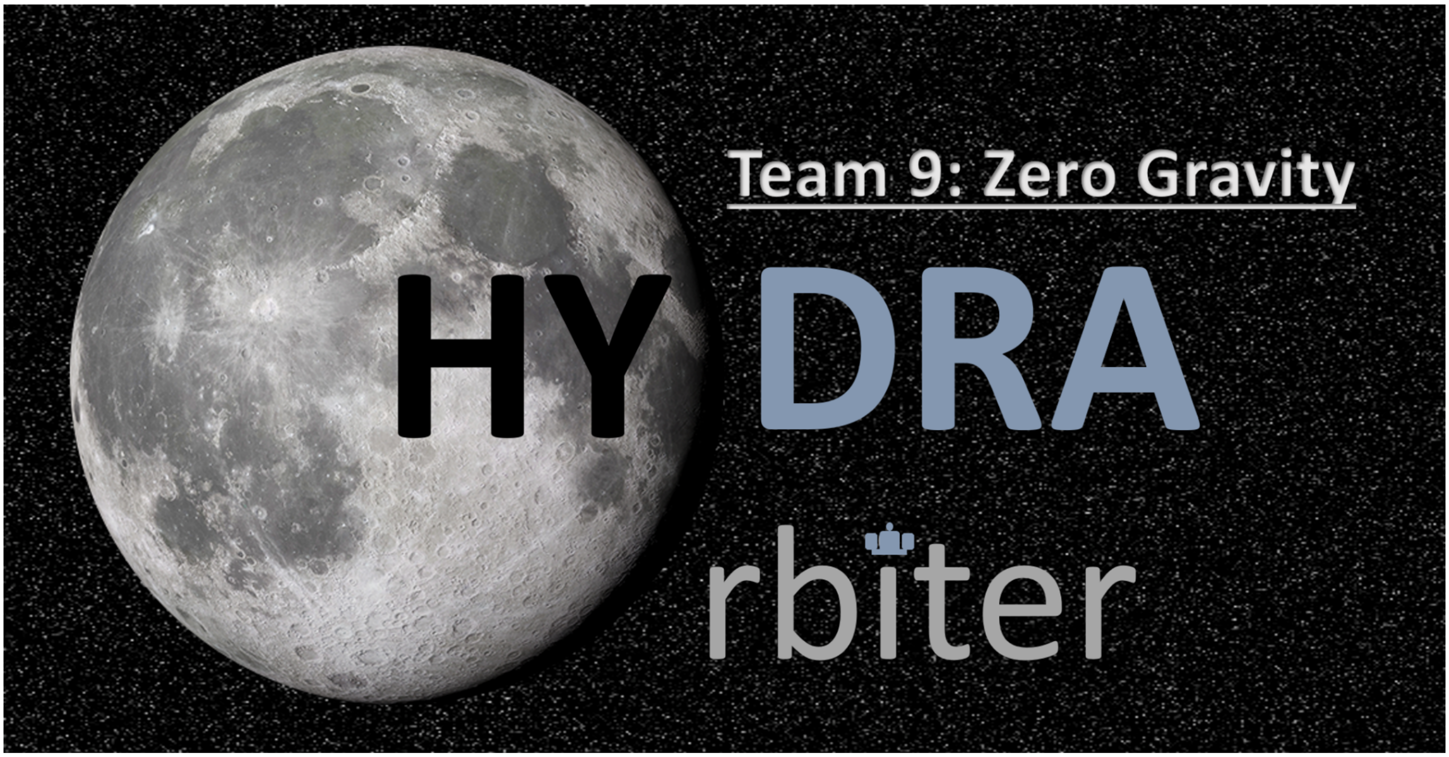
NASA L'SPACE Mission Concept Academy
Preliminary Design Review
Team 9: Zero Gravity



By: Liam Begany, Kruti Bhingradiya, John Driver, Connor Dupuis, Kevin Formento, Ivan Parra Sanz, Michelle Quiñones, Jeivian Ramos

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1. Introduction and Summary

1.1 Team Introduction

Kruti Bhingradiya- ***Project Manager | Science Team | Astrophysicist*** Rising Sophomore and International student at University of Maryland majoring in Aerospace Engineering with a minor in Robotics and Autonomous Systems. She currently works in Collective Dynamics and Controls Labs at UMD as Researcher for Summer Pathways Program designing soft robotic actuators and researching ways to manufacture them through various additive manufacturing methods. She is also Lab Manager for Advanced Fabrication Lab, Instructional Fabrication Lab, Research Prototyping Lab, Rapid Prototyping Center and Makerbot Innovation Center at UMD through which she supports other researchers in designing, fabricating and prototyping research projects. She is also part of the Near Space Balloon Payload Program at UMD where she works in inflation, flight navigation, recovery and telemetry.

John Driver- ***Deputy Project Manager | Engineering Team | Mechanical Engineer***

Sophomore Mechanical Engineering student at the University of Charlotte. During his freshman year, he along with other freshman engineering students designed a front-leg wheelchair for a local Corgi puppy named Boots. He is currently an undergraduate research assistant in the Autonomous Robots and Systems Laboratory (ARSL) at UNC Charlotte where he is characterizing the range/reliability of the outdoor communications system used for the autonomous surface vessels in the ARSL. He is also a member of UNC Charlotte's 49er Rocketry and Projectile Society where he will launch a rocket for his Level 1 certification.

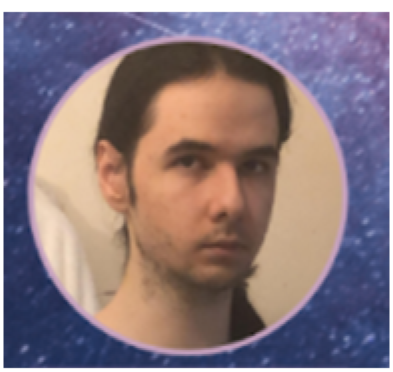
Kevin Formento- ***Lead Engineer | Engineering Team | Mechanical Engineer***

First Generation, hispanic, rising junior attending Temple University. Pursuing a career in Mechanical Engineering Technology. He is experienced in CAD, Engineering Research, Python, Robotics, and Astronomy. Previously partook in the NASA NCAS program.

Jeivian L. Ramos Torres- ***Lead Scientist* | *Science Team* | *Geologist***
Second-generation,Caribbean, rising sophomore from Penn State Berk, PA. Pursuing a career in Mechanical Engineering and Math. Participate in the Student Space Program Laboratory and NASA Big idea 2021. Shares an interest in science, math, and space.

Liam Begany- ***Engineering Team* | *Mechanical Engineer***
Student at Manhattan College in New York, studying Mechanical Engineering. His specializations include upperclassman engineering courses, FEA simulations, and CAD. He has been inducted into Pi Tau Sigma and Tau Beta Pi honor societies.

Connor Dupuis- ***Science Team* | *Astronomer***
Senior Computer Engineering student at the University of Florida. Over the summer of 2020 he partook in a software internship at Raymond James where his responsibility was to utilize the ServiceNow platform to implement AI chatbot functionality. Connor also Co-Founded Scanned, a startup which won a $10,000 grant from a local technology competition called Next Generation Tech. He is interested in big ideas and technology that will have an impact on others.



Ivan Parra Sanz-***Science Team* | *Physicist***
Senior student at Florida International University, majoring in Computer Science and minoring in Astronomy. His achievements are limited to good grades, a 2019-2020 internship centered around music software testing at FIU’s Honors Edge Lab, and membership of the honor society of Phi Kappa Phi. Interests include composing & recording music, theoretical astrophysics, video games, and writing.

Michelle Quinones-*Engineering Team | Aerospace Engineer*
First-generation, Hispanic, college student from Elizabeth, NJ. She recently graduated with Honors from Mercer County Community College, where she was a member of the engineering club, and will be pursuing a Bachelor's Degree in Mechanical Engineering at NJIT. She completed the NASA NCAS program where her work ethic won her the MVP award. She also shares an interest in CAD, CNC, and foreign languages.

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1.2 Mission Overview

1.2.1 Mission Statement

The goal of Team 9’s mission is to launch the orbiter HYDRA (Hydrogen Detection and Resonance Analyzer), named after the water-snake in Greek mythology, into the orbit of the Moon to investigate the water-ice deposits in the lunar South Pole Region. HYDRA shall be used to detect hydrogen within the water-ice deposits in the top 1 meter of regolith to +-1% accuracy at a spatial sampling of approximately 100 meters. The duration of the mission post-launch is one year and the orbiter shall be launched in June 2023. During this time, the HYDRA orbiter shall gather scientific data using various scientific instruments, including a sensitive antenna with ground penetrating radar and a neutron spectrometer to determine the location(s) of water-ice deposits in the lunar South Pole Region, specifically the Shackleton Crater. The scientific data shall be used to plan for in-situ resource utilization (practice of collection, processing, storing, and use of materials found or manufactured on other astronomical objects) and for sustained human presence on the Moon.

1.2.2 Mission Requirements

Parent Req #	Child Req# 1	Child Req #2	Child Req #3	Child Req #4
PWR1.0 Power System		The power system shall supply power for duration of the mission		
	PWR1.1	Solar panels shall supply 200 Watts of power while in operation.		
		PWR1.2	Power System shall have a three 1 kW lithium-ion rechargeable batteries	
THRM1.0 Thermal System		The thermal system shall monitor and control internal environment		
	THRM1.1	The thermal system shall use 100 Watts for heating		
		THRM1.2	Thermal system will be located in insulated box to help with thermal regulation	
			THRM1.3	Thermal system shall maintain the internal temperature of the orbiter at a stable 300 K
DS1.0 Data Acquisition System		Orbiter shall use instruments to obtain data for duration of mission		
	DS1.1	Orbiter shall be equipped with GPR, Neutron Spectrometer, on-system computer and hard drives		
		DS1.2	Instruments shall determine the abundance of water-ice in the top 1 meter of the regolith at a spatial sampling of ~100m	
			DS1.3	Instruments shall determine the abundance of water-ice at an accuracy of ~+-1%
COM1.0 Communication System		Communication System shall relate data to primary orbiter		
	COM1.1	Science instruments shall communicate with primary orbiter and relay data back to Earth		
		COM1.2	Radio system shall be used as backup during low power.	

PR1.0 Propulsion System		**Propulsion system shall get the HYDRA orbiter into orbit**		
	PR1.1	**Thrusters shall be used to maneuver and position the orbiter**		
		PR1.2	**Thrusters shall ensure the orbiter maintains a constant velocity of 1.63km/s for the duration of the mission**	
NS1.0 Navigation System		**The orbiter shall stay in orbit using a navigation system**		
	NS1.1	**The navigation system shall be comprised of sensors, star trackers, a gyroscope, and an accelerometer**		
STR1.0 Structure		**The structure of orbiter shall meet volume constraints**		
	STR1.1	**The structure shall meet volume constraints of up to 60.1 cm x 71.1 cm x 96.5 cm / (23.7 inch x 28 inch x 38 inch) when stowed.**		
		STR.1.2	**The structure shall meet mass constraints of up to 180 kg (396.8 lbs).**	
INT1.0 Internal Systems		**Internal systems must all communicate together throughout critical phases of the mission**		
	INT1.1	**Antenna and solar panels must deploy successfully**		
BUD1.0 Budget		**The mission shall meet budget constraints.**		
	BUD1.1	**The mission budget shall not exceed allowable funds of $250 million.**		

Table 1: Team 9 Mission Requirements

1.2.3 Mission Success Criteria

For mission success, the HYDRA orbiter must enter a polar orbit, safely deploy solar panels and antenna to accurately detect and map out the abundance of water ice in specific sections of the Moon in the top 1 meter of regolith at +-1% accuracy, or better, optimally at a spatial sampling of approximately 100 meters.

1. The HYDRA orbiter must withstand launch and must safely enter the circular polar orbit at 100km distance from the lunar surface.
2. Materials used in orbiter design must withstand a temperature range of -280 ℉ (-173 ℃) to 260 ℉ (127 ℃).
3. Collect data within the allowable accuracy and report back to the main orbiter and Earth.
4. Must have communication with the main orbiter for deployment of instruments.

5. The solar panels and other exterior components must safely deploy to ensure longevity of the mission.
6. The orbiter must gather data and directly communicate the data back to the main orbiter to deliver back to Earth over the duration of the year-long mission.

1.2.4 Concept of Operations (COO)

To be described in section 6.2, the payload shall launch in June 2023, and enter an equatorial orbit around the Moon approximately 3 days later. Calibrations shall only take place once the payload has entered the desired orbital conditions, but before detachment from the parent orbiter in order to minimize risks associated with navigation system calibration tests, as described in section 4.2.5. After calibration tests are complete, the payload shall detach from the parent orbiter before readjusting its orbit. This new orbit shall allow the orbiter to pass over the permanently shadowed regions at the lunar south pole for data collection, and its longitude shall increase after each pass such that it can map all of the desired regions, as described in section 4.2.4. The orbiter shall only collect data during these passes; when not actively collecting data, it shall be transmitting data back to the parent orbiter for analysis, generating power to recharge the batteries using solar radiation, and deactivating any non-necessary power-consuming equipment in order to maximize power retention.

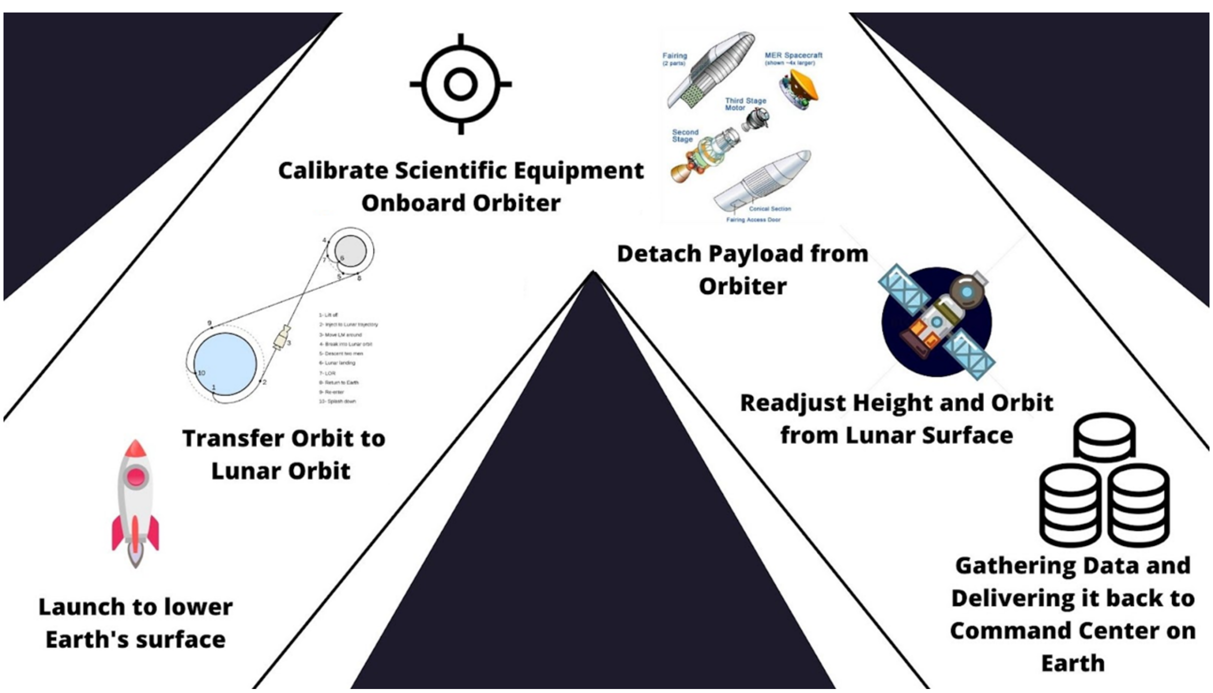


Figure 1: Concept of Operations Visual

1.2.5 Major Milestones Schedule

1. Finalized list of scientific instruments and other technologies for orbiter
2. Finalized background research into Moon
3. Finalized design/models
4. Finalized budget
5. Finalized fabrication of orbiter
6. Completion of pre-launch testing
7. Successfully launching the orbiter
8. Successful relocation of orbiter
9. Successfully deploying payload
10. Successful revolutions around Moon
11. Successful data collection

Pre-Phase A: Concept Studies

This phase shall begin on May 24, 2021 and outlines the tasks for Team 9 prior to mission planning. Team 9 shall be divided into teams and sub-teams according to expertise. Background research shall be conducted on past and current Lunar mission plans to brainstorm ideas and begin drafting. Each team member and sub-team shall have specific tasks to complete within a timeframe outlined in a Gantt Chart which shall outline major milestones. Team 9's mission goals are as follows:

1. Design an orbiter that utilizes science instruments including an antenna equipped with sensing technology to determine water-ice levels beneath the lunar surface.
2. Identify water composition and volatiles within the first 1 meter of regolith that can be used for rocket fuel and the creation of breathable air for sustained presence on the Moon.
3. Investigate specific locations that may have higher levels of water-ice such as Shackleton Crater and other Perpetually Shadowed Regions (PSRs).

Phase A: Concept and Technology Development

Phase A shall begin on June 9, 2021. This phase includes implementation of research to determine proper scientific tools necessary for mission success. It is crucial for Team 9 to determine instrumentation in this phase before commencing the design aspect of the mission outlined in part C/D. For this reason, it is crucial that the major mission milestones are determined including launch date, build according to specified constraints, deployment, timeline of mission from launch to orbit, HYDRA orbiter's trajectory plan, communications and data retrieval, etc.

Phase B: Preliminary Design and Technology Completion

Phase B initiates the implementation of design specifications outlined previously in phase A such as the subsystem requirements, designs, interfaces, and then integrating and testing.

- PDR Completion

Phase C/D: Final Design & Fabrication

Phase C is when the design is finalized and the Critical Design Review (CDR) milestone is met.

- CDR
- Code and Hardware Software
- Final 3D Model Design

Phase D is the systems integration and testing phase and when the Safety and Mission Success Review (SMSR) milestone is met.

- V&V Test Completion
- Manufacturing Assembly completion
- Flight Readiness Review (FRR) & Mission Readiness Review (MRR)
- Launch

Phase E: Operations and Sustainment

The purpose of Phase E is to conduct the prime mission to meet the initially identified needs and to maintain support for the mission's goals. The payload shall adjust altitude on the lunar orbit to gather the results of the mission and performance of the system.

- Result
- Data

1.3 Descent Maneuver and Vehicle Design Summary

A clamping system shall hold the lunar orbiter to the primar lunar orbiter. Once the orbiter approaches the Moon, the clamps shall detach and the lunar orbiter shall fire it's cold gas thrusters to align the orbiter's orbit with the desired site of observation.

Once the orbiter is above the desired location while also at the desired altitude and travelling at the desired speed, the antenna associated with GPR shall extend from the chassis of the orbiter facing the lunar surface and begin scanning for the specific frequency of water-ice.

The current CAD model for the orbiter consists of two solar arrays (each containing four separate solar panels), the vehicle body, and models of payload equipment stored within the body. The maximum design specifications for size and mass are 60.1 cm X 71.1 cm X 96.5 cm and 180 kg respectively. The current size and mass for the orbiter is 59.0 cm X 70.2 cm X 94.8 cm and 161.25 kg. The body itself is 80 kg, made out of 2024 Aluminum Alloy.

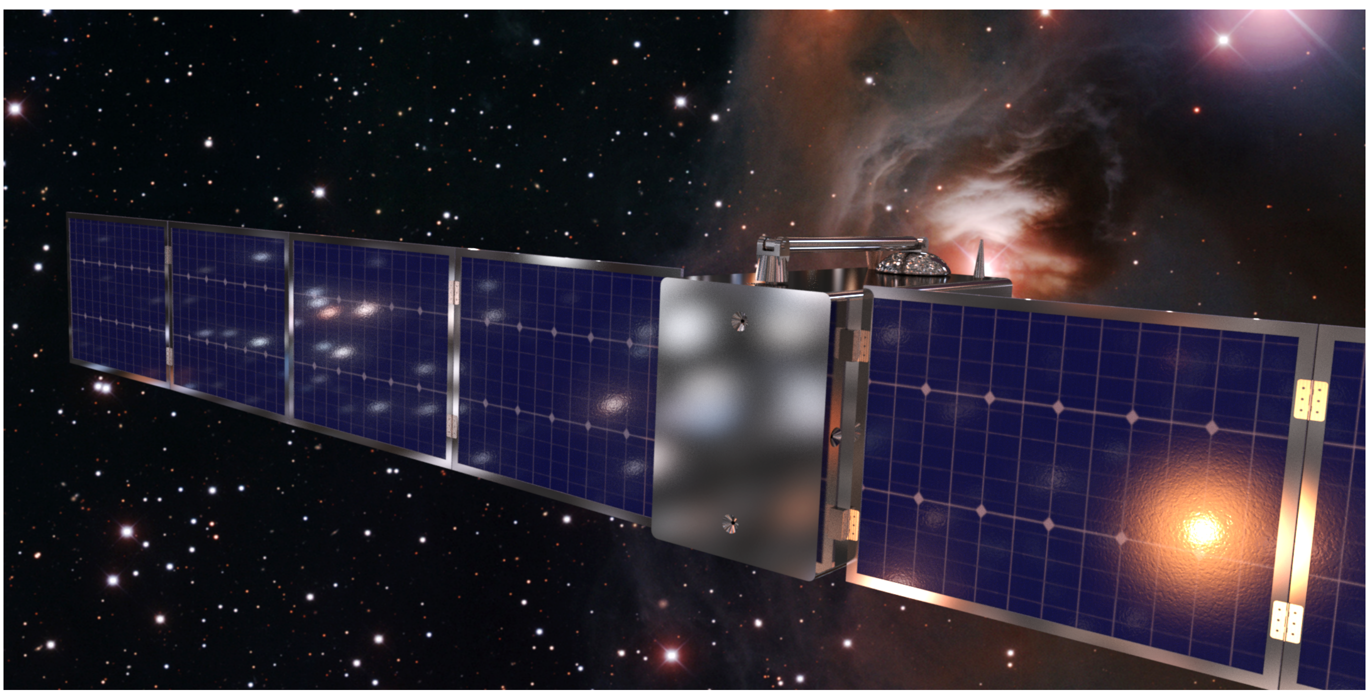


Figure 2: Orbital Concept Rendering

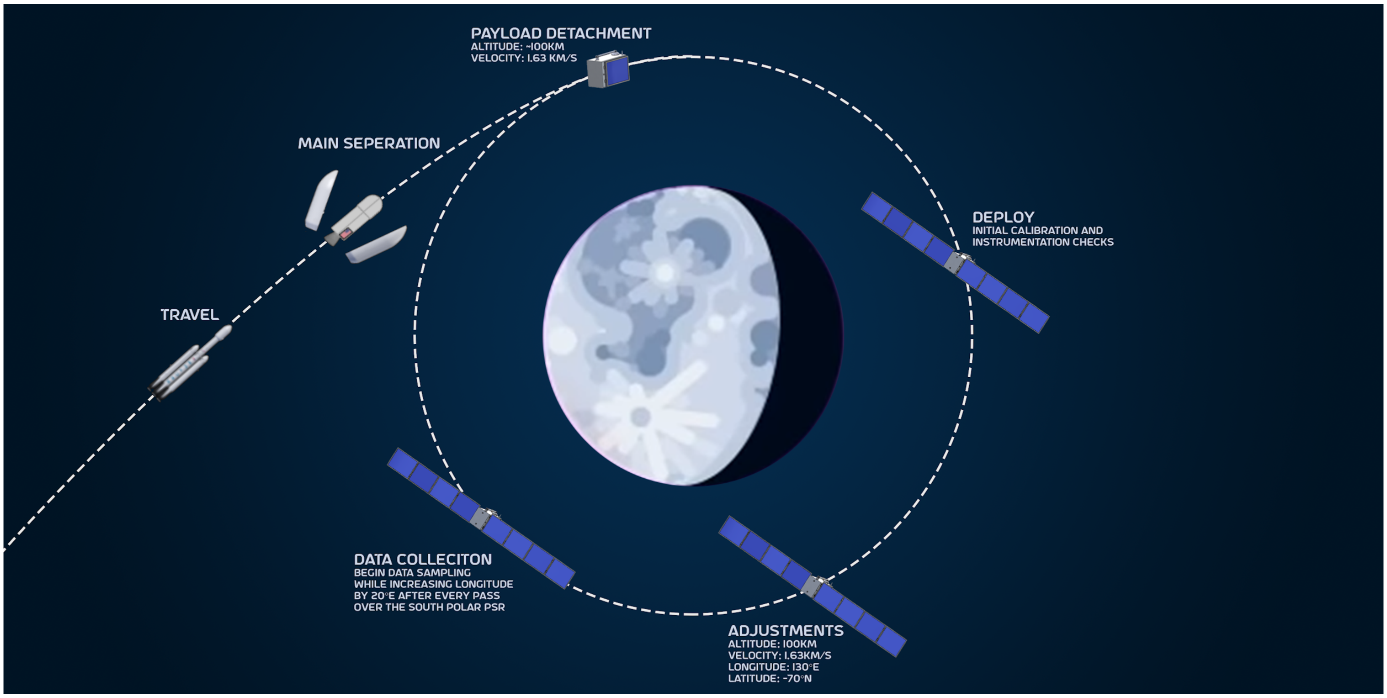


Figure 3: Entry, Descent, and Landing (EDL)

Figure 3 displays a walkthrough of the mission specifically geared towards the entry of lunar orbit. HYDRA shall travel from Earth on a trajectory towards the moon and separate from the main payload once in range of the Moon's gravitational pull. After successfully detaching, HYDRA shall deploy it's solar arrays, and data and communication antennas. Once fully deployed, HYDRA shall adjust it's altitude and velocity and then begin data collection.

1.4 Payload and Science Instrumentation Summary

Ground Penetrating Radar

Ground penetrating technology probes the subsurface using radar waves within a selected frequency band. The radar wave return, which is captured by the 10 meter (5 meter dipole) antenna, is sensitive to changes in the electrical reflection characteristics of rock, sand, and any water that may be present in the surface and subsurface. Water, like high-density rock, is highly conductive, and has a very strong radar return. Changes in the reflection characteristics of the subsurface, caused by layers deposited by geological processes in the ancient history of Mars, are also visible. Sourcing SHARAD, which currently orbits Mars on the Mars Reconnaissance

Orbiter, the system can have a horizontal resolution of between 0.3 and 3 kilometers and a vertical resolution of 15 meters with a total mass of 15.0 kg.

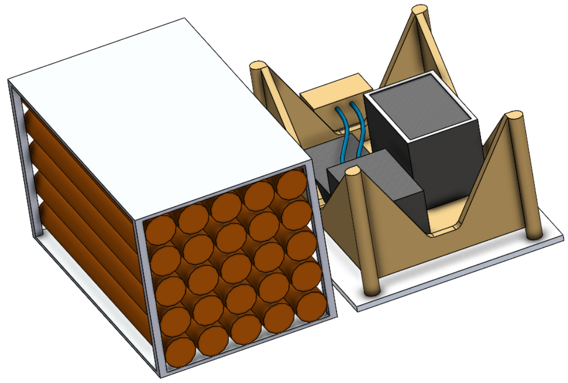


Figure 4: CAD Assembly of SHARAD Instrument

GPR works in two main ways. One mode of operation involves a pulse generator that applies a narrow pulse of energy to the antenna, which acts as a band-pass filter, and produces a single sine wave cycle that is broadcast. The returned echoes are then collected as a function of time.

An alternate mode of operation uses a step-frequency or "chirp" technique to form radar pulses. This method utilizes a spread in frequency to permit synthesis of a short effective pulse from a much longer transmitted signal. The planetary GPR discussed here uses a more simple impulse generator, for which the pulse width and the propagation velocity in the target medium are used in setting the range resolution.

GPR consists of both an antenna and a wave generator, whether it be "chirps" or "pulse" (described above). A transmitter is required to emit the radar waves in chirps or pulses to scan and provide the high-depth resolution of the subsurface.
An antenna is required for the capturing of the emitted radar waves where they then can be sent to the main orbiter, and then back to earth for signal processing and analysis.

No serious DSP or analysis should happen on the payload or orbiter. A potential issue with GPR technology is that it can only detect macroscopic levels of ice, likely blocks greater than 10cm.

Neutron Spectrometer

The Neutron Spectrometer operates using two methods, active and passive. Active neutron methods use a radioisotope source to produce energetic neutrons that interact with H in the surrounding regolith. Whereas passive methods rely on galactic cosmic ray-induced production of neutrons and gamma rays from the regolith. The energy distribution of neutrons and gamma rays as leakage fluxes coming from any airless planetary body is dependent on the influx of galactic cosmic rays (GCR) that influence neutrons and gamma rays to the top meter of the regolith. The Neutron Spectrometer developed by NASA from the Glenn Research Center shall be utilized. The mass is listed as 2.0 kg.

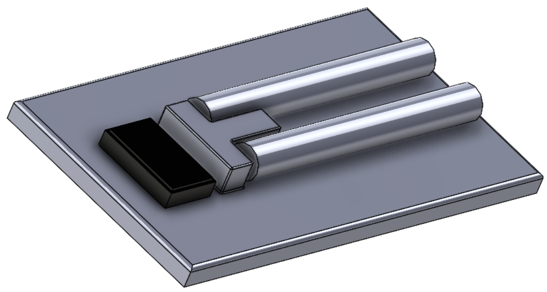


Figure 5: CAD Model of Neutron Spectrometer

Lithium Ion Batteries and Solar Panels

The solar panels shall be the main source of gathering energy for the payload, converting photons from the sun to energy, and the converted energy shall be collected by three 1 kWh batteries from Ibeos that can resist the harsh environment of space and provide energy when needed to fulfill the payload mission. Each battery shall have a mass of 7.5 kg according to the manufacturer. Using information from the solar arrays on the International Space Station, each solar panel shall generate 0.048 kW/m^2 which accounts for the efficiency of the panel. All eight solar panels on the HYDRA Orbiter shall have a surface area of 0.507 m^2 each resulting in 200 Wh of total power generation. The mass of each solar panel shall be approximately 1.2 kg for the designed size.

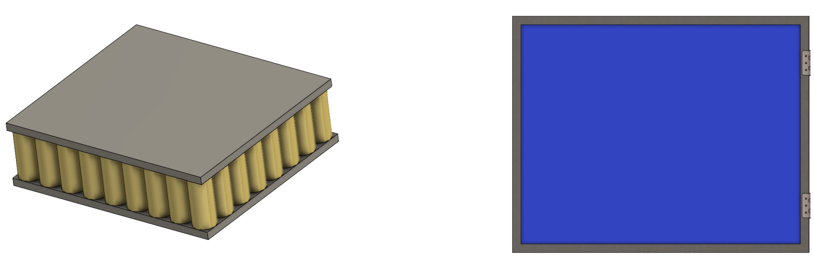


Figure 6: CAD Models for Li-ion Battery (left) and Solar Panel (right)

Thrusters and Fuel Containers

The HYDRA Orbiter shall have 12 cold gas thrusters manufactured by Nammo. Each thruster shall have a mass of 60 g and capable of producing 100 mN of thrust at 2.5 bar. The main objective of the thrusters shall be maintaining orbit and position of the orbital throughout the duration of the mission. Two fuel tanks shall contain pressurized fluid to be used as propellant during the mission. Each fuel tank has a mass of 2.87 kg and internal volume of approximately 1,000,000 mm^3 (0.001 m^3).

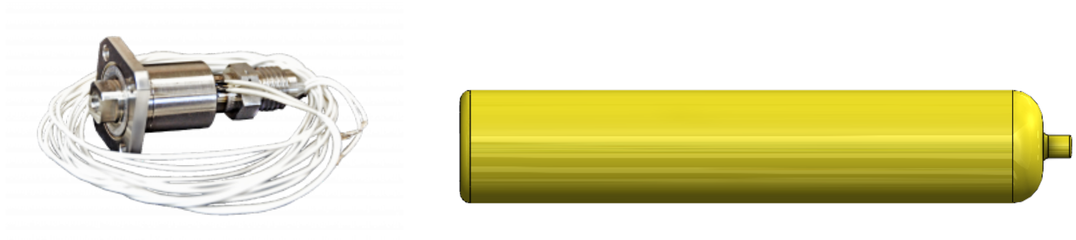


Figure 7: Cold Gas Thruster (left) and CAD Model of Fuel Tank (right). Note, thruster modeled as converging - diverging nozzle in CAD Assembly

Location System

Software that shall keep track of the orbiter's position relative to the Moon and parent orbiter by continuously calculating its orbital location. This system shall make use of a gyroscope to determine the orbiter's current orientation, while an accelerometer shall be used to determine its current height above the lunar surface by measuring the lunar pull of gravity on the payload. Finally, a sun sensor shall allow the orbiter to determine its current position along its orbit by tracking the position of the Sun, then calculating based on the Earth's and Moon's known location in their respective orbits.

Star Tracker

Star trackers provide full knowledge of the spacecraft's orientation and position, allowing the spacecraft to know where the Sun is, but also where Earth and Mars are. This allows the orbiter to position itself pointing in any direction in the sky, which shall be crucial when doing a maneuver. The star tracker is a smart camera that takes a digital picture of the stars and then compares the image with those in its own catalog of thousands of stars to identify the stars in the image. Once it does that, it knows exactly where it was pointing at the time of the picture, and sends a message to the computer conveying that information. The absolute location not regarding where the orbiter is pointing may be determined with other sensors and relaying information back to Earth.

Figure 8: CAD Model of Star Tracker

Radio and Communication system

If the orbiter ever enters a low-power situation, it shall cease function of its other science instruments and rely only on this radio system for communication, until power is back to acceptable levels. This low power radio system is intended as the primary communication tool for between the payload and the main orbiter. This system shall also be used to supply the main orbiter all the collected data from the GPR. A high gain antenna modeled after the one used on the Lunar Reconnaissance Orbiter shall be used. In addition, a low gain antenna modeled after the one used on the Mars Rover. The mass of each shall be 3.9 kg and 155 g respectively. Lastly, an amplifier manufactured by General Dynamics shall be implemented with a mass of 1.37 kg.

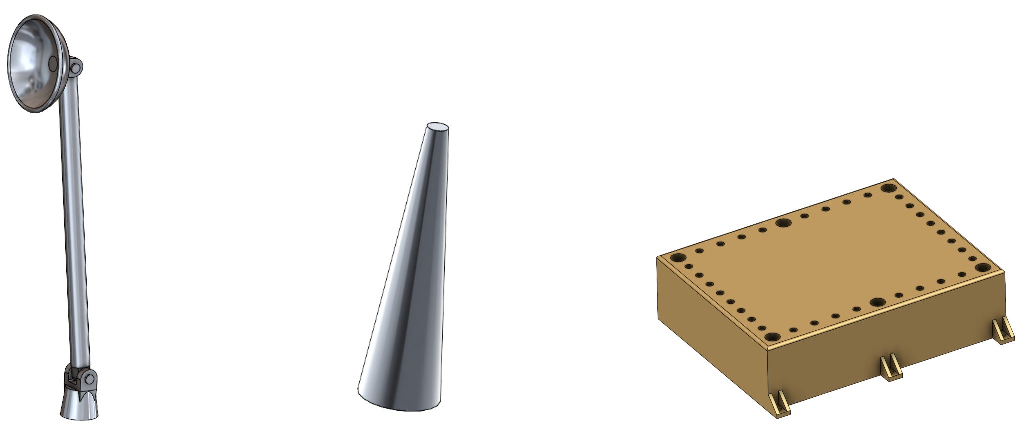


Figure 9: CAD Models of High Gain Antenna (left), Low Gain Antenna (middle), and Amplifier (right)

Internal System
Software installed on the orbiter and supported by hardware that ensures all instruments work together. This includes a solid state drive, or SSD, that can hold up to 120GB of memory, as well as a RAD750 CPU with a rate of 200 MHz. The necessary applications to keep the payload running as desired are to be installed on internal software running on the aforementioned hardware. These components shall work in tandem with other systems in order to store the collected data, communicate with the parent orbiter, and manage possible risks.

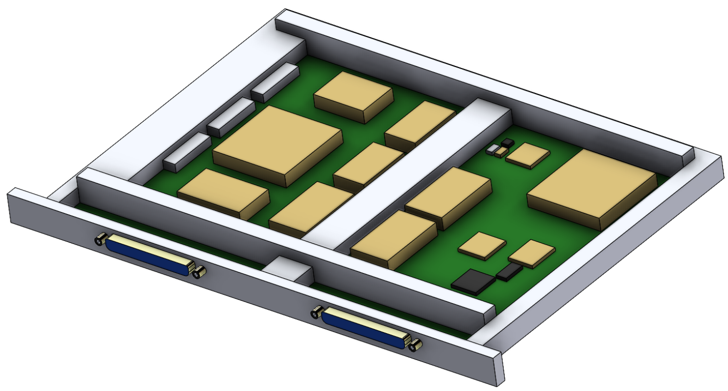


Figure 10: CAD Model of On-Board Computer

2. Evolution of Project

2.1 Evolution of Mission Experiment Plan

Over the course of the summer, the team made several changes to the mission experiment plan due to factors influencing the changes, such as further research giving the team new insights. During the initial brainstorming portion of the project, only the antenna was planned to be used for radar capabilities. After further research into technology that would support the scientific objectives, the team decided on including infrared sensing. This allows the orbiter to collect more data on the regions to be researched. The team continued to add on scientific instruments and back-up components after seeing there was extra volume and mass that could be utilized for this end.

Another change to the mission experiment plan was expanding upon the success criteria set as a team. For the initial submission, the main criteria was based on the scientific criteria of water-ice detection in different sections of the Moon, but additional success criteria was included after feedback. There exist success criteria for different systems of the spacecraft, such as mechanical and power success. The updated success criteria led the team to include more components to the orbiter to meet said criteria. An example of this is the addition of a tertiary battery as a back-up system.

2.2 Evolution of Descent Maneuver and Vehicle Design

During the initial brainstorming of Team 9's vehicle design, different types of spacecraft for the team design were considered. One of the initial ideas was to use a rover with the same scientific instrumentation that was chosen for the orbiter. After discussion, the team decided that the rover would limit data collection since it would only be able to very gradually scan certain areas at a time, on top of concerns regarding power generation inside a PSR. The chosen design of an orbiter would allow the payload to scan more regions of a larger scale during a shorter period of time compared to a rover.

Another initial design idea was to use a swarm spacecraft. One of the disadvantages of using this spacecraft would be the mass and volume constraints of having more than one spacecraft for the mission. By choosing the orbiter spacecraft that only has one unit, the team was able to manage the volume and mass constraints easier and include back-up components.

For the overall project, the team was given the option to choose a different Mission Start than the one chosen for the spacecraft. For Mission Start 2, the mission would have begun at an altitude of 10km above the lunar surface with negligible forward velocity. Since the team decided on an orbiting mission concept, Mission Start 2 would not provide the spacecraft with the distance desired between it and the lunar surface necessary to complete the mission.

By researching different types of spacecraft, the team was able to decide on the optimal type of spacecraft for the final design. The orbiter fits the success criteria and scientific objectives that have been set as a team.

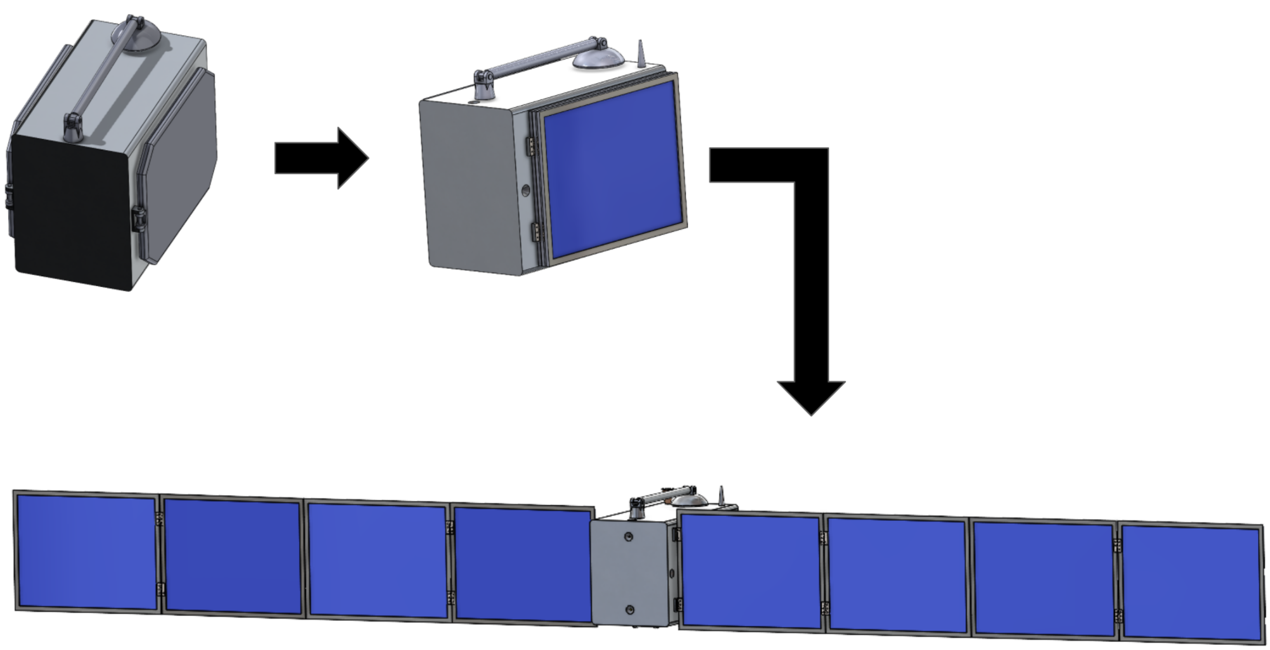


Figure 11: Design Iterations

From figure 11 above, the various design iterations can be observed. The first iteration was a basic concept design for the general shape of the body as well as the location of exterior components. The second iteration includes reworked solar panels, thrusters for maneuverability, and some necessary internal components. For the final iteration, the body and solar panels were resized and optimized to fit volume constraints. Within the body, all components were added and fastened into place such that everything fit with space in between components to allow for proper cooling.

2.3 Evolution of Payload and Science Instrumentation

Throughout the summer, the payload and science instrumentation had evolved through different ideas and designs. Initially, the payload was to include an infrared detector, based on NASA's Stratospheric Observatory for Infrared Astronomy, or SOFIA, which had previously utilized its infrared telescope to detect water molecules on the sunlit surface of the Moon.

However, after further discussion from the engineering and science team, it was decided a Ground Penetrating Radar, or GPR, would be more fitting for the mission. This choice was made after research was done on the Mars Reconnaissance Orbiter's Shallow Radar, or SHARAD, which made use of a GPR to detect subsurface water-ice. The reasoning lies in that while an infrared telescope would have difficulty penetrating the lunar regolith, the GPR makes use of radio waves capable of traversing the desired medium, well and beyond the desired depth of ~1m. While the GPR would require a transmitter and receiver to function as desired, the team realized that the equipment required for the payload's communication system could fulfill both functions at once, which made accommodating the GPR a straightforward task.

During the first budget review, the team saw that the budget was capable of supporting another data collecting instrument. While accounting for the GPR's capabilities, the science team realized that it was only capable of detecting macroscopic levels of ice -- such as blocks of at least 10cm. In order to increase the accuracy of the system, the science team decided on a neutron spectrometer, or NS, based on the one used for NASA's Mars Odyssey mission. This was due to the NS's capability to detect small amounts of H that the GPR may fail to detect, down to grain-sized deposits. This choice was only made after the whole team agreed that including the NS was both physically and financially feasible, as dictated by the payload's dimensions, weight and budget.

Besides the data-collecting instruments, the payload also relies on various other systems to function correctly, such as the navigation system, the thermal system, and the communication system. While the team as a whole was swift to agree all of the aforementioned systems were necessary for the mission, research had to be done in order to determine the specifics and criteria for each one. For example, in order for the thermal system to work as desired, the team would have to account for the extreme temperatures the orbiter would have to withstand while in orbit, the drastic changes in temperature dictated by solar radiation and internal heat, the desired temperature range for all components to function correctly, the power supply necessary for the thermal system to maintain the aforementioned range, and the dimensions of the system respective to the payload. Thus, determining the criteria for each system was a gradually evolving process, especially due to the need for certain systems to rely on others; e.g. the power system and the thermal system, the data-collection system and the communication systems, and so forth.

Furthermore, the navigation system was given special consideration once the team realized the difficulties associated with accurately determining the orbiter's position across its orbit. While initially the payload was meant to rely solely on internal software to continuously calculate its position respective to the Moon and parent orbiter, eventually both the science and engineering team opted to include sensors aboard the orbiter. These include Sun sensors and star trackers, meant to keep track of the Sun or specific guiding stars, respectively, which would aid the orbiter in aligning itself such that the data-collecting instruments would be aimed at the lunar surface, and the solar panels away from it. On top of that, a gyroscope and accelerometer were deemed necessary for orbital positioning, as well as an infrared detector that would help detect the orbiter's current position above the lunar surface.

3. Descent Maneuver and Vehicle Design

3.1 Selection, Design, and Verification

3.1.1 System Overview

HYDRA shall enter a polar lunar orbit while attached to the main orbiter. Spacecraft in orbit around a planet have the ability to collect more data and get more detailed information about the region that it shall investigate, and the advantage of observing more surface area over a period of time. Once optimal, the HYDRA orbiter shall detach from the main orbiter at 100 km from the lunar surface with an orbiting velocity of 1.63 km/s and enter its own polar orbit. Thrusters shall be used to maneuver the orbiter and position it in orbit around the southernmost pole. Once detached and in orbit, the solar panels shall unfold to generate power for the batteries. Once the panels are deployed, the GPR antenna shall deploy due to the elastic properties of the material housing the antenna. In addition, communications to the main orbiter shall begin. Radar technology shall record the data collected until it is relayed to the main orbiter. Once the data is released, and there is confirmation of the data retrieval, the data captured on HYDRA shall be deleted to allow for additional data collection.

Descent:

The descent system shall be broken up into two stages. Stage one shall be detachment from the main orbiter via release of the clamps. Stage two shall consist of engaging thrusters to finalize orbital position.

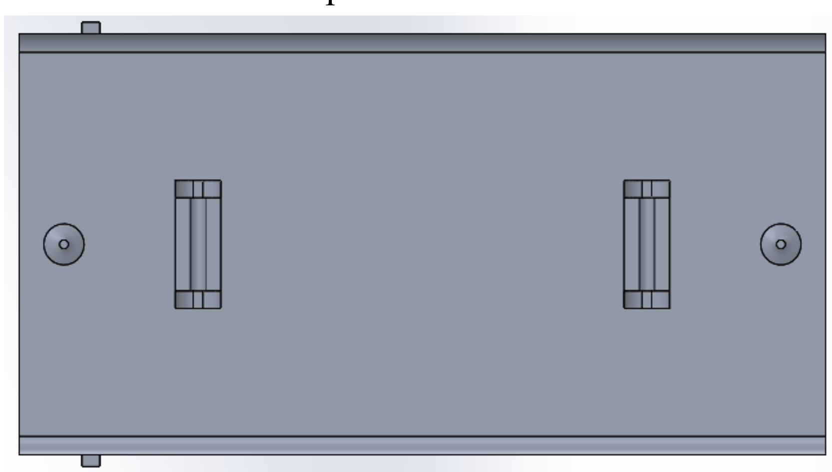


Figure 12: Visual of Clamp System for Release of HYDRA Orbiter

Vehicle:

The vehicle system shall maintain the structural integrity of the spacecraft and allow the spacecraft to survive and complete its scientific objections for the mission. The body of the orbiter shall have walls made out of 2024 Aluminum alloy at 12 mm thick to ensure structural integrity and to prevent serious damage from debris. The body is split into three sections on the inside, with 4 holes at each corner to allow for wiring and tubing to reach the desired component.

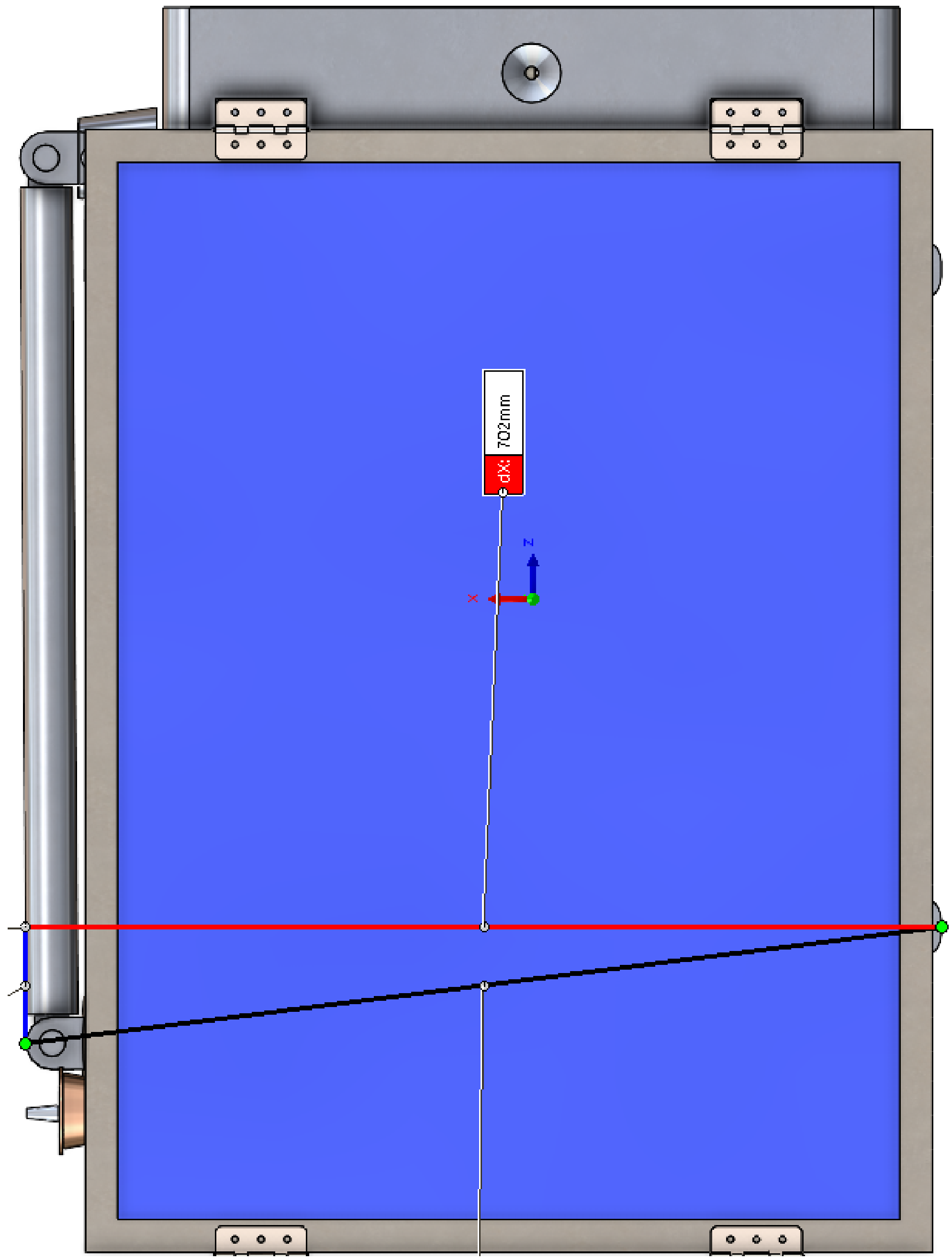


Figure 13: 702 mm (70.2 cm) Height Dimension

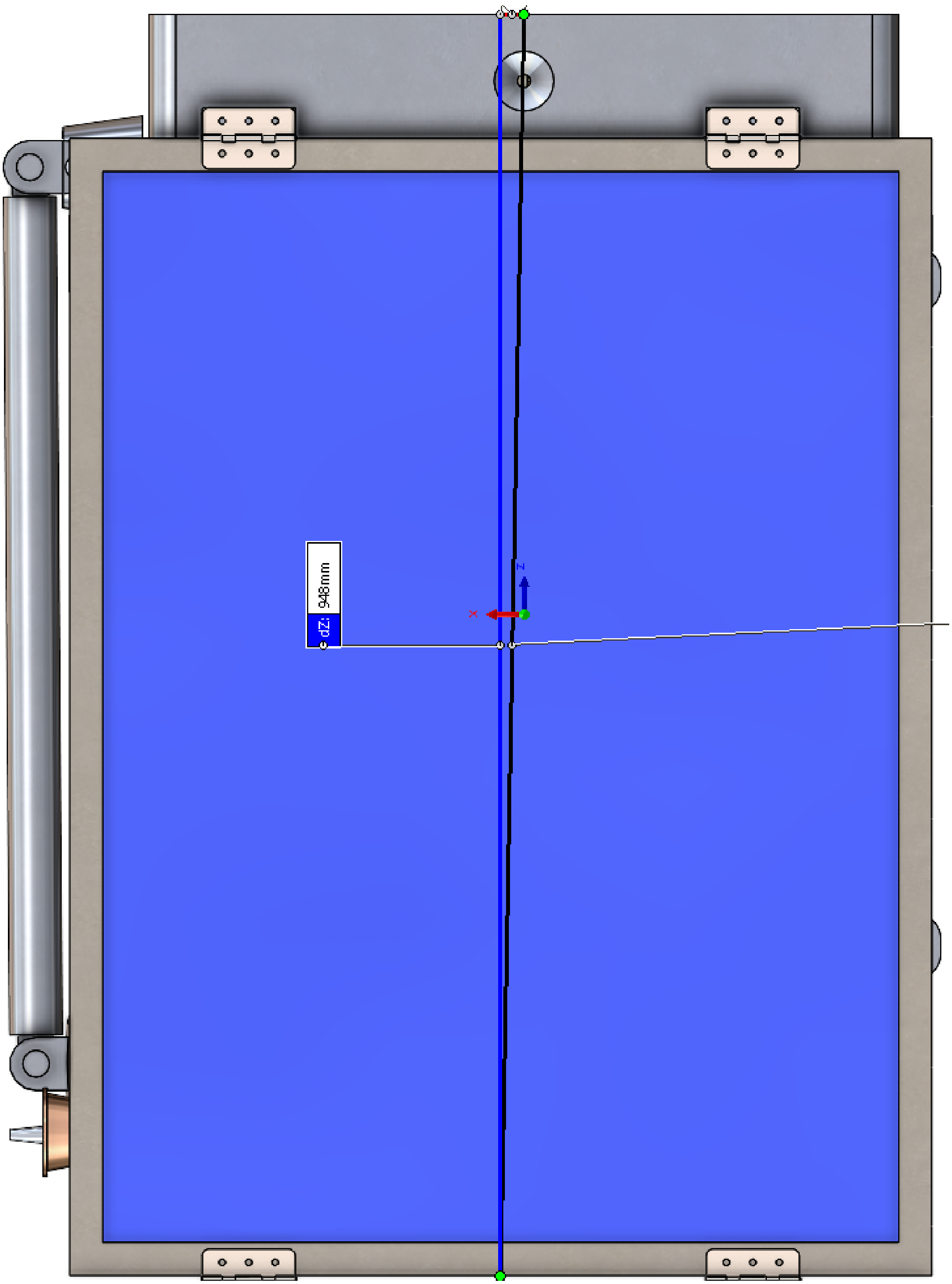


Figure 14: 948 mm (94.8 cm) Length Dimension

NOT PICTURED: SOLAR ARRAY. EACH ARRAY ADDS 52 mm TO EACH SIDE WHEN STORED

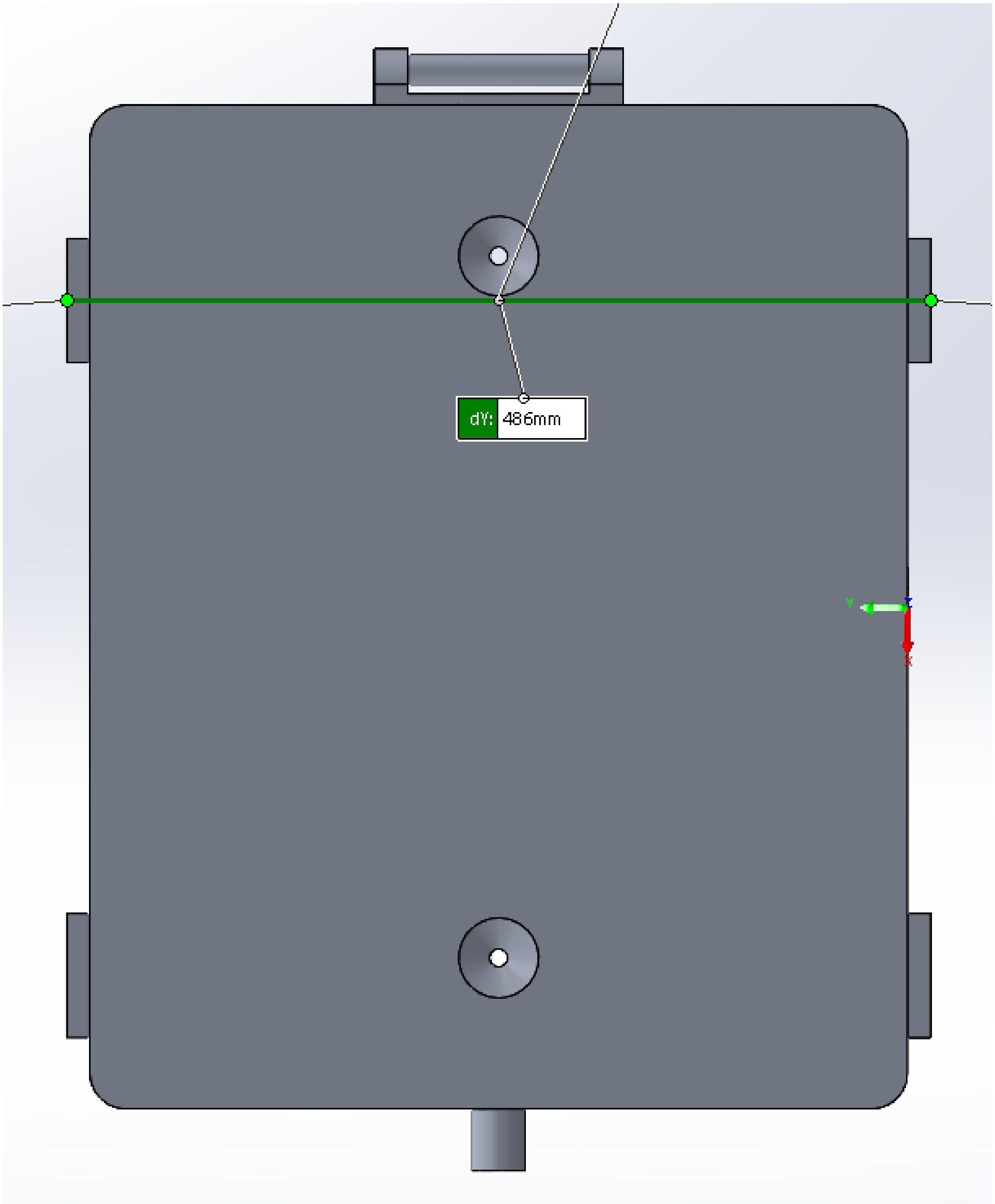


Figure 15: 486 mm (48.6cm) Width Dimension (total width: 590 mm (59.0 cm))

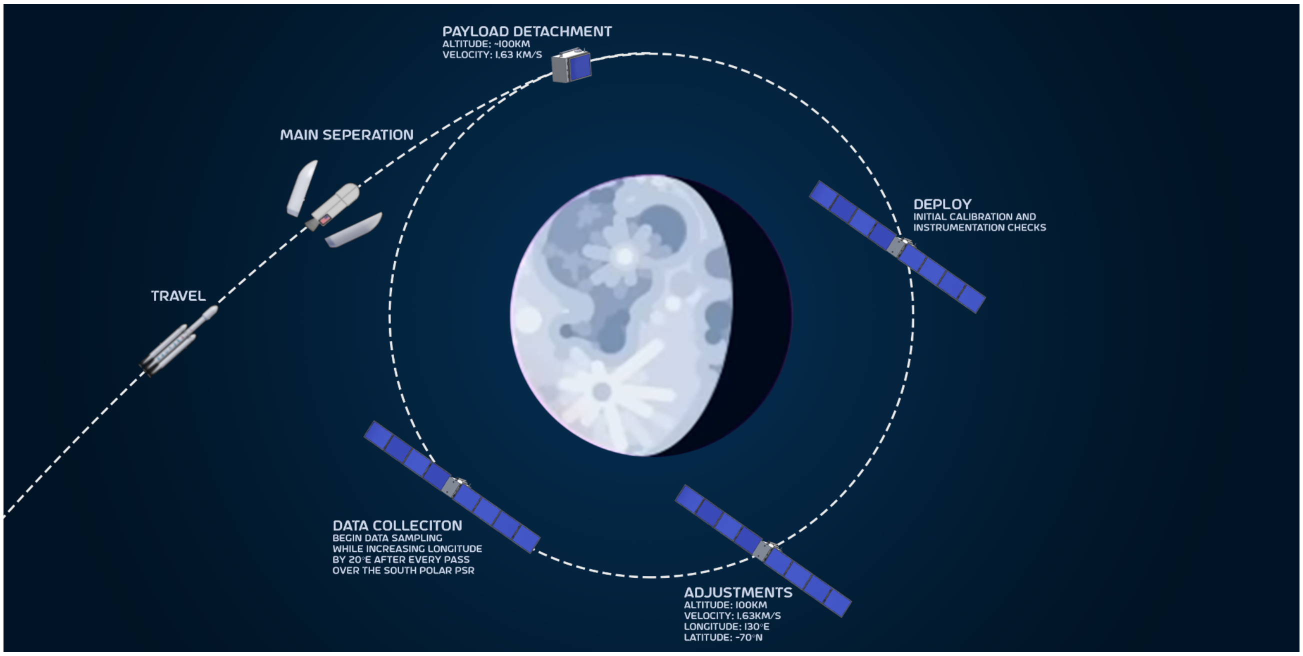


Figure 16: Entry, Descent, and Landing (EDL)

3.1.2 Subsystem Overview

The descent system shall include components on the interior and exterior of the spacecraft. The interior components shall consist of the tank and tubing for the cold gas thrusters, while the thrusters shall be located on the exterior of the spacecraft. The cold gas thruster system represents an important advance in propulsion technology suitable for small satellites, with limited budget, mass, volume, and power. The payload shall contain compressed nitrogen, due to its use as a long-term storable propellant in space vehicles and ideal for small satellites. Thruster shall provide sufficient force to stabilize and maintain the altitude of the orbiter.

3.1.3 Dimensioned CAD Drawing of Entire Assembly

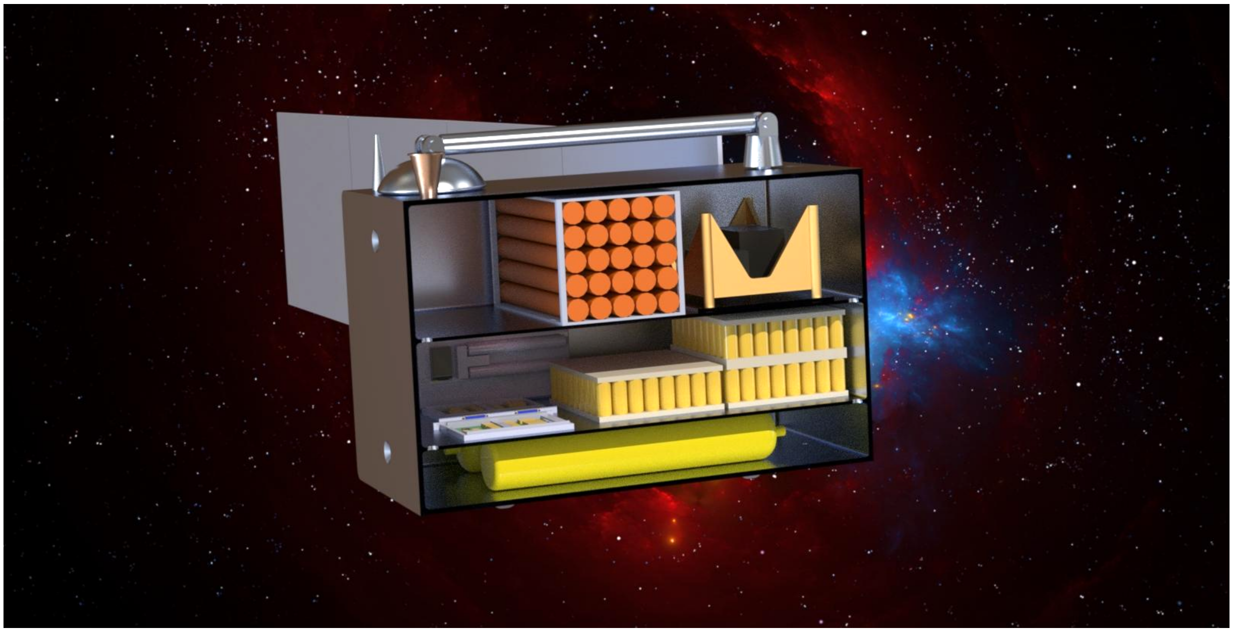


Figure 17: Rendered Section View of HYDRA Orbiter

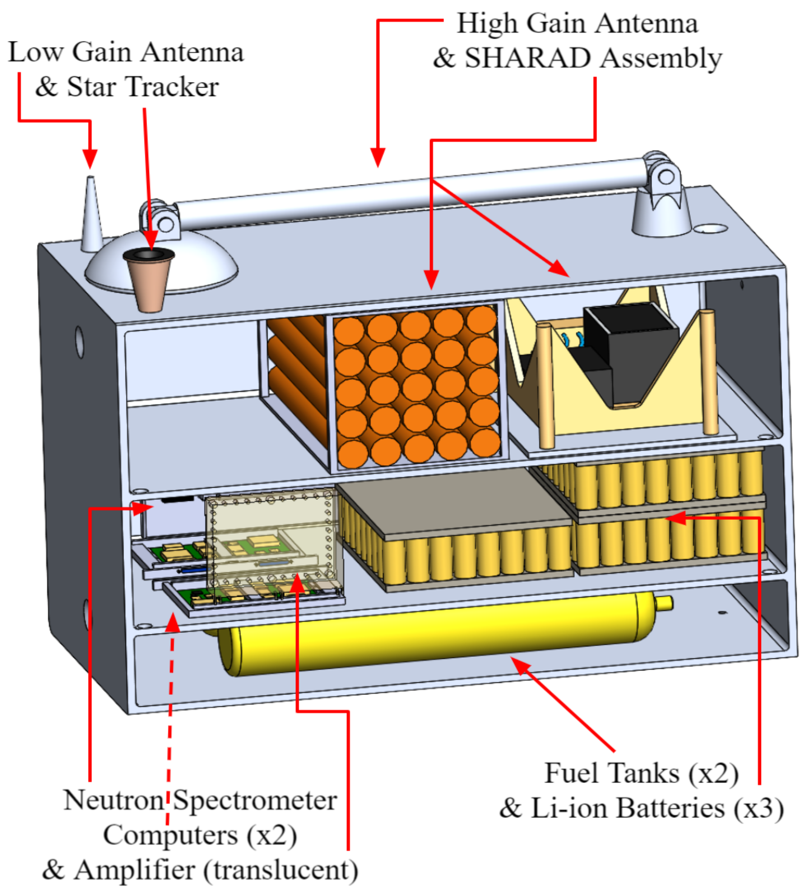


Figure 18: Annotated Section View of HYDRA Orbiter

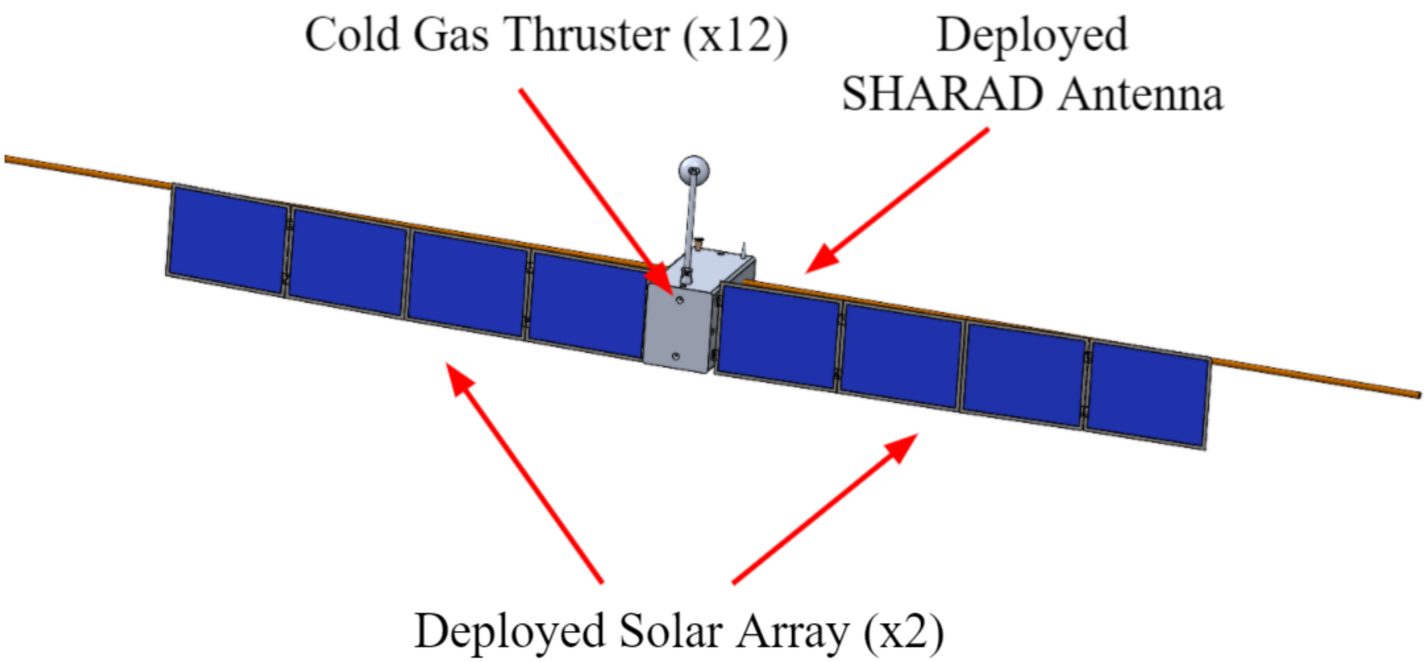


Figure 19: Annotated Fully Deployed Assembly

As pictured in the figure above, once fully deployed, the HYDRA orbiter shall extend out to a wingspan of 10 meters.

3.1.4 Manufacturing and Integration Plans

Manufacturing Procedures:

Goddard Space Center shall be the facility contracted to manufacture and construct the HYDRA orbiter. Their Mechanical Systems Division (MSD) and Advanced Manufacturing Branch (AMD) shall allow the team to construct and test multiple different sections of the orbiter at once before assembly. Tests ranging from space and launch environment simulations to acoustic and electromagnetic interference can be conducted on site, allowing for the manufacturing process to run more smoothly. It is expected to have the orbiter fully manufactured in approximately two years.

Resources:

- Electroplating facilities in the AMD
    - Allows for cleaning and surface finishing
- Machining Technologies facility in the AMD
    - Lathe and milling machines
    - CNC machining
    - Water jet machining
- High Capacity Centrifuge
    - Allows for launch simulations that provide up to 30 g's of force on the spacecraft hardware
- Acoustic Test Facility
    - Tests the scientific equipment for audio interferences using reverberation chambers and noise chambers that produce up to 150dB to ensure equipment shall remain stable during launch
- Space Environment Simulation
    - Tests the scientific equipment in an ultra-low pressure environment to ensure equipment can function in a vacuum
    - Tests equipment in various thermal conditions
- Spacecraft Systems Development and Integration Facility (SSDIF)
    - 1.3 million cubic foot clean room, largest in the world
    - Allows for integration and assembly of orbiter parts
- Vibration Test Facility
    - Simulated launch vibrations
- Magnetic Test Facility
    - Exclusive to the Goddard Center
    - Allows for an evaluation of the magnetic movement of the spacecraft
- Electromagnetic Interference facility
    - Tests spacecraft to see if it is vulnerable to electromagnetic radiation

Hours of work:

- Each of the engineering personnel shall work a standard eight hour workday with breaks and lunch. Additional hours may need to be added depending on the progress and deadlines of the project.

Integration Plans:

The design of the HYDRA orbiter shall allow the body of the orbiter to be built and then the interior components (battery, science instruments, etc.) to be integrated into the orbiter. To ensure that all parts shall fit within the orbital, dimensions for all parts from manufacturers shall be accounted for in the CAD model, and all parts manufactured in house shall be designed such that they fit in the remaining space. Making sure that all components fit within the orbital is crucial such that proper wiring and cooling may occur.

3.1.5 Verification and Validation Plans

Development Stage Verification:

During the development stage of the orbiter design and fabrication, the materials used for the HYDRA orbiter shall go through several tests for the following factors:

1. **Pressure:** acoustics tests, vibration tests, tests under a high capacity centrifuge, and space environment tests in order to ensure the materials are able to withstand the pressure associated with launch and with the vacuum of space.
2. **Impacts:** the aforementioned pressure tests shall also be utilized to determine the materials' capacity to withstand direct impacts in space.
3. **Temperature:** thermal vacuum tests, in order to ensure the materials can endure the extreme temperatures associated with space, ranging from 100K to 400K.
4. **Gravity:** space environment simulations and magnetic tests in order to determine the materials' ability to withstand low-gravity conditions.

Validation Plans:

Testing shall be performed, under conditions designed to simulate the vehicle destination, in regards to:

- Extreme, and drastic changes in temperatures. Testing shall take place inside an artificial vacuum where temperatures can range up to a high of 400 K, and to a low of 100 K, such that it can simulate the heat caused by solar radiation and payload equipment, as well as the lack of heat associated with the vacuum of space. This testing shall also ensure the thermal system functions properly when approaching extreme temperatures, limiting it to a range of 300 K.

- Pressure, utilizing a high capacity centrifuge to simulate the vibrations and high pressure the payload shall endure during launch, the low pressure of the vacuum once in orbit, and the force exerted on the exterior and interior components of the spacecraft.
- Data collection, by testing the instruments' capability to detect subsurface water-ice here on Earth. Testing shall occur while also testing for other factors, in order to determine the payload's efficiency and accuracy under the expected conditions, both while stationary and while in movement. Testing shall also ensure collected data is safely stored in the on-board SSD, and that said data is not corrupted and able to be transmitted.
- Communication, by ensuring the payload can both receive and transmit data under the simulated environment, and that the amplifier functions as expected. This shall be performed while testing for data collection, in order to test the instrumental transmitter and receiver, and to analyze the incoming test data. Testing shall take place both while stationary and in movement.
- Movement, by simulating low-gravity conditions in order to test for the navigation system's accuracy during motion at the desired speed and trajectory. Also, test the thrusters capability to influence its movement during these motions, including the amount of fuel utilized.
- Power, by exposing the payload to direct sunlight, thus ensuring that the payload can collect energy via solar panels at the desired rate, that collected energy is correctly stored in the equipped batteries, and that it can distribute this power efficiently through the system. Testing for power management shall be performed during any combination of power-intensive tests (such as data collection and communication).

For further details on verification and validation plans, please refer to sections 3.1.4, 4.1.4, and 5.2.2.

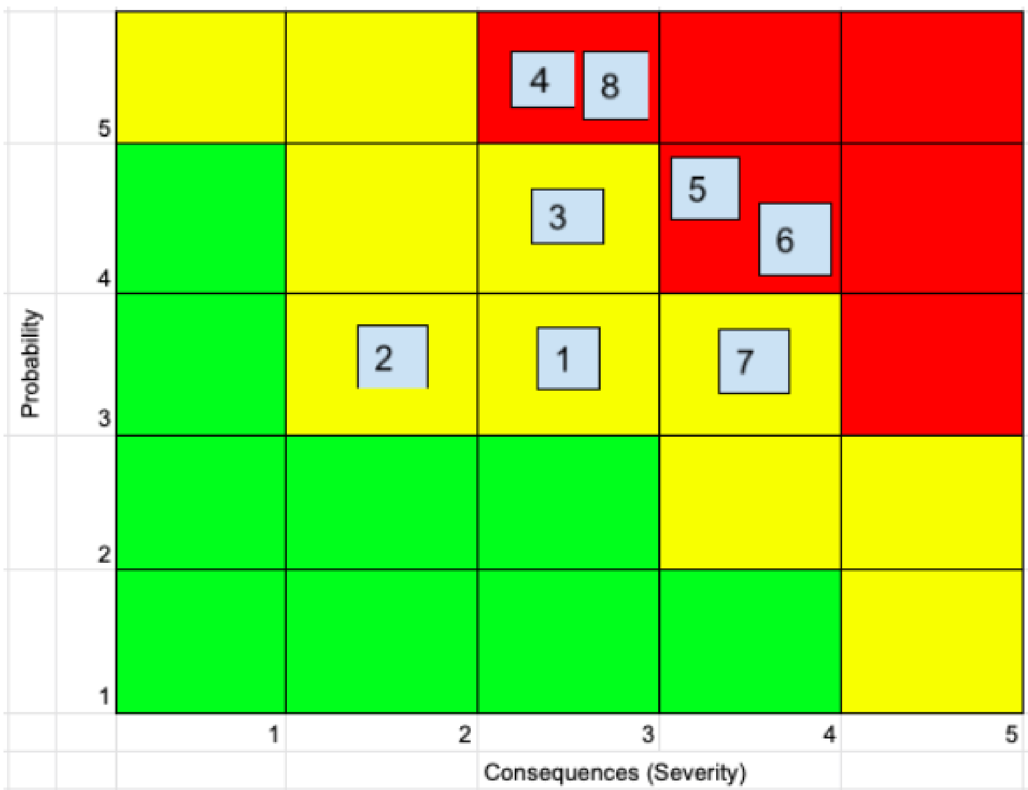
3.1.6 FMEA and Risk Mitigation

Documenting and understanding the critical risk in a project is an aspect for mission success. Failure Mode and Effects analysis (FMEA) is an organized approach to prepare and locate potential failures that can exist within the design of Team 9's spacecraft. The documented descent maneuver and vehicle design FMEA is below.

Function	Failure Mode(s)	Effect(s)	SEV	Cause(s)	OCC	Design Control (Prevention)	Design Controls (Detection)	DET	RPN	Recommended Action(s)
Adjust altitude from lunar surface	1. Thruster damage, 2. Tank Damage 3. Tubing Damage	Possible loss of altitude adjustment		Space debris damaging thruster, other system interference or damage		Tubing and tank Interior Casing,	Onboard computer message			Assess damage and utilize working components to continue mission
Exterior Protection	1. Damage to insulated box of interior components 2. Damage to exterior components	Possible Mission or Instrumentation Failure		Pressure, temperature, or other environment change		Higher Factor of Safety	Onboard computer message			Assess damage and continue mission when possible

SEV = severity OCC = occurrence
DET = detection RPN = risk priority number

Table 2: FMEA table



Criticality	L x C Trend	Approach
High	v Dec.(Improving)	M - Mitigate
Med	^ Inc.(Worsening)	W - Watch
Low	- Unchanged	A - Accept
		R - Research

Rank & Trend	Approach	Risk Title
1 -	W	Budget constraint risk
2 -	A	Delayed Schedule
3 ^	M	Mass & Volume constraint risk
4 v	R	Space debris
5 -	R	Exceeding Temperature
6 ^	M	Structure integrity failure
7 ^	R	Solar Radiation
8 v	M	Unplanned Risk

Table 3: Risk Mitigation

3.1.7 Performance Characteristics and Predictions

The solar panels shall generate 200W of power which shall supply power to all instruments. To maintain internal temperatures, the steps outlined below shall be taken during the fabrication of the satellite and solar panels to assure protection of instruments.

1. Metamaterial Optical Reflectors (meta-OSRs) shall be glued to the solar panels. This coating reflects infrared heat away from the satellite due to the nature and properties of the quartz tiles from which it is made. (University of South Hampton, 2018-46) The purpose of the material is to prevent internal overheating of instruments.
2. Thin sheets of Kapton shall be used for insulation purposes to maintain internal heat. This thin polyamide film shall help protect the instruments from the extreme cold of the space environment due to its dielectric properties. The Kapton material shall keep the orbiter operating between 10–30 °C (50–86 °F) internally, this temperature is due to the heat provided by the electronics while in operation. (University of South Hampton, 2018-46)
3. A patch heater shall be used to warm the interior should internal temperatures drop.
4. A radiator shall reject excess electronic waste heat. An existing structural panel shall be used for this purpose to keep costs low and keep the orbiter within the given weight constraints. (Tomboulin, 2014-47)

HYDRA shall be scheduled to launch in the month of June. Anticipated weather obstacles on Earth include rain, thunderstorms, high winds, and/or catastrophic natural disasters which shall ultimately postpone the launch. Once HYDRA leaves earth, weather should only potentially affect data transmission due to poor weather conditions on Earth.

3.1.8 Confidence and Maturity of Design

The initial idea for detecting water-ice on the moon was to utilize an infrared telescope and search for the wavelength unique to water molecules (6.1 microns) (Potter-37). However, it was decided that, while using infrared is very useful for locating water-ice on the surface, it does not satisfy the objective of the mission. Ground Penetrating Radar, also known as GPR, was the next idea for a device that shall satisfy mission objectives. A computer simulation shall be conducted to mimic the forces on the final CAD model to ensure structural integrity during launch prior to manufacturing. The simulation shall also be used to optimize the design to reduce costs and limit potential failures. Prior to launch, various tests shall be performed to confirm that all systems are working properly and shall perform during the mission. Tests that shall be performed include performance tests for all major components such as communication systems, propulsion systems, data collection, energy harvesting, etc. in extreme temperature conditions and in a vacuum.

3.2 Recovery/Redundancy System

Due to mass and volume constraints, multiple versions of major components on or within the orbital cannot be stored as backup in case the main component fails. Major components include solar panels, thrusters, GPR, the Neutron Spectrometer, antenna, and other necessary equipment. Therefore, a higher factor of safety must be used when designing and manufacturing these components. A higher factor of safety typically results in a more robust design of the components which shall lead to an increase in necessary materials and cost. Smaller and cheaper components that are used to complete a system shall have backups in the event of failure

3.3 Payload Integration

Payload integration shall be described utilizing *Figure 16: Annotated Section View of HYDRA Orbiter* from section 3.1.3.

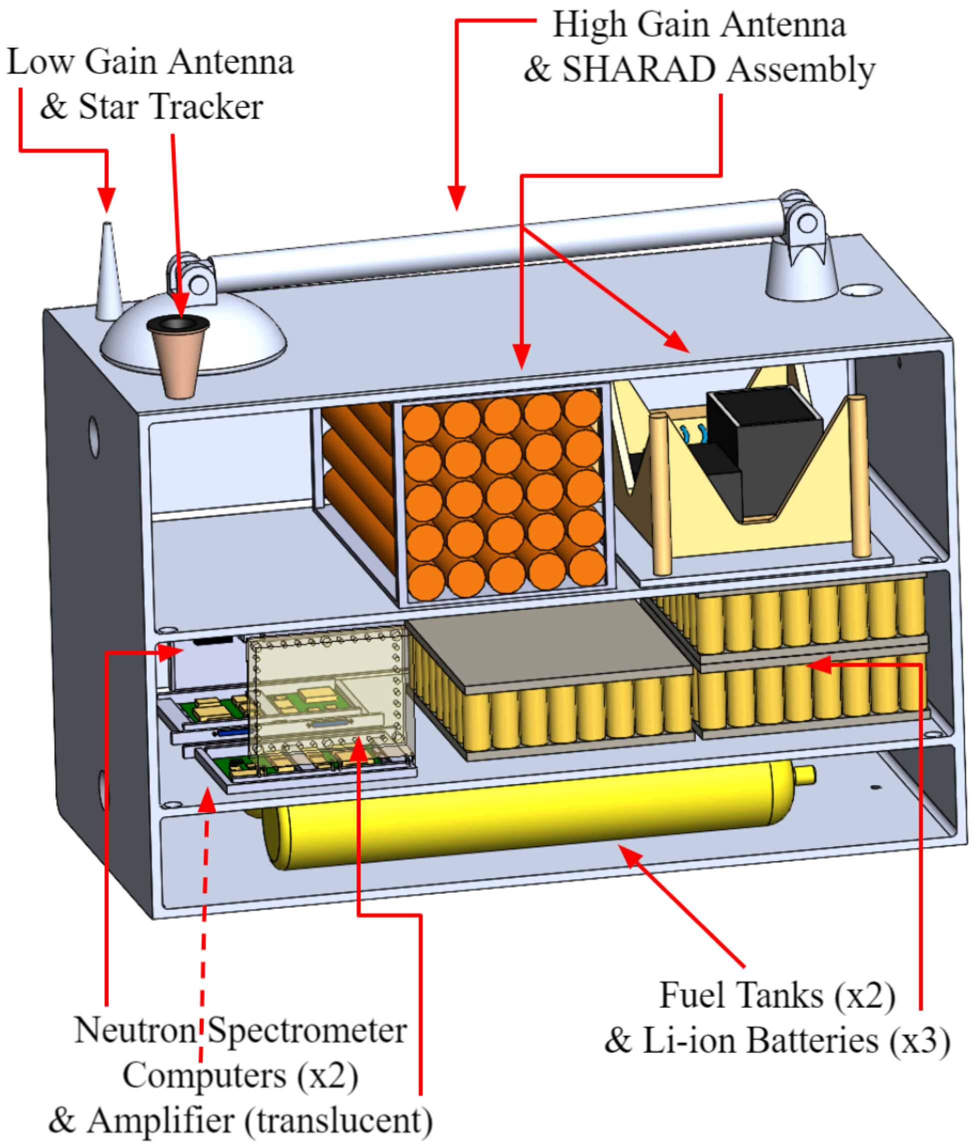


Figure 20: Annotated Section View of HYDRA Orbiter

Beginning from the bottom of the HYDRA orbiter, which can be observed in section 3.1.1, two bars shall be elevated off of the surface and then connected via welding to the underside of the orbiter. These bars shall serve as a means for the primary orbiter to latch onto. Moving inside of the orbiter, two fuel tanks shall be welded down. This weld shall be completed along the base of the tank that makes contact with the body. To ensure the tanks are secure, reinforcement shall be added as necessary. Next, tubing shall be run out of the fuel tanks via six-way valves. The valves shall be controlled by the on-board computer. Wiring and tubing from the fuel tanks to the thrusters and computer shall run through the designated holes within the interior walls.

Moving into the middle compartment of the HYDRA orbiter, a primary and back-up on-board computer shall be bolted down onto the interior wall. Wiring shall run out of both computers to all components in the event that the primary computer fails. An amplifier shall be mounted on the wall perpendicular to the computers via bolts. Wiring shall be run out of the amplifier to both computers and shall be wired directly to one of the batteries. Across from the amplifier, the Neutron Spectrometer shall be mounted onto the wall, utilizing bolts as well. The wiring and power supply shall be the same as the amplifier. Adjacent to the computers, the three batteries shall be mounted. The mounting must allow room between the walls of the orbiter for wiring and tubing to be placed.

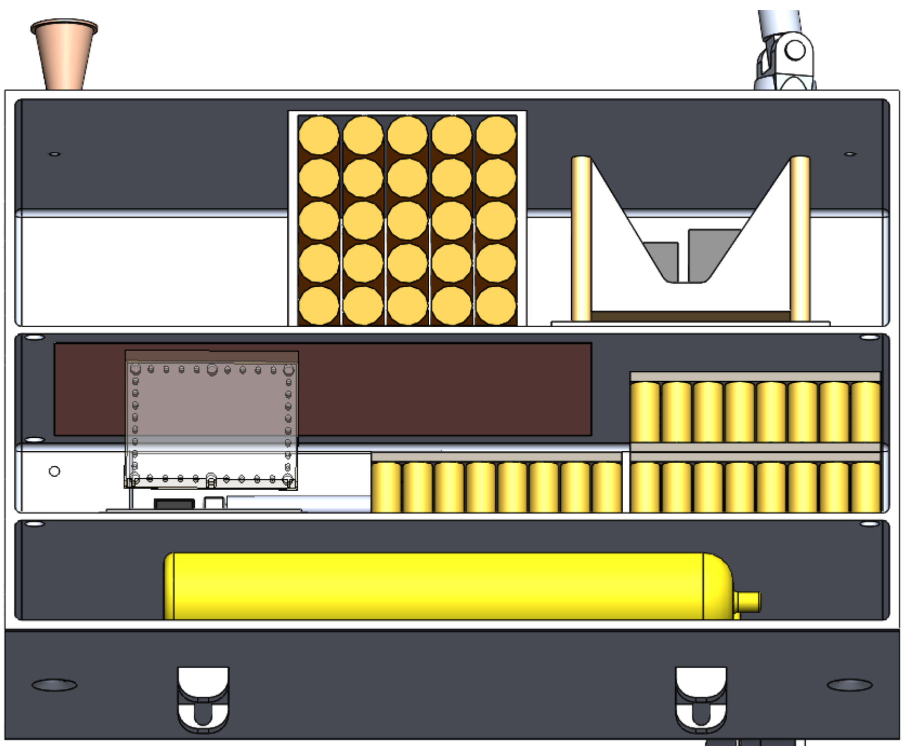


Figure 21: Alternate Section View of HYDRA Orbiter

As seen in the figure above, a large patch heater shall be stuck onto the wall of the orbiter using heat resistant adhesive. The heater shall be connected to a thermal sensor, the computers, and the batteries.

The uppermost compartment of the HYDRA orbiter shall contain the SHARAD Assembly, which consists of the 10 m antenna and the SHARAD Electronics Box (SEB). The antenna shall be stored in an aluminum frame to prohibit the antenna from deploying prematurely. The SEB shall contain all necessary equipment required for data collection. Both the aluminum framing and SEB shall be welded and bolted down onto the interior wall of the orbiter to decrease the probability of becoming loose, since the assembly is the heaviest component.

On the top surface of the HYDRA orbital, the high gain antenna, low gain antenna, and star tracker shall be welded into place. Wiring shall be fed through a hole underneath each of the components and connect to the necessary internal components. The welding performed on these components must be done well such that there is no risk of breaking off due to take-off, or to allow the harsh temperature of space to interfere with the internal temperature.

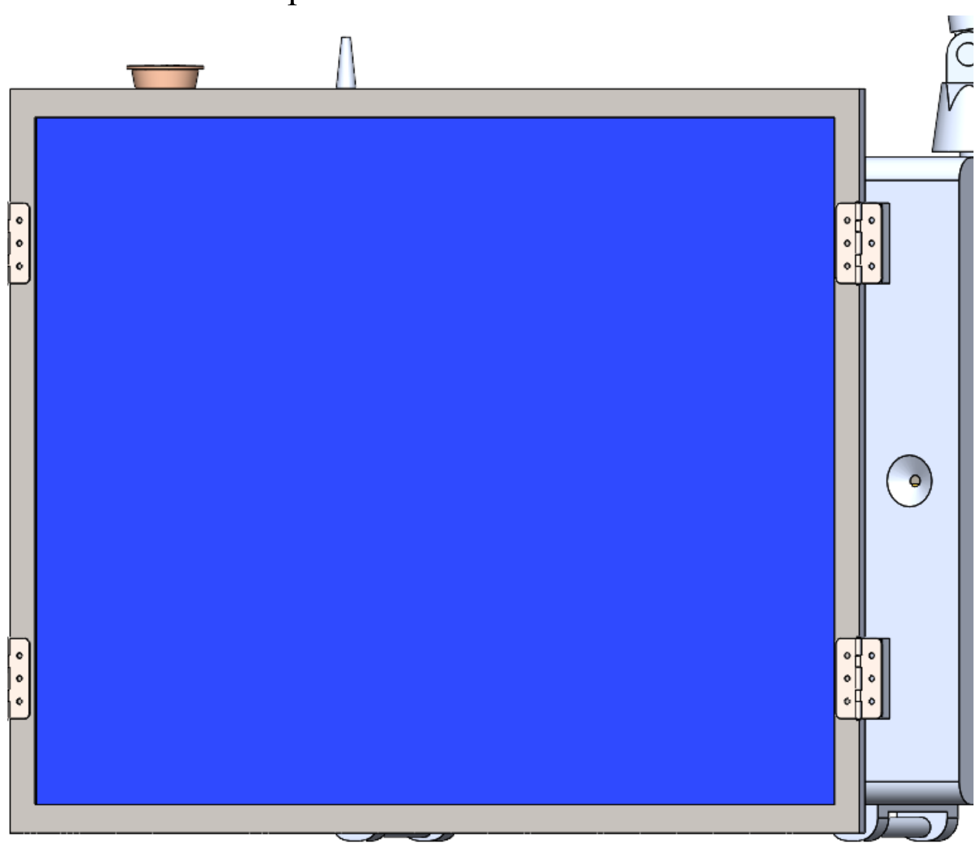


Figure 22: View of Solar Array Connection with Body

In the figure above, it can be observed that the solar arrays shall be bolted onto the HYDRA orbiter using hinges. The hinges shall have an electric locking mechanism that shall be disabled once the orbiter is in position. Wiring shall run down the length of the solar array for the collection of solar energy and to disable the hinges, ultimately connecting to the batteries or the computers. Lastly, not pictured above, but a sun sensor shall be installed on the front face of the orbiter that shall be pointed towards the sun to aid in navigation and positioning of the orbiter.

4. Payload Design and Science Instrumentation

4.1 Selection, Design, and Verification

4.1.1 System Overview

The payload is composed of four main systems; those being power, thermal, data acquisition, and communications. These systems are critical to maintaining the internal instruments and subsystems of the payload.

The power system is responsible for all components that generate or use power. Below is a list of those components and their associated values.

- Solar panels rated to generate 200Wh of power (Garcia-15)
- Ground Penetrating Radar - 10W (Seu-30)
- Neutron Spectrometer - 10W (NASA-30)
- Amplifiers - 60W (General Dynamics-17)
- Patch Heater - 100W (Tutco-42)
- Three 1kW lithium-ion rechargeable batteries (PSSCT-38)

The thermal system is implemented to maintain constant operating temperatures for the equipment on board the payload. Components in the thermal system include heaters, insulation, and radiators.

Data acquisition consists of the scientific instruments, various sensors, and data handling equipment on board the payload. This system's purpose is to capture, record, and prime data for communication.

Communications is a system designed to relay information between the payload and the main orbiter.

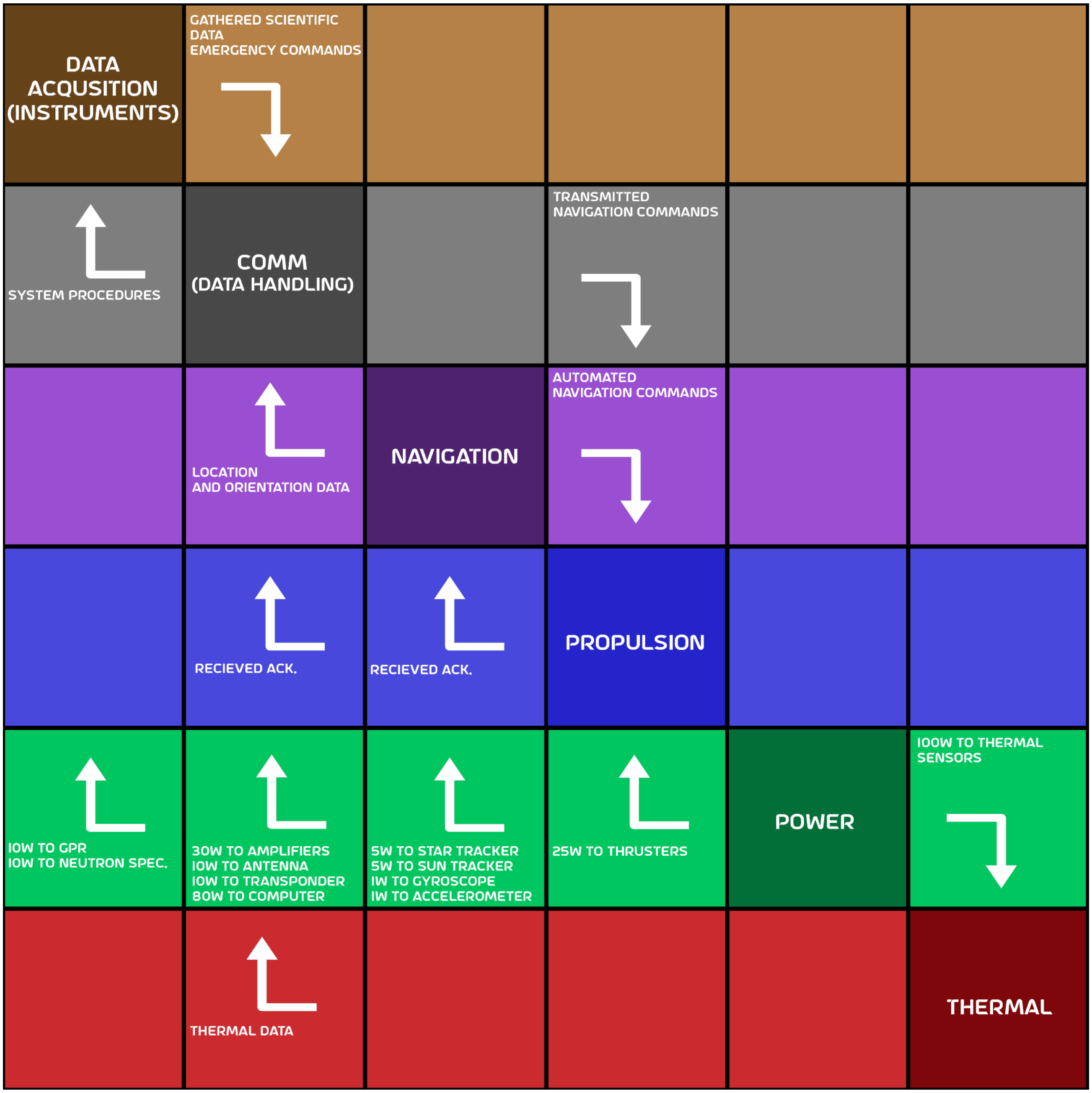


Figure 23: N^2 Chart

4.1.2 Subsystem Overview

The interior systems, such as the power, data acquisition, thermal, propulsion, communication, and navigation shall be integrated with the payload to serve the mission's HYDRA to complete the specified requirements necessary to extract data for detecting Lunar's ice. The payload interior structure shall contain the instrumentation packed and securely held inside the payload.

- The power system shall provide the required energy to power all the system to maintain the payload operative during the mission, it uses solar panels to regain the energy needed and shall be stored in lithium batteries.
    - **Power System:**
        - Solar panels rated to generate 200Wh of power
        - Three 1 kW lithium-ion rechargeable batteries

- The thermal system shall maintain the temperature of the payload stable to prevent overheating/freezing damage of the instrumentation.
    - **Thermal System:**
        - Patch Heater - 100W (Tutco-43)
        - Insulation
        - Radiators

- The main components for detecting water-ice are the science instrumentation, GPR and Neutron Spectrometer, that are essential for the mission. Both instrument methods are similar using electromagnetic waves that shall be able to penetrate the subsurface of the Moon one meter deep, that had been used in the MRO. GPR is well accepted in geophysical techniques that use radio waves of low frequency to probe the ground. It has been stated that the GPR shall be used for future Lunar missions and has the potential to map the Lunar surface and abundance of H2O in the Poles regions. Neutron spectrometer measures visible and near-infrared wavelengths, and is primarily used to detect hydrogen abundance, as the purpose of the mission is to locate H2O, it shall greatly increase the locating ice in the Lunar South Pole Region.
    - **Data Acquisition Systems:**
        - Ground Penetrating Radar - 10W (Seu-40)
        - Neutron Spectrometer - 10W (NASA-30)
        - Solid State Drive/SSD (GIGA-BYTE-18)
        - On-board computer (BAE Systems-5)

- Communication systems shall provide the data collected and be constantly informed of all the systems operating normally throughout the payload.
    - **Communications Systems:**
        - Amplifier - 60W (General Dynamics-17)

        - Antenna - 10W (AMOS-2)
        - Transponder - 10W (AMOS-2)
        - On-system computer - 80W (BAE Systems-5)
- Propulsion and navigation system shall orbit the moon Lunar South Pole region.
    - **Propulsion Systems:**
        - Thrusters - 25W (Northrop-35)
        - Tank (Northrop-35)
        - Tubing (Northrop-35)
    - **Navigation System:**
        - Sun Sensor - 5W (CubeSatShop-9)
        - Star Trackers - 5W (ESA-11)
        - Accelerometer - 1W (Micromega Dynamics-27)
        - Gyroscope - 1W (HoneyWell Aerospace-23)

4.1.3 Manufacturing Plan

Manufacturing Procedures:

As described in section 3.1.4, Goddard Space Center shall be the facility contracted to manufacture and construct the HYDRA orbiter, and it can be expected to have the orbiter fully manufactured in around 2 years. During testing and integration of the orbiter, engineers and other personnel that directly work with the orbiter shall be required to wear white classroom coveralls (also called a “bunny suit”).

Resources:

- Some of the components for the HYDRA orbiter shall be built at the Goddard Space Center.
- When available, scientific instrumentation shall be commercial-off-the-shelf, but priority shall be given to scientific instrumentation utilized in past spacecraft. The conditions that each system shall go through during the mission shall determine the type of components utilized for the orbiter.

Hours of work:

- Each of the engineering personnel shall work a standard 8 hour workday with breaks and lunch. Additional hours may need to be added depending on the progress and deadlines of the project.

Schedule of Delivery:

- Before scientific instrumentation and other onboard materials are integrated in the orbiter, the exterior components such as the box and solar panels shall be fabricated.
- Once exterior components have been completed, scientific instrumentation shall be fabricated, integrated, and tested for the orbiter.

Table of Components

Component	Vendor
Ground Penetrating Radar (GPR)	Geophysical (GSSI-20)
Neutron Spectrometer	Alion Science (Alion Science-1)
Solid State Drive (SSD)	GIGA-BYTE (GIGA-BYTE-18)
Solar panels 200Wh	Spectrolab (Spectrolab-42)
Lithium-ion rechargeable	SatSearch (satsearch-39)
Patch Heater	Tutco-Farnam Custom Products (Tutco-43)
Insulation	Northrop Grumman (Northrop-35)
Radiators	Northrop Grumman (Northrop-35)
Amplifiers	General Dynamics (General Dynamics-17)
Antenna	SpaceCom (AMOS-2)
Transponder	SpaceCom (AMOS-2)
On-system computer	BAE Systems (BAE Systems-5)
Thruster	Northrop Grumman (Northrop-35)
Tank	Northrop Grumman (Northrop-35)

Tubing	Northrop grumman (Northrop-35)
Sun Sensor	CubeSatShop (CubeSatShop-9)
Star tracker	Ball Aerospace (Ball Aerospace-6)
Accelerometer	MicroMega (Micromega Dynamics-27)
Gyroscope	HoneyWell Aerospace (HoneyWell Aerospace-23)

Table 4: Vendor List

4.1.4 Verification and Validation Plan

Testing is required to prevent any interior system damage caused by the vibration of the rocket and harsh environment of space. The power system shall provide the required energy to power all the system to maintain the payload operative during the mission, it uses solar panels to regain the energy needed and shall be stored in lithium batteries. The payload shall maintain in that orbit until all the data has been collected to map out the abundance of ice around the region. The Goddard Space Center is uniquely positioned to provide engineering design, development, and testing for spaceflight vehicles and systems. Capability is available in the areas of human space vehicle systems, life support systems and environmental control, flight design, integrated environment testing, and robotics. Having all the material and facility to provide for required testing. The importance of V&V plans reduce the risk and improve the efficiency of the payload.

Testing facility: Goddard Space Center
Tests include:

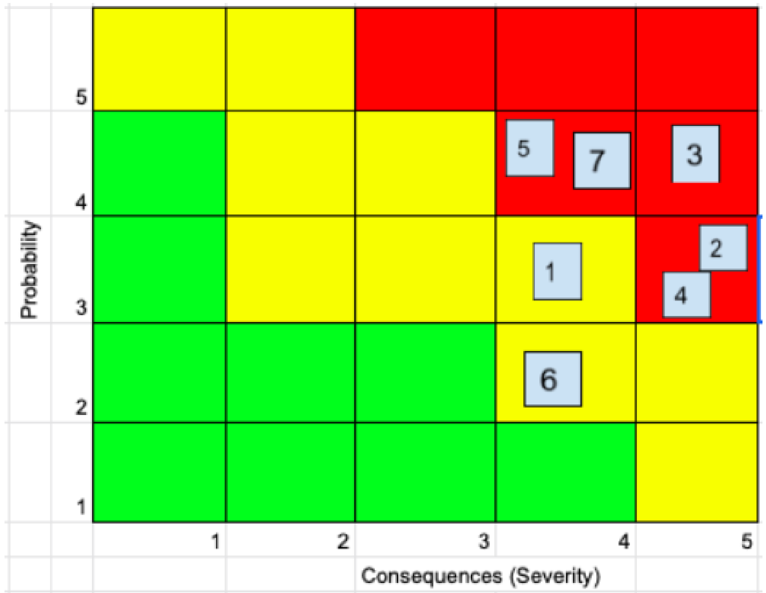
- Electromagnetic interference/compatibility
- Navigation, guidance, and control
- Simulations Launch and Space environment
- Thermal Vacuum Chamber
- Battery System
- Communication system

4.1.5 FMEA and Risk Mitigation

Function	Failure Mode(s)	Effect(s)	SEV	Cause(s)	OCC	Design Control (Prevention)	Design Controls (Detection)	DET	RPN	Recommended Action(s)
The GPR and Neutron spectrometer shall be use to collect the data from the surface of the Moon to localize deposit of ice	1. instrumentation damage 2. Frequency isn't correct	Effecting the extraction of data or receiving strange data	9	vibration, space environment, affected instrumentation, wrong measurement and calibration	3	test tolerance and space environment, calibration and measurements	Testing the instrumentation in different aspect	2	54	Check the science instrumentation and have it calibrated before integrating to the payload
Trajectory and orbiting around the Moon with ease and maintaining orbit	1.Navigation system malfunctioning	Won't be able to pass the regions specified for the mission	8	Software problem in the navigation system, camaras not working properly	4	software and system function test,	Star and planet location test, balance test	2	64	Navigation system is important to calibrate the components.
All System working together to maintain function of the payload	1. Malfunctioning on a system that can damage the rest of the payload system, for example thermal, Propulsion, etc.	Malfunction of payload	9	Mistake in making each system, Misplaced cable	4	Check the system connection and durability test	Test each system and test the payload components	3	108	All the systems will have their role during its mission to detect ice, make sure that all systems are correctly integrated, secure, and connected to each other.
Solar panels needs to be facing the Sun to regain the energy required	1.Unable to move on the payload 2. solar cells are damage by radiation	Can loose the only source of energy for the entire payload	7	space environment, software	3	software and system function test, space environment test	test movement of solar panel to follow the sun	2	42	Solar panels will be the only power source of the payload, to make sure it follows the Sun and is resilient towards the radiation.

SEV = severity OCC = occurrence
DET = detection RPN = risk priority number

Table 5: FMEA Table



Criticality	L x C Trend	Approach
High	v Dec.(Improving)	M - Mitigate
Med	^ Inc.(Worsening)	W - Watch
Low	- Unchanged	A - Accept
		R - Research

Rank & Trend	Approach	Title Risk
1 -	R	Loss of Communication
2 -	M	Power supply failure
3 ^	R	Navigation & Propellent System Failure
4 v	R	Science instrumentation failure
5 -	R	Calibration failure
6 v	W	Testing V&V
7 v	R	Thermal System failure

Table 6: Risk Mitigation

4.1.6 Performance Characteristics

The mission shall begin with the three lithium-ion batteries fully charged, and power generation by the solar panels shall only begin after:

1. The system detaches from the parent orbiter and the panels can deploy;
2. Any measure of power has been spent by the orbiter, and;
3. The panels are in view of solar radiation, which shall allow photons to be collected. On average, the solar panels shall generate a total of 200Wh of power to be stored in the lithium-ion batteries. During the entire duration of the mission, the thermal system shall consume about 100W when operational, as dictated by the internal and external temperature of the orbiter, necessary to keep the HYDRA orbiter in the ideal range of 300 K.

Other power-consuming equipment, such as the communications system and data collecting instruments, shall only consume power when necessary. The GPR and the neutron spectrometer shall require about 10W each per pass above the designated polar region, which shall take about 13.828 min each. Meanwhile, the amplifier required for communication between the parent orbiter and the HYDRA orbiter shall take roughly 60W per use, which shall only take place after one pass over the designated polar area is completed.

Testing, as described in sections 3.1.4, 3.1.5, 4.1.4, and 5.2.2, shall be performed prior to launch in order to ensure the payload shall behave as expected once it enters orbital conditions. Calibration measurements of the scientific instruments necessary for mission success shall also take place prior to detachment from the parent orbiter, as described in section 4.2.5.

4.2 Science Value

4.2.1 Science Payload Objectives

The HYDRA orbiter's main mission purpose is to detect water-ice deposits in the Lunar South Pole region, and to map out the abundance of ice underneath the surface. HYDRA shall be equipped with instrumentation designed to maintain the payload in orbit and gather the data needed for exposing the Lunar ice deposit, orbiting the Moon poles region from 100 km above the surface, with regolith ~-+1% of accuracy, or better, optimally at a spatial sampling of ~ 100m. The science instrumentation for detection, the GPR and the Neutron Spectrometer, shall penetrate the surface of the moon, at least one meter deep. Uncovering the deposit of ice stored underneath the Moon’s surface, water being an essential resource, shall assist with future lunar missions.

4.2.2 Creativity/Originality and Significance

The HYDRA orbiter is designed to measure the abundance of water ice in specific sections of the Moon. While research has been conducted into the water-ice deposits, a spacecraft with HYDRA’s unique science instrumentation has not been sent to the Moon to research the deposits located on the Moon. The Lunar Reconnaissance Orbiter has mapped a majority of the lunar surface and done research into water on the Moon through the Lyman Alpha Mapping Project (LAMP), but the HYDRA orbiter would bring unique science instrumentation to the Moon for more in-depth research.

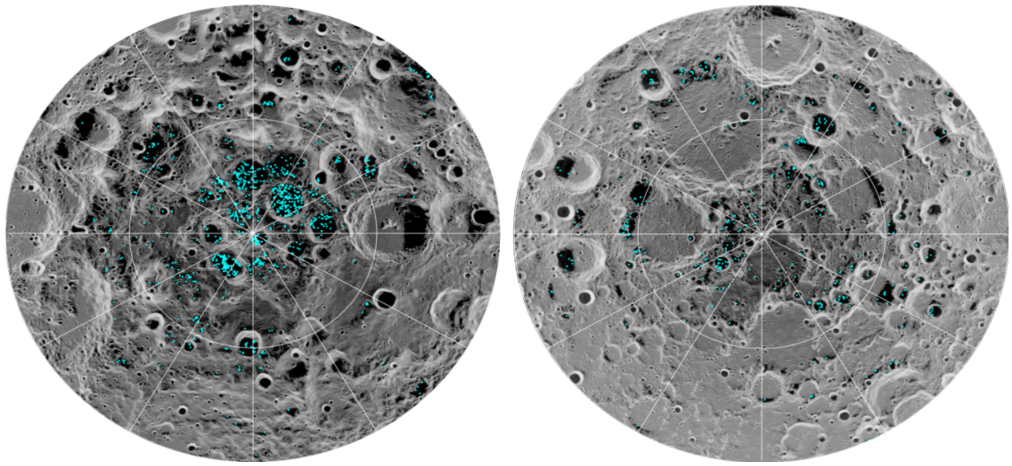


Figure 24: Lunar Water Deposits, Photo Credit: NASA

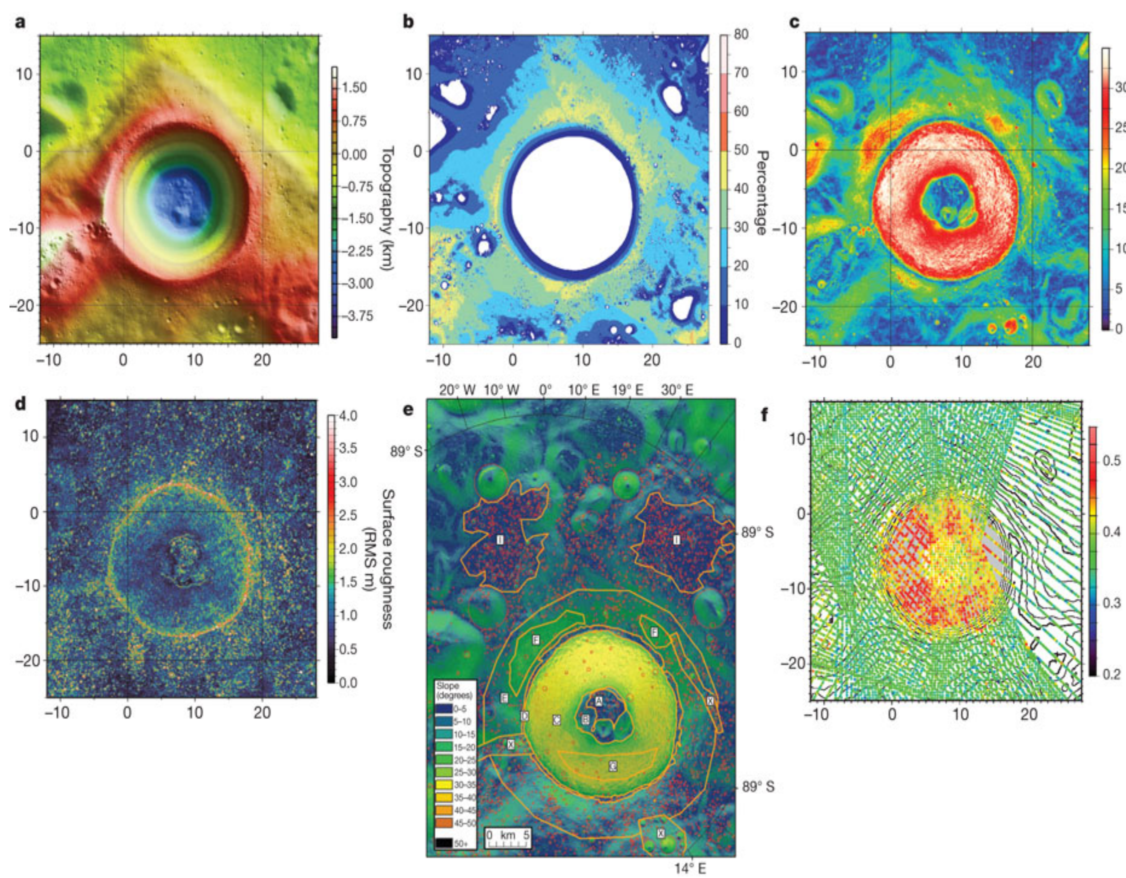


Figure 25: Lunar Regions, Photo Credit: NASA

4.2.3 Payload Success Criteria

As previously discussed, the main success criteria for the scientific instruments is that they would be able to measure water abundance in the top 1 meter of regolith in polar ice caps of the moon with accuracy of around ~+-1% with spatial sampling of ~100m. The payload deliverables would be the data collected by GPR and neutron spectrometer which would, on further analysis, prove helpful in determining the presence of water on lunar ice caps, which would furthermore help in improving the team's understanding about the lunar atmosphere, surface, and potential for colonization.

As the instruments shall map the abundance of water-ice detected in the SPR, the mission may conclude after the whole region has been traversed and mapped. Therefore, for the mission to be considered a success, either instrument must have detected and mapped any abundance of water-ice on the SPR, only at the desired depth and accuracy, and then the orbiter must have successfully transmitted the acquired data back for analysis. After the whole SPR has been mapped, failure of detection of any water-ice by either instrument at said depth and accuracy would be tantamount to mission failure, unless the payload is allowed to retraverse the whole region again.

In the case that the orbiter were to fail to traverse the whole desired region, either due to all data-collecting instrumentation breaking down, thermal system failure, permanent power loss, or mission control permanently losing contact with the payload, would also qualify as mission failure.

4.2.4 Experimental Logic, Approach, and Method of Investigation

During the alignment process, the HYDRA orbiter shall travel at a speed of 1.63km/s, in order to ensure an orbital period of 2.074 hours. After the orbiter has successfully achieved a lunar polar orbit, it shall start collecting data once it approaches the lunar south pole region. This approach shall be timed to occur at a longitude of 130°E as the sun is directly overhead when passing over the lunar equator beforehand, in order to maximize solar power intake. Ideally, data collection shall only take place once the orbiter has reached a latitude of -70°N, and the longitude shall increase by 20°E after every pass over the south polar PSRs, using the thrusters and navigation system to modify its orbit accordingly. Figure 26 displays the south pole region.

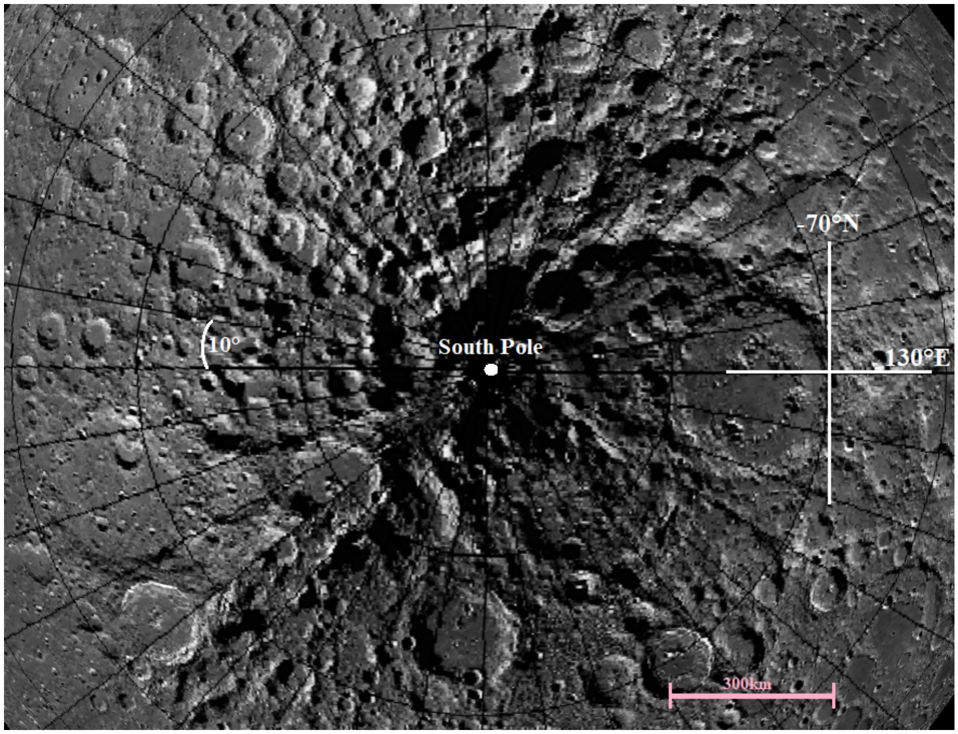


Figure 26: South Pole Region

The main instruments used during this data collecting endeavor shall be the GPR and the neutron spectrometer. As the orbiter passes over the PSRs, the GPR shall continuously transmit radar waves directed towards the lunar surface, while the neutron spectrometer shall direct energetic neutrons in tandem towards the same direction, both operating at a spatial sampling of about 100m. Both instruments are meant to work complementary to each other, as while the GPR excels at detecting thicker layers (about 10cm) of water-ice, it struggles to distinguish grain-sized water-ice deposits from the regolith. By contrast, the neutron spectrometer is capable of detecting smaller quantities of H that the GPR may overlook. The orbiter shall then receive any returning waves or neutrons from the lunar surface, and interactions with subsurface water-ice, if any, shall be used to map its abundance across the traversed PSRs. This shall also allow the orbiter to detect the abundance of subsurface water-ice at a depth of at least 1 meter. This process shall repeat every time the orbiter passes over the south polar region until the whole desired region has been mapped, and data shall be stored aboard the SSD, then transmitted back towards the parent orbiter for analysis after every pass using the communications systems. During its progress through the orbit, the solar panels shall generate power to store, when possible, in order to provide enough energy for the orbiter to function properly. This is necessary for the instruments to be able to collect the necessary data, for the thermal system to maintain the orbiter at the desirable temperature range through the mission, and for the navigation system to keep track of the mission through its orbit.

4.2.5 Testing and Calibration Measurements

Once the payload has successfully entered orbit around the Moon, calibration of the orbiter equipment shall be necessary to verify their proper functioning and accuracy.

Before detachment from the parent payload, tests shall be performed by the Sun sensors and star trackers at separate times. As the payload passes in line of sight of the Sun, the sun tracker shall attempt to determine the orbiter's location respective to the lunar surface and to the Sun's current position on the celestial sphere. These shall be compared to the current known values of the orbiter's position and alignment, in order to verify their accuracy. The star tracker shall perform a similar test when not in view of the Sun, using Arcturus, or α Boötis, as its guiding star.

The orbiter shall also attempt to scan the non-PSRs for subsurface water-ice using the GPR. As it is expected that the existence of subsurface water-ice deposits in these parts is minimal, this shall allow the team to measure any imperfections or noise associated with the GPR at the time, which shall be accounted for once the orbiter begins to collect actual data on the desired regions. The neutron spectrometer, too, shall perform similar calibrations. This shall also help verify that the transmitter and receiver work as intended after launch.

The team shall also keep track of the amount of power consumed during these tests, in order to verify that they match up with the predicted values as described in sections 4.1.1, 4.1.2, and 4.1.6.

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

Science Instrumentation Precision Table:

There are uncertainties involved with each science instrument, which are described in the table below. The precision value of each instrument is meant to be taken into account when analyzing the acquired data, as the mission aims to detect water-ice with an accuracy of about +-1%. That being said, the SPR could be traversed and mapped more than once, in order to make up for any inaccuracy involved with the instrumentation, but only if mission conditions would allow the orbiter to do so. Calibration measurements should take place before the mission occurs in order to verify the accuracy of each instrument, using the methods described in section 4.2.5.

Science Instrumentation	**Precision Value**
Ground Penetrating Radar	Possible to estimate within 90%, several factors can influence precision (GPRS-19)
Neutron Spectrometer	Within 96-97%, depending on the wavelength and direction of incoming neutrons (Gehring-16, Osipenko-28)

Table 7: Science Instrumentation Precision

Contingency Plan for Science Instrumentation Failure:

In the case of science instrumentation failure, the mission shall continue with the instrumentation that is efficiently working. This shall limit the data collection, but still allow for some data collection to happen. Both data-collecting instruments failing, however, shall qualify as mission failure. In such a case, the system shall transmit all data collected so far to the parent orbiter before finalizing the mission.

4.2.7 Expected Data and Analysis

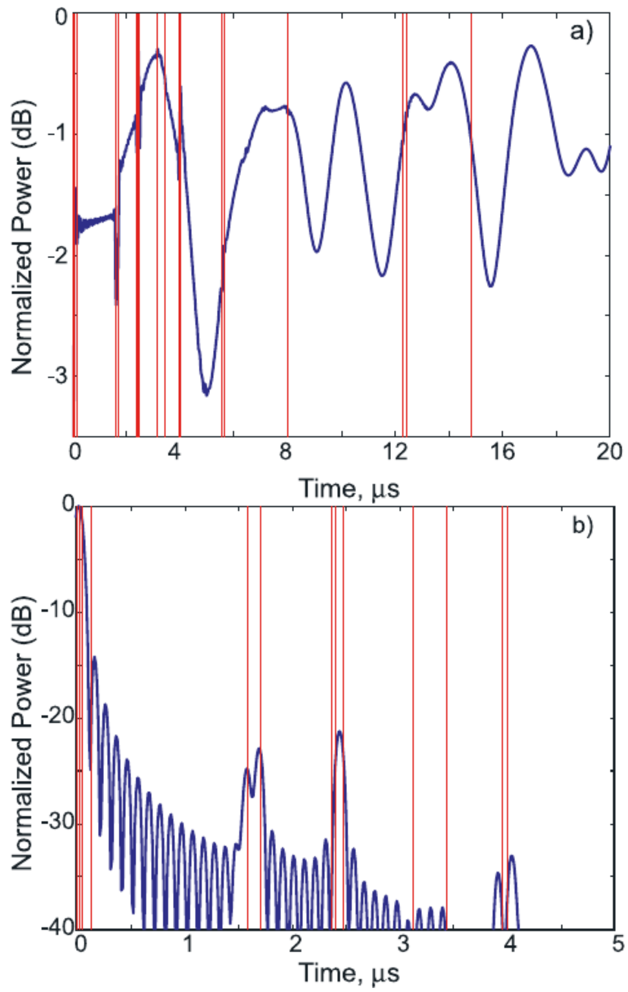


Figure 27: a) Simulation of SHARAD EDR data from a plane parallel Martian stratigraphy (as described by Shchukoet al. [2003]). (Seu-41) Plot represents the power received by the instrument as a function of time. The vertical lines markinstants of time in which an echo from a subsurface dielectric interface reaches the radar. (b) Simulation of SHARAD RDR data from a plane parallel Martianstratigraphy (as described by Shchuko et al. [2003]). Plot represents the power received by the instrument as a function of time after range compression. The vertical lines mark instants of time in which an echo from a subsurface dielectric interface reaches the radar. Peaks corresponding to individual subsurface reflections are clearly visible. Echoes coming from layers that are too deep or too close to each other are not discernible.

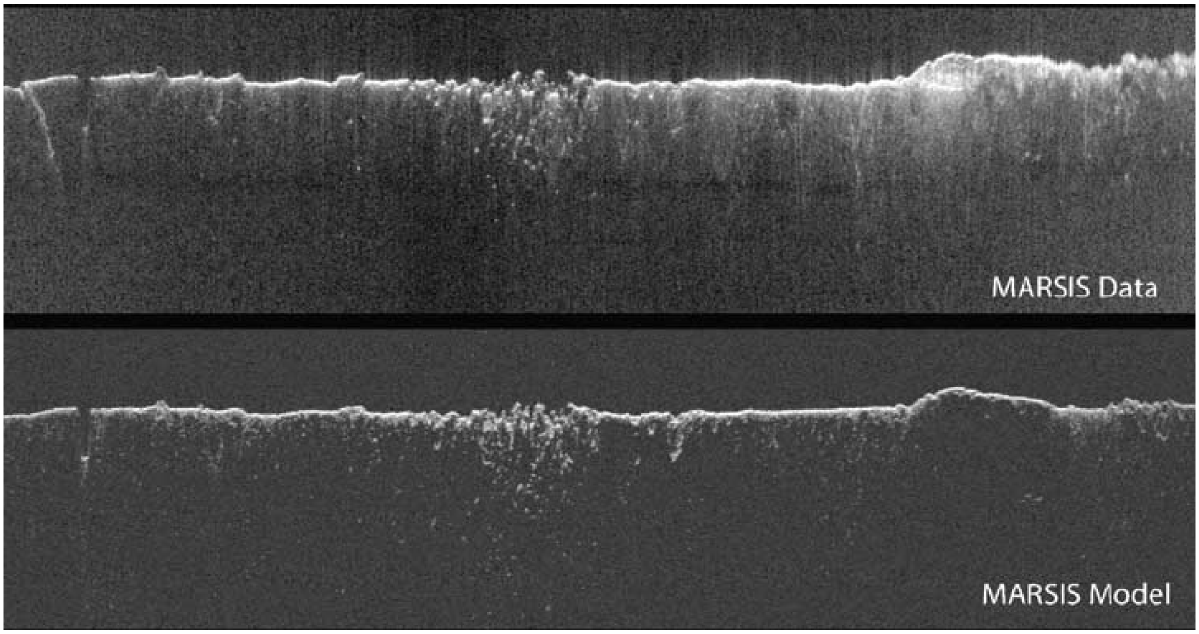


Figure 28: (bottom) MARSIS clutter simulation model using MOLA DEM for Mars Express Orbit 2737. (top) MARSIS radargram for the same orbit. Note features near relatively steep slopes on the right that do not show up in the simulation. (Seu-41)

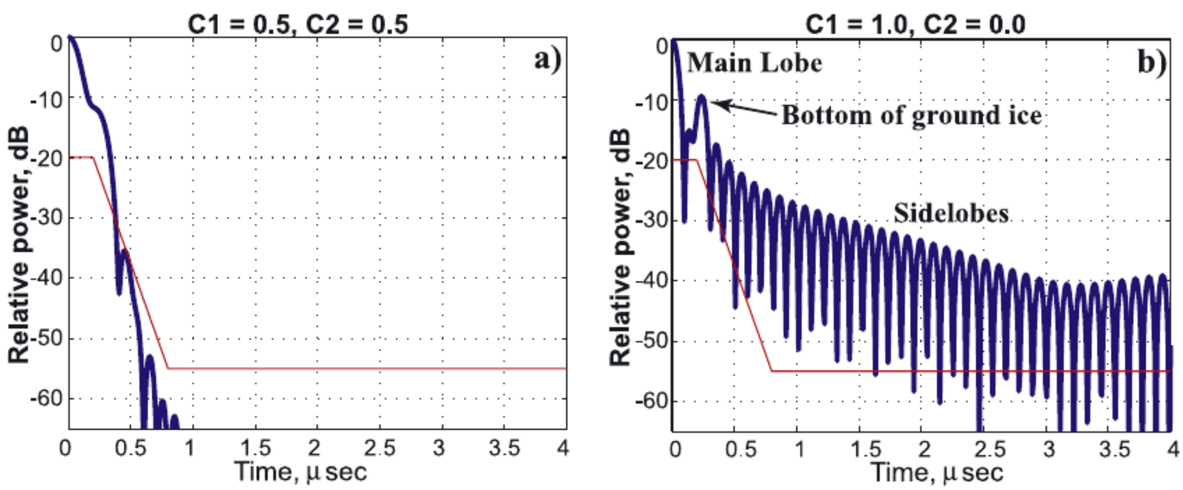


Figure 29: Model SHARAD detection of bottom of ice-filled pore space at 15 m depth. (a) Nominal SHARAD Hanning weighting. (b) No weighting at all. The red line gives the sidelobe specification for the SHARAD design, which has been achieved in the flight instrument with Hanning weighting. (Seu-41)

Figure 29 depicts findings from a subsurface model with 15m of ice-filled pore space on Mars as detected by SHARAD, a GPR technology developed by Agenzia Spaziale Italiana (ASI) for Mars Reconnaissance Orbiter (MRO) mission.

The data obtained by the radar is going to be similar to what SHARAD did except for instead of analyzing all forms of materials present, the GPR on HYDRA would just analyze the regolith looking for ice in the lunar polar surface.

The analysis of GPR data would help in locating exact positions of where exactly the water in ice can be found on the lunar surface.

Ground Penetrating Radar obtains data by transmitting radio signals of high frequency to ground and receiving reflected signals back which is eventually stored in digital media. The GPR analyses the data based on Signal-to-(Galactic)-

Noise Ratio (SNR) which depends on numbers of factors and can be expressed as:

$$SNR = (P_p G^2 \lambda^2 \Gamma)/(64\pi^2 R_0 K_g B_N L),$$

where P_p is transmitted power, G is antenna gain, λ is wavelength, Γ is surface power reflection coefficient, R_0 is distance from spacecraft to surface, T_g is the limiting galactic noise temperature, K is Boltzmann's constant,B_N is bandwidth, and L is propagation loss. The uncertainties in this calculation are only the parameters which are independent of the surface model. They usually occur during the analog-to-digital conversion and can be calculated based on the given table.

Parameter and Units	Nominal Value (Linear)	Uncertainty (Linear)	Requirement (Linear)	Contribution to SNR, dB	Margin, dB
		Signal Contribution			
Peak power	10 W	± 2.5 W	>10 W	10	−1.25[a]
Antenna gain	1			0	
Wavelength	15 m	negligible	15 m	23.5	
Surface Fresnel reflectivity	0.1	model dep.		−10	
$64\pi^2$	631.7			−28	
Range	320 km[b]			−110	
Receiver gain max				87	
Losses	3.2		N/A	−5	
Signal power at ADC				−2.5 dBm[c]	
		Noise Contribution			
Boltzmann constant	1.38×10^{-23} J/K			−228.6	
Galactic noise temp., T_g	$10^{4.9}$ K			49	
Noise bandwidth (MHz)	10	negligible		70	
Receiver gain max				87	
Losses	3.2			−5	
Noise power at ADC				2.4 dBm	
SNR at ADC				−4.9 dB	−1.25

Table 8: Analog to Digital Conversion

The power or intensity of the signals are usually graphed against the time, given that GPR is time-domain based radar. These graphs then help analyze the difference in surfaces and their locations. The signals also contain information about the dielectric parameter as it penetrates through ground and receives back.

As GPR uses electromagnetic radiation, the higher the frequency of radiation is, the better would be the resolution of the data obtained. A possible trade off for using high frequency radiation would be that it would not penetrate in the ground as would low frequency radiation with lesser resolution would. While this could be a problem while analyzing materials situated deeper in the ground of the moon, it would not be a concern for this analysis given that the maximum depth the water in the form of ice is searched for is 1m.

5. Safety

5.1 Personnel Safety

5.1.1 Safety Officer

The HYDRA safety officer shall be John Driver. Team safety shall be priority throughout the mission and in-depth research into safety protocol/procedures, equipment, and hazard mitigation is conducted to ensure team safety. The list of personnel and environmental hazards are not exhaustive. He shall be on-site during launch and testing. The research conducted for personnel hazards was based on standard practices for laboratory and facilities. The research conducted for environmental factors was predominantly based on past spacecraft missions that involved spacecraft that stayed in orbit of a body of mass such as a planet or moon.

5.1.2 List of Personnel Hazards

The following is a list of potential personnel hazards that can potentially be encountered throughout the project. The hazard mitigation section below details safety information that shall minimize these hazards. This list is not exhaustive.

- COVID-19
- Cuts/injury from equipment and tools
- Fume/particulate inhalation
- Heat sources
- Fire from batteries
- Metal dust
- Falls/Back Injury
- Chemical Exposure
- Electrical hazards
- Lifting and Pushing
- Slips, Trips, and Falls
- Noise from Facility Equipment
- Eye injury

5.1.3 Hazard Mitigation

The following guidelines are in place to mitigate personnel hazards listed and described.

Personal Protective Equipment (PPE):

- White Cleanroom Coveralls ("Bunny Suit")
- Safety Goggles
- Safety Helmet
- Safety Gloves
- Helmets, Welding Apron, and other PPE specific to specific tasks (Ex: Welding Apron, helmet, etc. for welding)

Emergency Procedures:

- In an emergency situation, HYDRA orbiter personnel shall refer to the Goddard Space Center Emergency Procedures.

General Facility and Laboratory Safety Rules:

1. If an engineer or other personnel is unfamiliar with a tool or equipment used for the HYDRA orbiter then that personnel needs to request training before use. Exercise caution when using unfamiliar tools and equipment.
2. All personnel shall be required to wear PPE when at the facility site.
3. Appropriate clothing is required when working in the facility site.
4. All incidents are required to be reported to the safety officer, head personnel, and other needed personnel.
5. Review safety information for lab and facility equipment before use
6. All chemicals, equipment, and other materials shall be properly documented and stored when not in use. Each chemical and equipment shall have the correct documentation (safety data sheets (SDS), operating procedures, etc.) both online and inside the facility.
7. It is the responsibility of any personnel to know the hazards and risks of any materials or machinery they are working with.
8. No food or beverage should be in the facility site.
9. Personnel working on the HYDRA orbiter are required to follow the Goddard Space Center and other facility's safety and emergency procedures.

Risk Mitigation:

- Cuts/injury from equipment and tools
    - If any personnel is unfamiliar with a piece of equipment or tool that is needed for their work, they need to request training and consult the manual (located onsite). Personnel are required to wear the proper PPE when using potentially harmful equipment.
- Fume/particulate inhalation
    - All personnel should wear the appropriate PPE and other equipment and exercise caution when operating equipment that generate particulates or fumes. The facility shall be properly ventilated and cleaned regularly.
- Heat sources
    - Exercise caution when using heat-related equipment or tools. Do not touch with bare hands. Do not leave equipment unattended and ensure that equipment is off and cool before leaving.
- Fire from batteries and other potential causes
    - All batteries and other equipment should be properly stored.
- Metal dust
    - The work area should be cleaned with a vacuum or another similar tool after cutting is completed.
- Falls/Back Injury
    - Proper safety equipment shall be utilized when heights are involved. Personnel shall only do what they are capable of doing.
- Chemical Exposure
    - Use proper PPE when handling chemicals and refer to Safety Data Sheets (SDS) before use.
- Electrical hazards
    - Proper PPE with proper insulation shall be used when needed. Electrical equipment shall be inspected before use.
- Lifting and Pushing
    - Personnel shall only lift and push what they are capable of doing.
- Slips, Trips, and Falls
    - All spills and other related incidents shall be reported and clearly identified. Safety cautions shall be in place until fully cleaned up.
- Noise from Facility Equipment

    - When loud machinery is operating, personnel are required to wear proper PPE.
- Eye injury
    - All personnel are required to wear eye protection (face shields, safety glasses, etc.) on site.

5.2 Vehicle/Payload

5.2.1 Environmental Hazards

There are many different environmental hazards that can threaten the safety of the HYDRA orbiter throughout the mission. The following environmental hazards for the HYDRA orbiter may/shall be encountered throughout its lifespan. The hazard mitigation details information such as tests that shall be conducted before launch to ensure the success and safety of the mission. This list is not exhaustive.

1. Vacuum
2. Solar Ultraviolet (UV) radiation
3. Charged particle (ionizing) radiation
4. Plasma
5. Surface Charging and Arcing
6. Temperature extremes
7. Thermal cycling
8. Micrometeoroids
9. Orbital Debris
10. Vibrations
11. Gravity
12. Explosion

5.2.2 Hazard Mitigation

The following guidelines are in place to mitigate the environmental hazards listed and described:

1. Extreme temperatures, both hot and cold, shall be mitigated via use of the onboard thermal system, which is designed to keep the orbital at a comfortable temperature range. This shall also account for changes in temperature caused by

radiation, or lack thereof, and thus prevent equipment damage caused by thermal cycling.

2. Most equipment shall be stored inside of the orbiter, such that the surface can protect it from direct radiation, changes in pressure, and micrometeoroids or debris. This shall prevent any surface arcing or breakdowns from taking place. Equipment stored externally, such as the solar panels or antenna, are designed specifically with external operating conditions in mind, and are thus expected to withstand the aforementioned threats.
3. In the event of the orbiter becoming low on power, it shall cease using most of its instruments and rely solely on the communications system. It shall then stay in contact with the parent orbiter until power is restored back to acceptable levels.
4. Before launch, the electrical and software onboard the HYDRA orbiter shall be reviewed and checked a final time to ensure "it covers all operating modes and flight procedures, and that it can process information correctly. " (European Space) Navigation shall also be tested.
5. The HYDRA orbiter shall go through several tests to ensure that it can carry out its mission. The tests are described below.

Tests:

1. Thermal vacuum Test: This test is designed to reproduce the extreme changes in temperature that spacecraft experience in space.
2. Vibration Test: This test is designed to simulate the conditions during launch. The HYDRA spacecraft shall be progressively shaken "at different strengths on a vibrating table" (European Space-12). To ensure integrity, the conditions created shall be up to 30% more severe than those expected at lift-off.
3. Acoustic Test: This test is designed to subject the spacecraft at very intense noise similar to the noise during launch. A reverberating chamber shall be utilized for this test.

Launch Day Safety:

1. All pre, during and post launch procedures shall be followed (unless on an emergency basis).
2. All personnel shall wear the proper PPE.
3. All personnel shall follow the safety guidelines of launch day location.

4. During launch, all personnel shall be the needed distance away from the rocket.

6. Activity Plan

6.1 Budget

This budget plan consists of all the costs associated with the completion of the HYDRA orbiter project. With an initial allotted amount of 200 million dollars as the budget constraint, the plan was helpful in precisely documenting the expenditures for the mission from beginning to end. The mission is planned for three years, which is accounted for in the budget The budget constraint is met by the total cost of the HYDRA orbiter project being $76,998,354.88. The budget is split up into three main categories: personnel (1), travel (2), other direct costs (3). The bottom of the budget shows the final cost calculations. Personnel is the costs associated with the salaries of the science, engineering, and administrative team. A salary of $80,000 with a fringe rate (benefits) cost of 28% was used to calculate the salaries for personnel. The final cost of personnel is $7,367,616.00. Travel is the costs associated with the personnel traveling for the launch of the orbiter. This includes the plane flight, hotel, transportation to and from the launch site, and per diem costs. Travel consists of five days starting approximately two days before the launch date. Flights were planned from the location of team members to Orlando, Florida. The area hotel is based in the Cape Canaveral/Cocoa Beach area. Transportation includes a compact car rental. Per diem is 75% of the daily per diem rates for travel days to and from the launch. The final cost for travel is $64,800.00. Other direct costs are all of the costs associated with the orbiter components itself and the manufacturing, test facility, and other resources needed for the orbiter. The final cost for other direct costs is $57,632,416.00.

Additional Information

	# People on Team	FTE Year 1	FTE Year 2	FTE Year 3	FTE Year 4	FTE Year 5	FTE Year 6	HELP COLUMN
Science Team:	6	1	1	1	0	0	0	?
Engineering Team:	14	1	1	1	0	0	0	?
Administrative Team:	4	1	1	1	0	0	0	

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

Year	Yr 1 Total	Yr 2 Total	Yr 3 Total	Yr 4 Total	Yr 5 Total	Yr 6 Total	Cumulative Total	
PERSONNEL								?
Science Team	$ 480,000.00	$ 480,000.00	$ 480,000.00	$ -	$ -	$ -	$ 1,440,000.00	
Engineering Team	$ 1,120,000.00	$ 1,120,000.00	$ 1,120,000.00	$ -	$ -	$ -	$ 3,360,000.00	
Administrative Team	$ 320,000.00	$ 320,000.00	$ 320,000.00	$ -	$ -	$ -	$ 960,000.00	
Total Salaries	$ 1,920,000.00	$ 1,920,000.00	$ 1,920,000.00	$ -	$ -	$ -	$ 5,760,000.00	
Total ERE	$ 535,872.00	$ 535,872.00	$ 535,872.00	$ -	$ -	$ -	$ 1,607,616.00	?
TOTAL PERSONNEL	$ 2,455,872.00	$ 2,455,872.00	$ 2,455,872.00	$ -	$ -	$ -	$ 7,367,616.00	
TRAVEL								
Total Flights Cost	$ -	$ -	$ 13,200.00	$ -	$ -	$ -	$ 13,200.00	?
Total Hotel Cost	$ -	$ -	$ 36,000.00	$ -	$ -	$ -	$ 36,000.00	?
Total Transportation Cost	$ -	$ -	$ 6,000.00	$ -	$ -	$ -	$ 6,000.00	?
Total Per Diem Cost	$ -	$ -	$ 9,600.00	$ -	$ -	$ -	$ 9,600.00	?
Total Travel Costs	$ -	$ -	$ 64,800.00	$ -	$ -	$ -	$ 64,800.00	
OTHER DIRECT COSTS								
Total Outsourced Manufacturing Cost	$ -	$ 7,000,000.00	$ -	$ -	$ -	$ -	$ 7,000,000.00	
|> Science Instrumentation	$ -	$ 7,000,000.00	$ -	$ -	$ -	$ -	$ 7,000,000.00	?
|> Other COTS Components	$ -	$ -	$ -	$ -	$ -	$ -	$ -	?
Total In-House Manufacturing Cost	$ -	$ -	$ -	$ -	$ -	$ -	$ -	
|> Materials and Supplies	$ -	$ -	$ -	$ -	$ -	$ -	$ -	?
Total Equipment Cost	$ 9,600,000.00	$ 9,600,000.00	$ 9,600,000.00	$ -	$ -	$ -	$ 28,800,000.00	
|> Manufacturing Facility Cost	$ 9,600,000.00	$ 9,600,000.00	$ -	$ -	$ -	$ -	$ 19,200,000.00	?
|> Test Facility Cost	$ -	$ -	$ 9,600,000.00	$ -	$ -	$ -	$ 9,600,000.00	?
In-House Manufacturing Margin	$ 4,800,000.00	$ 4,800,000.00	$ 4,800,000.00	$ -	$ -	$ -	$ 14,400,000.00	?
Total Direct Costs	$ 16,855,872.00	$ 23,855,872.00	$ 16,920,672.00	$ -	$ -	$ -	$ 57,632,416.00	?
Total MTDC	$ 2,455,872.00	$ 9,455,872.00	$ 2,520,672.00	$ -	$ -	$ -	$ 28,832,416.00	?
FINAL COST CALCULATIONS								
Total F&A	$ 245,587.20	$ 945,587.20	$ 252,067.20	$ -	$ -	$ -	$ 1,443,241.60	?
Total Projected Cost	$ 17,101,459.20	$ 24,801,459.20	$ 17,172,739.20	$ -	$ -	$ -	$ 59,075,657.60	
Total Cost Margin	$ 5,130,437.76	$ 7,440,437.76	$ 5,151,821.76	$ -	$ -	$ -	$ 17,722,697.28	?
Total Project Cost	$ 22,231,896.96	$ 32,241,896.96	$ 22,324,560.96	$ -	$ -	$ -	$ 76,798,354.88	?

********** Do not change percentages in the boxes below unless mission concept instructions specify otherwise.

F&A %	10%	10%	10%	10%	10%	10%
Manufacturing Margin	50%	50%	50%	50%	50%	50%
Total Cost Margin	30%	30%	30%	30%	30%	30%
ERE - Staff	28%	28%	28%	28%	28%	28%

Figure 30: Team 9 Budget

6.2 Schedule

The scientific instruments and other technologies were researched and listed with the explicit intent of being used to detect water-ice above the Lunar South Pole region. During extensive research and careful consideration, the Engineering and Science teams decided to use the GPR and Neutron Spectrometer, as the main scientist instrument on the payload, that shall provide the data required to pinpoint and determine the amount of the Lunar's ice found in the South Polar Region.

The Science team conducted research about the properties and background of the Moon, in order to better determine what instruments would be ideal for the mission. Research was centered about near surface water and ice spread widely around the Lunar South Polar Region. From there, the Science team proposed methods on how to detect the ice with a radar and/or spectrometer from the payload.

The Design/Models of the payload was part of the Engineer team's task. Such a model represents the ideal design for the payload, and was created in accordance with the instrumentation proposed by the Science team, to gather informative data about the Lunar South Polar Region. The Design was made using CAD software to determine the height, volume, structure, and mass of the payload, all in line with the constraints placed upon the mission.

The Budget of the mission is $76,998,354.88, which was calculated by the business team, and shall cover team 9's expenses on the material, construction, scientific instrument, meeting, hardware, launch site, etc. Making use of the aforementioned budget, and with the ideal design in mind, the payload shall be assembled using the proposed materials and instruments, alongside the fabrication of any necessary software and hardware. The instruments shall be tested before launch, to ensure they shall be capable of fulfilling the mission's objectives once in orbit.

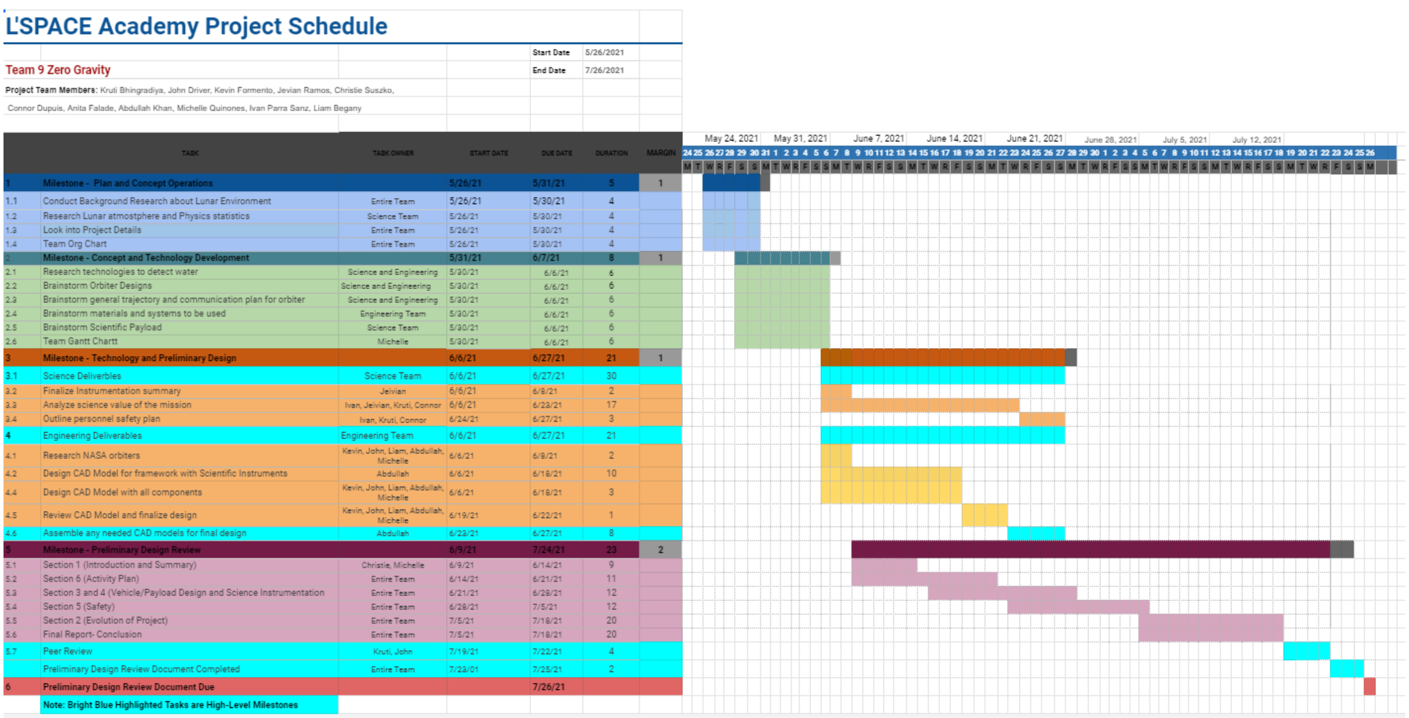
The desired launch day shall occur on June 14th, 2023, at a selected launching location. The payload shall be attached to a parent orbiter as it enters orbit around the Moon 3 days after launch, and shall then readjust its orbit such that it consistently flies over the lunar south pole, a process that shall take approximately 2.42 hours after detachment. Calibration measurements shall also be performed prior to and after detachment. Afterwards, data for the mission shall be collected while the payload orbits the south polar region of the Moon, passing over the PSR approximately every 2.074 hours. The gathered data shall be sent to the site to be processed, then used for mapping the location of the South Polar Region where water is most abundant on the Moon.

Schedule

Pre Phase A: Concept Studies	**May - June 2021**
● Team Slide	May 24, 2021
● Organization Chart	May 31, 2021
● Research and Investigation	June 6, 2021
Phase A: Concept and Technology Development	**June - July 2021**
● Gantt Chart	June 7, 2021
● Draft PDR section 1	June 14, 2021
● Draft PDR section 6	June 21, 2021
● Draft PDR Section 3 and 4	June 28, 2021
● Draft PDR Section 5	July 5, 2021
Phase B: Preliminary Design & Technology Completion	**July - August 2021**
● PDR Completion	July 29, 2021
Phase C/D: Final Design & Fabrication	**2022-2023**
● CDR	May or July 2022
● Manufacturing Assembly completion	December 2022
● V&V Test Completion	January to March 2023

• Flight Readiness Review (FRR) & Mission Readiness Review (MRR)	May 2023
• Launch	June 2023
Phase E: Operations and Sustainment	**2024**
• Data & Result	June 2024

Table 9: Schedule



L'SPACE Academy Project Schedule

Team 9 Zero Gravity

Start Date 5/26/2021

End Date 7/26/2021

Project Team Members: Kruti Bhingradiya, John Driver, Kevin Formento, Jevian Ramos, Christie Suszko, Connor Dupuis, Anita Falade, Abdullah Khan, Michelle Quinones, Ivan Parra Sanz, Liam Begany

	TASK	TASK OWNER	START DATE	DUE DATE	DURATION	MARGIN
1	Milestone - Plan and Concept Operations		5/26/21	5/31/21	5	1
1.1	Conduct Background Research about Lunar Environment	Entire Team	5/26/21	5/30/21	4	
1.2	Research Lunar atmostphere and Physics statistics	Science Team	5/26/21	5/30/21	4	
1.3	Look into Project Details	Entire Team	5/26/21	5/30/21	4	
1.4	Team Org Chart	Entire Team	5/26/21	5/30/21	4	
2	Milestone - Concept and Technology Development		5/31/21	6/7/21	8	1
2.1	Research technologies to detect water	Science and Engineering	5/30/21	6/6/21	6	
2.2	Brainstorm Orbiter Designs	Science and Engineering	5/30/21	6/6/21	6	
2.3	Brainstorm general trajectory and communication plan for orbiter	Science and Engineering	5/30/21	6/6/21	6	
2.4	Brainstorm materials and systems to be used	Engineering Team	5/30/21	6/6/21	6	
2.5	Brainstorm Scientific Payload	Science Team	5/30/21	6/6/21	6	
2.6	Team Gantt Chartt	Michelle	5/30/21	6/6/21	6	
3	Milestone - Technology and Preliminary Design		6/6/21	6/27/21	21	1
3.1	Science Deliverbles	Science Team	6/6/21	6/27/21	30	
3.2	Finalize Instrumentation summary	Jeivian	6/6/21	6/8/21	2	
3.3	Analyze science value of the mission	Ivan, Jeivian, Kruti, Connor	6/6/21	6/23/21	17	
3.4	Outline personnel safety plan	Ivan, Kruti, Connor	6/24/21	6/27/21	3	
4	Engineering Deliverables	Engineering Team	6/6/21	6/27/21	21	
4.1	Research NASA orbiters	Kevin, John, Liam, Abdullah, Michelle	6/6/21	6/8/21	2	
4.2	Design CAD Model for framework with Scientific Instruments	Abdullah	6/6/21	6/18/21	10	
4.4	Design CAD Model with all components	Kevin, John, Liam, Abdullah, Michelle	6/6/21	6/18/21	3	
4.5	Review CAD Model and finalize design	Kevin, John, Liam, Abdullah, Michelle	6/19/21	6/22/21	1	
4.6	Assemble any needed CAD models for final design	Abdullah	6/23/21	6/27/21	8	
5	Milestone - Preliminary Design Review		6/9/21	7/24/21	23	2
5.1	Section 1 (Introduction and Summary)	Christie, Michelle	6/9/21	6/14/21	9	
5.2	Section 6 (Activity Plan)	Entire Team	6/14/21	6/21/21	11	
5.3	Section 3 and 4 (Vehicle/Payload Design and Science Instrumentation	Entire Team	6/21/21	6/28/21	12	
5.4	Section 5 (Safety)	Entire Team	6/28/21	7/5/21	12	
5.5	Section 2 (Evolution of Project)	Entire Team	7/5/21	7/18/21	20	
5.6	Final Report- Conclusion	Entire Team	7/5/21	7/18/21	20	
5.7	Peer Review	Kruti, John	7/19/21	7/22/21	4	
	Preliminary Design Review Document Completed	Entire Team	7/23/01	7/25/21	2	
6	Preliminary Design Review Document Due			7/26/21		
	Note: Bright Blue Highlighted Tasks are High-Level Milestones					

Figure 31: Gantt Chart

6.3 Outreach Summary

In any NASA-related mission, it is important to use these opportunities to increase public awareness and appreciation for science, technology, engineering , and mathematics (STEM). Outreach allows the public to learn and understand the work conducted by thousands of NASA engineers, scientists, and other professionals. Team 9's outreach program shall focus on targeting education and the public as a whole.

On the educational side of outreach, online engagement shall target specific age groups such as elementary, middle, high, and university students. The accounts shall highlight diversity and positively influence children and all ages alike. Providing school children with envelopes with pre-paid postage stamps to send letters to NASA employees that give their age, a photo and some of their goals then having each letter [possibly] responded to, that share a similar background, shall help expand awareness and promote inclusivity. Many children lack role models in their personal lives, especially young girls when it comes to STEM. Drawing's and contests can also be held for out-of-state students to win a chance to visit NASA sites and learn more about space missions. Having a personal connection to NASA, space travel and NASA'S current missions could be the answer to increasing awareness, and excitement, that it shall only continue to grow as the children move on to middle school, high school, and college where they shall begin to decide their career paths.

To engage with the public as a whole, Team 9 shall have its own social media accounts (Youtube, Instagram, etc.) where it shall update the public when certain milestones in the project are reached. Through social media, key personnel involved with the HYDRA orbiter shall conduct interviews and speak about their work on the orbiter. They shall be able to share their knowledge and experience with future scientists and engineers and inspire them to pursue their personal and career goals. The engineers working on the HYDRA orbiter can also reach out to high school/university Robotics teams to become mentors and advisors for them. They can support engineering students with their projects.

In terms of launch day, the launch shall be live streamed across multiple social media platforms (YouTube, NASA website, etc.). Other milestones of the mission shall also be shared with the public as they happen and the data collected from the orbiter shall be shared for scientific research and innovation.

The outreach plan shall run from the beginning of the finalized design to the end of the mission and shall be funded by the mission's budget. The outreach budget will be $200,000, which will be used to cover costs of materials and supplies, staffing, travel, planning, paid outreach interns, and programmers.

6.4 Program Management Approach

Team 9 organized team roles based on interests of each individual team member and the requirements given. There was a minimum of two members for each of the three sub-teams which are the Engineering, Science, and Administration teams. The number of team members in each sub-team was allocated based on the amount of work required for each to complete over the course of the project. The team leads for each sub-team were chosen based on experience and knowledge of the team members. Each sub-team worked independently, but team members communicated with other sub-teams during team meetings and the team leads reported back to the deputy project manager and the project manager. Meetings were held every Wednesday and Sunday, unless changed based on team members schedules. Meetings were set-up where teams reported their progress to other teams. While components such as research and CAD were done by each team member individually, a constant cycle of iterating and reviewing was maintained so that all team members remained impormed throughout the process and obtained important information necessary for project completion. One issue that arose during the project was setting meeting times for the weekly team meetings. To solve this issue, weekly meeting dates were set by feedback from each team member using an online scheduling platform, LettuceMeet (https://lettucemeet.com/) and communication over Discord and Zoom. The majority vote won the meeting time and the team planned accordingly.

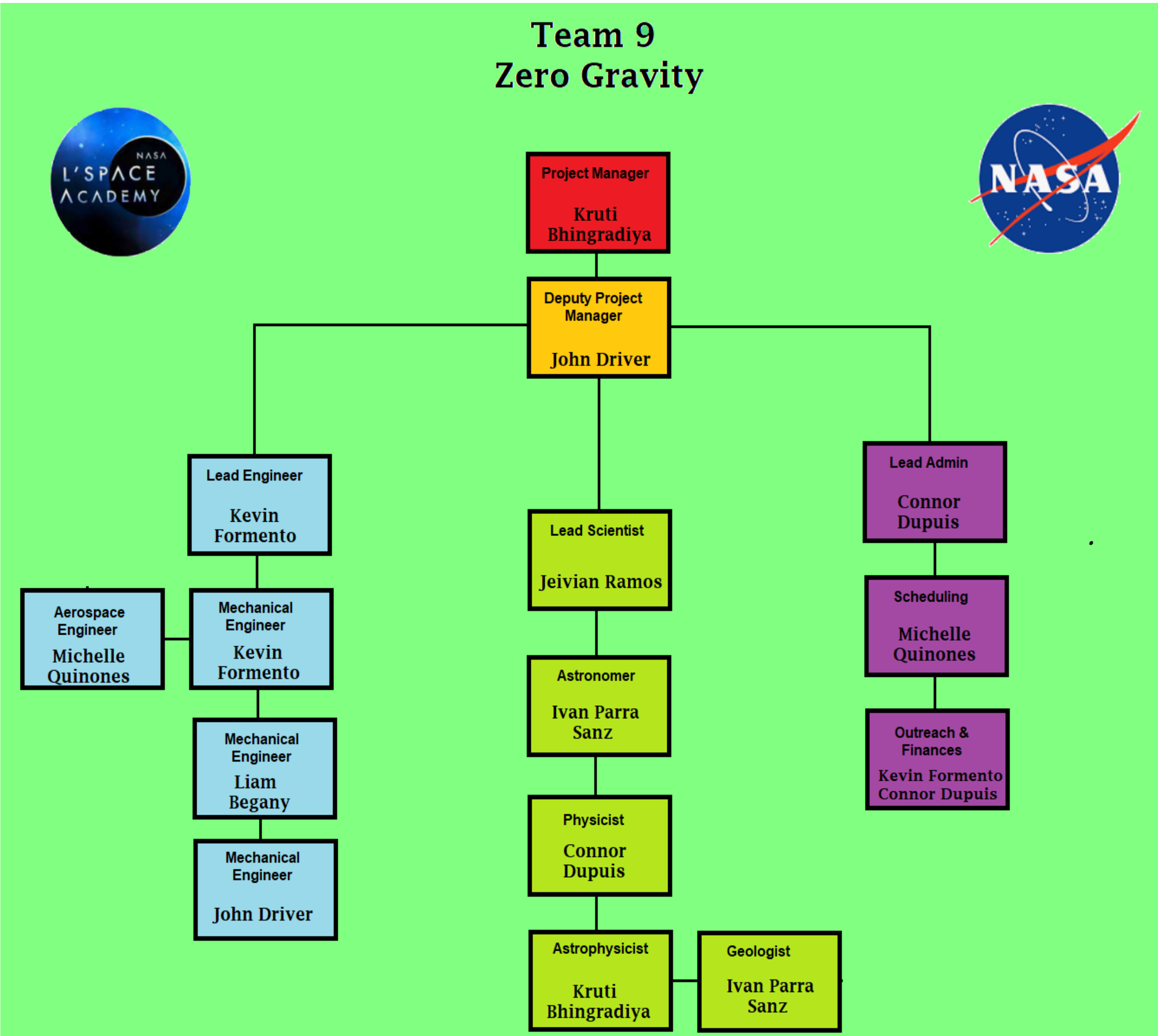


Figure 32: Team 9 Organization Chart

7. Conclusion

This PDR introduced the next generation of lunar exploration missions with this mission - Lunar Water-Ice Strategic Scientific Investigation. Team 9’s goal was to better understand the abundance of water-ice deposits in the lunar South Pole Region through the designed spacecraft. This would support the vision of “in-situ resources utilization” on the Moon for future manned missions to the lunar surface. Team 9’s final dimensions for the HYDRA Orbiter is 59.0 cm X 70.2 cm X 94.8 cm and 161.25 kg, which fits the design specifications of 60.1 cm X 71.1 cm X 96.5 cm and 180 kg. Team 9’s orbiter is designed to detect hydrogen within the water-ice deposits in the top 1 meter of regolith to +-1% accuracy at a spatial sampling of approximately 100 meters. The HYDRA Orbiter has unique science instrumentation, including a Ground Penetrating Radar (GPR) and a Neutron Spectrometer to support the science objectives of the mission.

The team plans on conducting the Critical Design Review (CDR) starting May 2022 and the Test Readiness Review (TRR) in May 2023. After completion of the CDR and TRR, risk assessments shall be reassessed and updated. The orbiter shall launch in June 2023, arriving at its destination within the same month. After successful communications and systems tests, the HYDRA orbiter shall begin its mission and begin collecting data from its science instruments. We shall provide the resulting data from the orbiter by June 2024.

If given additional time to work on the PDR, the team would conduct more research into system design and testing of key components to ensure mission success. On top of that, more research would be conducted regarding the orbiter's descent maneuvers, in order to determine a more optimal way to enter a circumpolar lunar orbit, as well as more efficient orbital motions to map the desired region. This would also include determining the ideal launch site for the payload, based on the Moon's position along its orbit at the time.

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Team 9 would like to thank everyone who assisted in the development of this Preliminary Design Review (PDR). The team is very grateful to their mentor, Tyson Hill, for the support and feedback given throughout this PDR. Thank you to Dann Garcia and Sheri Boonstra for leading the Mission Concept Academy and hosting weekly Zoom sessions. The team would also like to thank all of the guest speakers that shared their experience and knowledge during Zoom sessions. Finally, the team would like to give a big thank you to everyone involved with the L'SPACE Mission Concept Academy Summer Program for giving the team the opportunity to be involved with this amazing program that has provided every member of this team with valuable knowledge, skills, and experiences.

References

(1) Alion Science. (2021, March 30). *Spectrum solutions*. Alion Science. https://www.alionscience.com/spectrum/?utm_source=google&utm_medium=cpc&utm_campaign=brand-grafik&utm_content=ew-sept-2020&gclid=CjwKCAjwo4mIBhBsEiwAKgzXOMPZdQNatrOWUPQ6HbsrysuqPtv8QwGQeD1hSiYobn5uSlMN4zCwIxoCRs4QAvD_BwE.

(2) AMOS. (n.d.). *AMOS by SPACECOM – SPACECOM*. AMOS by Spacecom Home Page Comments. https://www.amos-spacecom.com/.

(3) Angelopoulos, M., Redman, D., Pollard, W. H., Haltigin, T. W., & Dietrich, P. (2013, September 20). *Lunar ground penetrating radar: Minimizing potential data artifacts caused by signal interaction with a rover body*. Advances in Space Research. https://www.sciencedirect.com/science/article/abs/pii/S0273117713005772.

(4) Boynton, W. (n.d.). GRS. NASA Mars. https://mars.nasa.gov/odyssey/mission/instruments/grs/

(5) BAE Systems (2021). *Radiation-hardened electronics*. BAE Systems. https://www.baesystems.com/en-us/product/radiation-hardened-electronics

(6) Ball Aerospace. (n.d.). *Star trackers*. Ball Aerospace. https://www.ball.com/aerospace/markets-capabilities/capabilities/technologies-components/star-trackers.

(7) Capitol Technology University. (2018, September 25). *Hazards of Space: How Satellite Missions Can Go Wrong*. Capitol Technology University. https://www.captechu.edu/blog/hazards-of-space-how-satellite-missions-can-go-wrong.

(8) Choum, F., Hawkes, A. (2021, January 4). NASA's SOFIA Discovers Water on Sunlit Surface of Moon. NASA. https://www.nasa.gov/press-release/nasa-s-sofia-discovers-water-on-sunlit-surface-of-moon

(9) CubeSatShop. (2021, March 11). *NSS fine Sun Sensor*. CubeSatShop.com. https://www.cubesatshop.com/product/digital-fine-sun-sensor/.

(10) Elsheakh, D. N., & Abdallah, E. A. (2019, April 2). *Detection of Underground Water by Using GPR*. IntechOpen. https://www.intechopen.com/chapters/66437.

(11) ESA. (n.d.). *Advanced star tracker*. ESA. https://www.esa.int/Applications/Telecommunications_Integrated_Applications/Alphasat/Advanced_Star_Tracker.

(12) European Space Agency (ESA). (n.d.). *Building and testing spacecraft*. ESA. https://www.esa.int/Science_Exploration/Space_Science/Building_and_testing_spacecraft.

(13) ETD - MSD - Our Work - Facilities.” *NASA*, NASA, etd.gsfc.nasa.gov/540/facilities.php

(14) Finckenor, Miria M., Groh, Kim K. de, (2015). A Research's Guide to: Space Environmental Effects. NASA. https://www.nasa.gov/sites/default/files/files/NP-2015-03-015-JSC_Space_Environment-ISS-Mini-Book-2015-508.pdf

(15) Garcia, M. (2017, July 31). *About the space station solar arrays*. NASA. https://www.nasa.gov/mission_pages/station/structure/elements/solar_arrays-about.html.

(16) Gehring, P. (n.d.). *Choosing the Right Neutron Spectrometer*. NIST Center for Neutron Research. https://www.ncnr.nist.gov/summerschool/ss07/SS2007_Gehring_a.pdf

(17) General Dynamics Mission Systems. (n.d.). *Spaceborne X-Band solid state power amplifier*. General Dynamics Mission Systems. https://gdmissionsystems.com/products/communications/spaceborne-communications/mission-data-links/x-band-solid-state-power-amplifier.

(18) GIGA-BYTE Technology Co., Ltd. (2021). *GIGABYTE SSD 120GB*. GIGABYTE Global. https://www.gigabyte.com/Solid-State-Drive/GIGABYTE-SSD-120GB#kf

(19) Ground Penetrating Radar Systems, LLC. (2021). *Ground Penetrating Radar [GPR] - An Electromagnetic Investigation Method*. GPRS.

https://www.gp-radar.com/article/ground-penetrating-radar-gpr-an-electromagnetic-investigation-method

(20) GSSI Geophysical Survey Systems, Inc. (2021, May 17). *Ground penetrating Radar (GPR) Equipment: GSSI Inc.: Georadar*. GSSI Geophysical Survey Systems, Inc. https://www.geophysical.com/.

(21) Hayne, P. O., Ingersoll, A. P., Paige D. A. (2014, April 30). *New Approaches to Lunar Ice Detection and Mapping*. Keck Institute for Space Studies. https://www.kiss.caltech.edu/final_reports/Lunar_Ice_final_report.pdf

(22) Hille, K. (2019, March 8). *NASA's LRO Sheds Light on Lunar Water Movement*. NASA.https://www.nasa.gov/feature/goddard/2019/lro-sheds-light-on-lunar-water-movement.

(23) Honeywell Aerospace. (n.d.). *GG1320AN digital ring laser gyroscope*. Honeywell Aerospace. https://aerospace.honeywell.com/us/en/learn/products/sensors/gg1320an-digital-ring-laser-gyroscope?utm_source=google&utm_medium=paid_search&utm_campaign=21_Navigation&Sensors_JD&utm_term=gyroscope&utm_content=gg1-1320an&s_kwcid=AL%217892%213%21494334803980%21b%21%21g%21%21gyroscope%2520for%2520salehttp%3A%2F%2Fexample.com%2Flanding-page%3FmyParam&_bt=494334803980&_bk=gyroscope%2520for%2520sale&_bm=b&_bn=g&_bg=116920607432&gclid=CjwKCAjwo4mIBhBsEiwAKgzXONnMWtlrFfJLEz-Q_C4u0ejyW0d8T4Hc_lnzglNuc8-AjRi760JFUxoCUOMQAvD_BwE.

(24) Isaac , H., & MacCulloch, G. (2004, February 1). *Adventures with GPR experiments through ice*. CSEG RECORDER Magazine. https://csegrecorder.com/articles/view/adventures-with-gpr-experiments-through-ice.

(25) Kovo, Y. (2020, March 12). *7.0 Thermal Control*. NASA. https://www.nasa.gov/smallsat-institute/sst-soa-2020/thermal-control.

(26) L'SPACE Mission Concept Academy Summer 2021 Lunar Water-Ice Strategic Science Investigation . (n.d.). PDF. L'SPACE.

(27) Micromega Dynamics. (n.d.). *Industrial accelerometers*. Micromega Dynamics. https://micromega-dynamics.com/products/recovib/industrial-accelerometers/?gclid=CjwKCAjwo4mIBhBsEiwAKgzXOAEasGHqbVsUH2eEiAveXOCwHzNH4FYBwYFmpzNNT9j7tv9SQixYbRoC-lYQAvD_BwE.

(28) M. Osipenko, et al. (2019). *Calibration of the compact neutron spectrometer at PTB*. Nucl.Instrum.Meth.A 931. Pg 135-141. https://inspirehep.net/literature/1698864

(29) National Research Council. (2011). *Limiting future collision risk to spacecraft an assessment of Nasa's meteoroid and orbital debris programs*. National Academies Press.

(30) NASA. (2019, October 31). *Lunar payloads*. NASA. https://www1.grc.nasa.gov/space/pesto/instrument-technologies-current/nasa-provided-lunar-payloads/#lightbox-image-7.

(31) NASA. (n.d.). *Detailed Characterization of Shackleton Crater*. NASA. https://sservi.nasa.gov/articles/detailed-characterization-of-shackleton-crater/.

(32) NASA. (n.d.). *Sensors*. NASA. https://mars.nasa.gov/mro/mission/spacecraft/parts/gnc/sensors/.

(33) NASA. (n.d.). *SHARAD*. NASA. https://mars.nasa.gov/mro/mission/instruments/sharad/.

(34) NASA. (n.d.). *Thermal Systems*. Mars Reconnaissance Orbiter. https://mars.nasa.gov/mro/mission/spacecraft/parts/thermal/.

(35) Northrop Grumman. (2021, July 23). Northrop Grumman. https://www.northropgrumman.com/.

(36) Planetary Science Institute. (2020, October 8). *SHARAD Science Operations at PSI*. Planetary Science Institute. https://www.psi.edu/SHARAD.

(37) Potter, S. (2020, October 26). *NASA's SOFIA discovers water on SUNLIT surface of moon*. NASA. https://www.nasa.gov/press-release/nasa-s-sofia-discovers-water-on-sunlit-surface-of-moon/.

(38) PSSCT. (n.d.). *PSSCT (Pico Satellite Solar Cell Testbed)*. PSSCT - eoPortal directory - satellite missions. https://directory.eoportal.org/web/eoportal/satellite-missions/p/pssct.

(39) satsearch. (n.d.). *50V / 1 kWhr Battery*. satsearch. https://satsearch.co/products/ibeos-kwhr-battery.

(40) Seu, R., Phillips, R. J., Biccari, D., Orosei, R., Masdea, A., & Picardi, G. (2007, May 18). *JavaScript disabled*. Journal of Geophysical Research. https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2006JE002745.

(41) Seu, R., Phillips, R. J., Biccari, D., Orosei, R., Masdea, A., Picardi, G., Safaeinili, A., Campbell, B. A., Plaut, J. J., Marinangeli, L., Smrekar, S. E., & Nunes, D. C. (2007, May 18). *SHARAD sounding radar on the Mars Reconnaissance Orbiter*. AGU Journals. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2006JE002745.

(42) Spectrolab. (n.d.). *Photovoltaics*. Spectrolab. https://www.spectrolab.com/.

(43) Tutco-Farnam Custom Products. (n.d.). *Design & spec your flexible HEATER online in 5 easy steps.* Tutco-Farnam Custom Products. https://farnam-custom.com/site/flex-specs.

(44) US Radar Inc. Subsurface Imaging Systems. (2020, March 23). *Ground Penetrating Radar (GPR) FAQ*. US Radar. https://usradar.com/ground-penetrating-radar-gpr-faq/.

(45) Worthington Industries. (n.d.). *High Pressure Composites Space*. Space - Worthington Industries. https://worthingtonindustries.com/Products/High-Pressure-Composites/Space.

(46) University of South Hampton. (2018, April 25). *New thermal coatings for spacecraft and satellites developed using metamaterials*. Phys.org. https://phys.org/news/2018-04-thermal-coatings-spacecraft-satellites-metamaterials.html.

(47) Tomboulian, Briana N., "Lightweight, High-Temperature Radiator for In-Space Nuclear-Electric Power and Propulsion" (2014). Doctoral Dissertations. 247. https://doi.org/10.7275/5972048.0 https://scholarworks.umass.edu/dissertations_2/247